Advanced Recycling Victoria

Establishing Australia's First Advanced Waste Plastics Recycling Facility

Best Available Techniques & Technologies (BATT)

June 2022

CONTENTS

D. Utilizing BATT for Site Management Plans

F. Appendices

Appendix 1	CSIRO 2021 report “Advanced Recycling Technologies to Address Australia’s Plastic Waste”
Appendix 2	Community and Stakeholder Engagement Report
Appendix 3	Chlorine balance on spiked run (Not Included - COMMERCIAL-IN CONFIDENCE)
Appendix 4	Greater Western Water (GWW) approved acceptance criteria for discharge to the tradewaste sewerage system
Appendix 5	Analysis results of 5 x process gas samples taken at the Licella Advanced Recycling facility, Somersby, NSW
Appendix 6	Risk Assessment For ARV Altona Facility Air Emissions
Appendix 7	Synergetics First Run Air Emissions Modelling report “Altona Cat-HTR facility air emission modelling and impact assessment”
Appendix 8	Synergetics Second Run Air Emissions Modelling report “Altona Cat-HTR facility air emission modelling and impact assessment”
Appendix 9	EnRisks report “Human Health Risk Assessment”

A. Introduction

Advanced Recycling Victoria (ARV) Pty Ltd is the proponent for the proposed Altona Advanced Recycling facility using Catalytic Hydrothermal Reactor (Cat-HTR™) technology (the Project). ARV is a fully owned subsidiary of Licella Holdings Limited (Licella). Licella is a global leader in hydrothermal upgrading – the process of chemically transforming plastics, biomass and other organic material (even non-recyclable plastics) into oil, which can be refined into advanced petrochemicals, biofuels and chemicals.

ARV is seeking to obtain the necessary regulatory and planning approvals for an Advanced Recycling facility using Cat-HTR™ technology for the chemical recycling of end-of-life waste plastics. ARV has identified a preferred site at 541-583 Kororoit Creek Road, Altona, Victoria. The site is within the Hobsons Bay City Council local government area, is owned by Dow Chemical Australia, was previously used as a chemical manufacturing site and is currently undergoing remedial works and decommissioning. Dow Chemical proposes to lease land to ARV at this site. The site is suitably zoned SUZ3 (Special Use Zone 3 - Petrochemical Complex Area).

The Advanced Recycling facility will fill a gap between the recycling of waste plastic into new plastic products and the disposal of waste plastics to landfill or destruction via incineration. So called end-of-life plastics, i.e., those that cannot be mechanically recycled into new plastic products, are typically sent to landfill or incinerated; however, the Cat-HTR™ process converts end-of-life waste plastics into useable chemicals and hydrocarbon products. This avoids landfilling or incineration of considerable quantities of plastics, while also displacing new petroleum hydrocarbon production derived from fossil fuels.

Activities such as this Project need to conform to EPA-Victoria Best Available Techniques and Technologies (BATT) requirements. The essence of BATT is that the selection of techniques to protect the environment should achieve an appropriate balance between the environmental benefits they bring and the costs to implement them. In addition, it should be demonstrated that no significant pollution is caused by an assessment of the environmental impact of emissions from the activity as a whole.

This Best Available Techniques and Technologies (BATT) report is an integrated document which describes both the operating techniques and technologies that will be established at the Project facility.

The following Summary Table itemizes the BATT aspects of the project. The discussion on each item then makes up the bulk of this document.

Summary Table: Best Available Techniques and Technology (BATT) Summary for ARV's Advanced Recycling Project using Cat-HTR technology

Item	BATT Consideration	BATT Proposal	Justification for BATT Proposal
B1	BATT for recycling waste plastic	Mechanical recycling of hard plastics is suitable for some plastics. Advanced Recycling is suitable for recycling plastics that can't be mechanically recycled especially for composite plastic packaging and soft, flexible plastics	• Recycling of end-of-life plastics in the world is consistently low with only around 13% of waste plastic being recycled. • Mechanical recycling of hard plastics can be carried out efficiently at a low cost. However mechanical recycling cannot be carried out many types of waste plastic especially for composite plastic packaging and soft, flexible plastics. • Advanced Recycling is new technology for processing waste plastic on a large, industrial scale. • Advanced Recycling of waste plastics is a higher-level step on the waste hierarchy for disposing of waste plastics compared to landfill or incineration. • Australia needs Advanced Recycling of plastic to increase plastics recycling above the 13% recycling level that is currently being achieved. Government targets for 80% recycling won't be reached without the commencement of Advanced Recycling.
B2	Advanced Recycling methods for processing waste plastic	Hydrothermal Liquefaction using Licella's Cat-HTR technology is the newest Advanced Recycling technology. It appears to be a superior technology compared to other Advanced Recycling technologies.	• Cat-HTR technology has advantages over other Advanced Recycling technologies. • CSIRO's Advanced Recycling report 2021 stated that some of the key advantages of Licella's Cat-HTR technology are that it: ❖ *has efficient heat transfer and operates at a comparatively low temperature, 450°C, which is associated with producing lower char than other processes* ❖ *accepts PET (which can clog pipes and contaminate products in pyrolysis processes)* ❖ *is tolerant of contamination (e.g. paper, cardboard) and is therefore good for processing multilayer plastics packaging* ❖ *can process thermoset plastics* ❖ *is tolerant of some chlorine (from PVC), which washes out with water as a salt.* • An Advanced Recycling facility using Cat-HTR technology should be established in Australia. • There is a current and growing market for Post-Consumer Recycled (PCR) plastic resin. This is the

			product that can be made when Advanced Recycled output product 'plasticrude" is processed as feedstock for plastics manufacturing.
B3	Cat-HTR technology	Information on Cat-HTR technology and development	• The Cat-HTR technology uses superheated, pressurized water to break down the carbon chains in plastics. • Effectively, the very hot, dense supercritical water acts as an energy source and solvent and a chemical moderator which breaks down the long chain hydrocarbon polymers. • Each Cat-HTR module will process 20,000tpy of waste plastic. Production throughput can be increased by having more modules constructed. • In the Cat-HTR Mass Balance 1 tonne of feedstock waste plastic will produce 150kg (15%) Process Gas, 720kg (72%) Plasticrude and 130kg (13%) Heavy Fraction bitumen. • Advanced Recycling facilities using Cat-HTR technology are under construction in the UK and under planning construction in Japan, Korea and Australia.
C1	Site suitability for establishing the first Australian Advanced Recycling facility using Cat-HTR technology	Establish an Advanced Recycling facility using Cat-HTR technology at the Dow Chemical site, Altona, Victoria	• The Altona Dow Chemical site has been assessed as being the best of 12 sites considered. • The Altona Dow Chemical site has SUZ3 land zoning which requires the SUZ3 land to be used for the use, manufacture and storage of petrochemicals. The local council has approved this site for an Advanced Recycling facility using Cat-HTR technology. There are very few areas in Australia with this zoning. • The Altona Dow Chemical site is available for leasing. It has excellent industrial infrastructure, access to utilities, excellent truck and highway/freeway access, land available for initial Advanced Recycling operations, additional land available for potential expansion of operations and a 1.3km buffer zone to residential areas. • A Stage 1 facility can be established that will have a single Cat-HTR module capable of processing 20ktpa of waste plastic feedstock. • Table 4.4 summarizes the utilities needed at the Altona site and their expected annual usage during Stage 1 Advanced Recycling operations. • A Community Engagement process was carried out.

C2	Collection of feedstock waste plastic	Collaborate with existing waste recycling companies for the collection of feedstock waste plastic	• The most efficient way to collect feedstock waste plastic is to collaborate with companies already undertaking this task including REDCycle, CurbCycle, iQRenew, Cleanaway, Violia, CityWaste and with Product Stewardship schemes. • The Feedstock Supply Chain will need to be expanded as ARV's Advanced Recycling operations are scaled up.
C3	Transportation and storage of feedstock waste plastic to site prior to Advanced Recycling processing	Use of 40ft shipping containers for the transportation of waste plastic to site and on-site feedstock storage	• The use of shipping containers for transporting baled waste plastics is already a normal way of transporting and storing waste plastics and provides an efficient, safe and low risk solution for managing waste plastic feedstock compared to just moving plastic bales or loose plastic stockpiles. • Waste plastic will be baled, loaded, transported and stored in 40ft shipping containers – 20 tonnes per container. • Litter management and fire safety management are effective when containers are used. • Shipping containers to be transported and stored at site with a maximum of 5 days feedstock supply (15 full containers) stored at site.
C4	Preparation of feedstock waste plastic for Advanced Recycling	Use of state-of-the art plastics sorting and preparation line for preparing waste plastic feedstock for Cat-HTR processing	• The latest technology for plastics sorting and preparation should be used. • iQRenew in NSW has constructed a facility that will shred the waste plastic feedstock, remove contaminants (glass, metals, paper, wood etc.), remove hard plastics for mechanically recycling, remove PVC and PVCD plastics for alternate recycling, clean the feedstock plastics and store it for Cat-HTR processing. It is planned to work with iQRenew to replicate this facility. • State-of-the-art equipment to be used in the plastics preparation line will include near-infrared optics to sort different plastics
C5	Minimizing GHG production from Advanced Recycling operations	Purchase "green" electricity supply. Use recycled Process Gas to fuel boiler heating.	• The main energy used in the Advanced Recycling facility is electrical energy. • An MOU has been signed with a company that can builds its own solar farms and can supply "green" electricity to the Advanced Recycling facility on a long-term basis. • It is estimated that Stage 1 operations will produce 3,571 t CO_2 GHG equivalent per year • This Item has been covered in the submission already issued to EPA Victoria "Development Licence Application Supporting Documentation – Altona Advanced Recycling Facility Using Cat-HTR™ Technology"

C6	Industrial water supply for Advanced Recycling operations	Purchase recycled industrial water from GWW for Advanced Recycling of waste plastics	• It is best to not use potable water for large industrial uses because this water is needed for community use. • The use of recycled industrial water for ARV's Advanced Recycling facility will mean that there is no impact on potable water usage for the rest of the community. • Greater Western Water (GWW) produces 100% recycled industrial water at its Altona water treatment plant. Their industrial water supply line passes by the Dow Altona site and is available for use at the Advanced Recycling facility. • Using GWW recycled industrial water minimizes operational risks for the Advanced Recycling facility because GWW has a very large volumes of recycled industrial water. • A Recycled Industrial Water supply contract will be signed between ARV and GWW for water supply to the Advanced Recycling facility.
C7	Discharge of wastewater from Advanced Recycling operations	Advanced Recycling wastewater to be treated onsite and then discharged into the GWW tradewaste line.	• GWW has effluent water standards that must meet before any wastewater it is discharged into the GWW tradewaste line. • ARV will construct an onsite Water Treatment Plant that will treat wastewater from the Cat-HTR process to meet the GWW tradewaste discharge standards so that site wastewater can be discharged into the GWW tradewaste line. • In Stage 1 of the ARV Advanced Recycling Project, it is more cost effective to discharge site process wastewater rather than treating it so that it can be recycled on site. In Stage 2 planning, the possibility of recycling wastewater onsite will be examined. • The site wastewater discharged in the GWW tradewaste line is processed at GWW's Altona water treatment plant and recycled as Industrial water. So, in fact, the use of GWW's industrial water and tradewaste lines enables water to be recycled for the Advanced Recycling process. • Separate to the discharge of Advanced Recycling wastewater, ARV will discharge site sewerage directly into the GWW tradewaste line in accordance with GWW guidelines. Site sewerage will also therefore be recycled for re-use as Industrial water.
C8	Generation of heat in site boilers for the Cat-HTR process	Natural gas to be used for Cat-HTR process start-up. When the process is underway, the	• The Cat-HTR facility has two boilers, these being - A supercritical steam generator that will produce steam at up to 550 deg Celsius. This steam is used for the Cat-HTR process.

		Process Gas manufactured onsite will be used instead of natural gas	- A standard boiler that will produce steam for activities such as Product Tank steam heating and steam cleaning site capability. • When the Cat-HTR process is in start-up mode, natural gas will be used as fuel for the boilers. • Once the Cat-HTR process is underway then a Process Gas will be manufactured from the breakdown of waste-plastic carbon chains. This Process Gas has an energy of 38MJ/kg which is similar to natural gas. • Upon the Cat-HTR process completing start-up and when the volumes of Process Gas are being manufactured, then Process Gas will be used for boiler heating instead of using natural gas. The natural gas line will be turned off at this time.
C9	Combustion of Process Gas and methods for exhaust flue gas treatment	When the UK facility is operational then Process Gas flue gasses will be monitored for harmful gasses. If required, the Altona facility can be fitted with flue gas exhaust scrubbers to the boiler exhaust flumes. This will remove most emission contaminants.	• Risk Assessment of the flue gas emitted from the combustion of Process Gas concludes that the risk of harmful gasses being emitted is Very Low. • Analysis of exhaust emission modelling shows that NOx emissions are present at levels higher than other air emissions such as SOx, Ammonia or other chemical compounds. Untreated, NOx levels are expected to be at 4.6% of the 1-hour allowable limits. • When the UK Advanced Recycling facility is operational in late 2022 then flue gas exhaust emissions can be monitored to verify pollutant levels. • The Altona facility will design its flue gas exhausts scrubbers based on results obtained from the UK facility flue gas emission results. • Two different types of exhaust scrubbing techniques are being considered, these being: ❖ The addition of a Catalytic Converter to boiler exhaust flumes which can remove 80% of NOx thereby dropping expected NOx levels to 0.92% of the 1-hour allowable limits. ❖ The addition of a Packed Bed Wet Scrubber which is effective for removing a range of emission contaminants but is only around 50% effective with treating NOx contaminants. A Packed Bed Scrubber would drop expected NOx levels to 2.3% of the 1-hour allowable limits. ❖ The Packed Bed Wet Scrubber is less effective and more expensive than a Catalytic Converter. • Reaction temperatures of the Cat-HTR process are expected to be under that in which dioxins and other gaseous compounds of environmental concern are created.

			• Due to the water that is used in the Cat-HTR process, any particulate matter that is present is trapped in the water phase and not in the Process Gas that is released. Consequently, the Process Gas that is used as fuel in the boilers is free of particulate matter.
C10	The technique for inserting plastics into the Cat-HTR process	Development of a proprietary method for injecting molten plastic into the Cat-HTR process	• The Cat-HTR process requires plastic to be added to super-heated water at high temperature and pressure. • Licella has developed a proprietary method for injecting molten plastic into the Cat-HTR process. • Licella's Cat-HTR pilot plants have trialed and now use a proprietary method for injecting molten waste plastic into the Cat-HTR process.
C11	Methods for product handling and storage – Process Gas	In Stage 1 most Process Gas will be used in boiler heating or sold to neighbouring industrial sites. Any excess Process Gas will be flared off.	• For Stage 1 Advanced Recycling operations, it is planned to process 60.6 tonnes per day of waste plastic. This will produce 9.1 tonnes per day of product gas. • Design details of the boilers are still being determined but it appears that most of the Process Gas will be used for boiler heating. • If there is any excess Process Gas, then it is planned to offer this for sale to neighbouring businesses including EnviroPacific who use natural gas for their soil decontamination business. • For Stage 1 operations, if there is any excess Process Gas above what is used for boiler heating and for sale, then the excess Process Gas will be flared off. • In Stage 2 operations consideration will be given to compressing Process Gas so that additional Plasticrude Oil can be manufactured. Given the low waste plastic feedstock throughput in Stage 1, it is not cost-effective for establishing a gas pressurization facility in this Stage.
C12	Methods for product handling and storage – Plasticrude and Heavy Fraction oils	Plasticrude and Heavy Fraction product oils will be stored in "special-purpose" Product Tanks on site until trucked to buyers	• For Stage 1 Advanced Recycling operations, it is planned to process 60.6 tonnes per day of waste plastic. This will produce 43.6 tonnes per day of Plasticrude and 7.9 tonnes per day of Heavy Fraction oil. • The Dow Chemical site has Product Storage Tanks that are no longer being used. It is planned to purchase these tanks from Dow and refurbish them for Advanced Recycling use for storage of Plasticrude and Heavy Fraction products. • The Product Tanks will: ○ Have a new prepared and bunded tank farm area (to Australian Standards).

			○ Be relocated to the new tank farm location ○ Be refurbished to ensure that they are suitable for ongoing use. This will involve conducting wall thickness testing, welding checks, external painting and the addition of insulation. ○ Have floating internal rooves. This will minimize oil vapour formation and the need to decant oil vapours for disposal. ○ Have internal heating using excess steam. This will ensure that Product Oil can be pumped to tankers for transportation to buyers.
C13	Transportation of Product Oils	Standard oil tanker trucks will transport Product Oil	- Standard tanker trucks will be used for transporting the Product oils, these being Plasticrude and Heavy Fraction (bitumen) oils.
C14	Management of site solid waste	Solid waste to be placed in skip bins that will be emptied into landfill on a regular basis	- Solid waste will be collected on site as follows: ○ Garbage from site personnel – food scraps, food wrapping etc. Any wrappings that can be recycled will go into the appropriate recycling streams. Dedicated bins will be used for non-recyclable rubbish and the collected by waste management contractors on a regular basis and sent to landfill. ○ Industrial wrappings from parts deliveries etc. Wrappings that can be recycled will go into the appropriate recycling streams. Dedicated bins will be used for non-recyclable rubbish and collected by waste management contractors on a regular basis and sent to landfill. ○ The Plastics Preparation Process is where contaminants such as glass, metal, paper, PVC plastic, hard plastics and grit will be removed from the waste plastic feedstock stream. As these contaminants are removed at different points in the plastics preparation line, it will be possible for most contaminants (such as glass, paper, metals, hard plastics and PVC) to be collected and recycled. Non-recyclable contaminants such as grit will be sent to dedicated bins that will be collected by waste management contractors on a regular basis and sent to landfill. ○ Solid waste from the Water Treatment Plant. Solid waste from the Cat-HTR wastewater will be removed from the water, dried and sent to dedicated bins that will be collected by waste management contractors on a regular basis and sent to landfill.
C15	Management of	Site odour management	- Odour could potentially come from:

	site odour emissions	measures will be included in the design of infrastructure and operations	○ Stored waste plastic feedstock upon shipping containers being opened and waste plastic being unloaded and prepared for Cat-HTR processing. ○ Product oil storage ○ Solid waste bins - Odour from waste plastic feedstock is not expected to be a problem based on the following: ○ iQRenew is now processing waste plastic at its facility at Tuggarah, NSW. The waste plastic is collected through the CurbCycle Project Central Coast NSW where soft plastics are bagged and placed in kerbside recycle bins. The waste plastic is removed from general recyclables at iQRenew's MRF then baled and transported to the Tuggarah facility for processing into waste-to-energy fuel. There is no evidence of odour emanating from the collected waste plastics. ○ Plastics preparation will be in a shed which stifles any odour emissions. - Odour from Product Oil tanks will not be a problem because the Product Oil tanks will be fitted with internal floating ceilings that minimize to the point of eliminating product tank fumes odour. This is proven technology from the petrochemical industry. - Odour from solid waste skip bins will be minimal as bins will be emptied on a regular basis. - Should any minor odour emissions occur despite the engineering design then the 1.3km buffer zone to residential areas will dilute the odour to the point where it will be difficult to detect.
C16	Management of site noise emissions	Site noise management measures will be included in the design of infrastructure and operations	- Modelled results presented in the Noise Modelling Study indicate that noise levels generated due to operation of the proposed advanced recycling facility would fall below the most stringent noise limits at all noise sensitive locations identified in the assessment and would be considered to have a low potential for human health impacts.
D1	ARV Management System Overview	Site Management System to encompass the total project activities.	- BATT is to have a management system that includes all aspects and components of Project activities. - Section 1: ARV Management System - Section 2: Safety and Training System - Section 3: ARV Environmental Management System

			- Section 4: ARV Production System - Section 5: ARV Maintenance System - Section 6: Administration - Section 7: Financial Control
D2	ARV Environmental Management Plan	The EMP should address all environmental aspects of the Project to ensure minimal, if any, impacts and harm to the environment	- The ARV Environmental Management Plan is still to be written – it will be finalized before site production activities commence. - The EMP will address Project Key Environmental Factors - The EMP will detail Project Environmental Objectives
D3	Site Emergency Procedures Management Plan	Detailed engineering design will include emergency response infrastructure. Site management will include training in emergency response preparedness and co-ordination of external emergency response	- The Site Emergency Procedures Management Plan is still to be written – it will be finalized before site production activities commence. - The SEPMP will include: ○ Risk assessments for all aspects of Advanced Recycling operations ○ Engineering design phase consideration of risk, accidents and emergency situations ○ Consideration before construction commences of risk, accidents and emergency situations ○ Consideration before operations commences of risk, accidents and emergency situations ○ Reviewing and updating Risk Registers on an annual basis. ○ Training in emergency response and co-ordination of internal emergency response and external emergency response agencies
E	Human Health Risk Assessment		- A HHRA has been carried out by EnRisks Pty Ltd that considered all aspects of the Project Stage 1 operations and the Project emissions. The HHRA is that the Stage 1 Project will have negligible impact on human health and the environment.

B. Information about BATT for Advanced Recycling and Cat-HTR Technology

B1.0 BATT for recycling waste plastic

Australia and the world generally have a linear economy approach to managing plastic usage – use the plastic once then throw it away for disposal.

Recycling rates for plastic in Australia have continued to remain stubbornly low. Most end-of-life plastics are discarded to landfill each year, with only 13.1% of total end-of-life plastics directed to mechanical reprocessing during 2019–2020. This demonstrates a clear need for new reprocessing approaches to close the loop for recycling different streams of end-of-life plastic products and packaging.

Advanced recycling offers a profound opportunity to complement mechanical recycling in helping to increase the total capacity for plastics recycling in Australia.

Source: Envisage (2021)

Figure B1.1 showing the tonnages of end-of-life plastic generated each year (in black) against the recycling rates (in green)

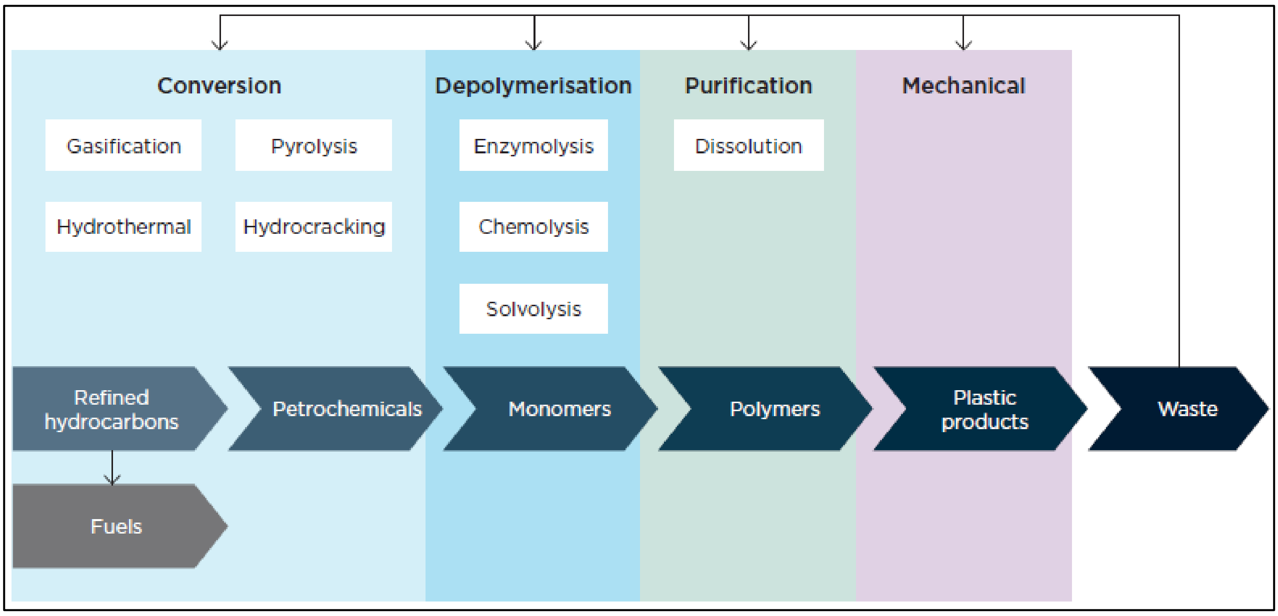
B1.1. What is Advanced Recycling for waste plastic?

In 2021 CISRO issued a report "Advanced Recycling Technologies To Address Australia's Plastic Waste" which is included as Appendix 1. The following excerpt is taken from this report:

"Advanced recycling of plastics is the conversion to monomer or production of new raw materials by changing the chemical structure of a material or substance through cracking, gasification or depolymerisation, excluding energy recovery and incineration.

Advanced recycling is also referred to as chemical, molecular or feedstock recycling. These terms can sometimes be used interchangeably. Advanced recycling is complementary to mechanical recycling. It can assist with diverting mixed, flexible and contaminated waste plastics that are not able to be mechanically recycled economically and would otherwise go to landfill. This report describes three major advanced recycling processes, purification, depolymerisation and conversion technologies, to produce intermediate products (light and heavy oil, gas, char). These products can be further processed into recycled polymers that are able to be manufactured into new products with recycled content, represented in Figure 1.2"

Figure B1.2 Summary of advanced recycling technologies and their products



B1.2 Why Advanced Recycling for flexible waste plastic is needed in Australia

Australia has the opportunity to create a plastics circular economy and implement global best practices to modernise our waste management practices. With 87% of Australia's 2.5 million tonnes per year of waste plastic currently entering landfill, there are major gaps in Australian infrastructure that must be addressed with higher order material recovery.

Advanced (also known as Chemical) Recycling is the next innovative solution for managing difficult to recycle end-of-life packaging plastics that are currently entering landfill, being incinerated or being exported. Our proposed Project will create a plastics circular economy and recycling solution for plastics that currently has no recycling solution. By 2030, key plastic polymer producers need to source and have committed to market 11.3 million tonnes of plastic recycled polymers. A scalable market for our Advanced Recycled product therefore exists to expand the use of our waste plastics feedstock collection, preparation and Advanced Recycling Cat-HTR technology in Australia and also internationally.

Waste plastics have, until recently, either been exported or dumped in landfill due to a lack of supporting process infrastructure. There is an opportunity for technology that can create higher value, local off-take markets for these materials. Advanced Recycling is the solution to enable recycling of wate plastics into a high value, synthetic crude oil (plasticrude). Plasticrude can be processed to produce new food grade plastic polymers that are in demand by brands and the polymer supply chain.

Licella Holdings Ltd has established Advanced Recycling Australia (ARA) Pty Ltd to commercialise its patented Cat-HTR technology in Australia. ARA will license the first plant to subsidiary Advanced Recycling Victoria (ARV) Pty Ltd. ARV will provide higher value alternatives for recycling end-of-life plastic feedstock than just dumping it in landfill or using it as fuel in waste-to-energy projects. Our Project includes innovative practices for creating supply chain partnership with companies such as REDCycle, CurbCycle, iQRenew, Cleanaway, Citywide and Violia to collect waste plastic from kerbside bins and industry and with Product Stewardship schemes such as the NPRS that is under development by the Australian Food and Groceries Council (AFGC).

At the National Plastics Summit on 2 March 2020, Prime Minister Scott Morrison put the challenge to industry to take responsibility for its plastic waste. Alongside this, the Prime Minister foreshadowed budget announcements to encourage demand for recycled plastic products and to expand industrial capability to produce them.

In early 2021 several companies with an interest in solving the problem of recycling end-of-life plastics created a collaboration to consider establishing advanced recycling of plastics. These companies signed a “Heads of Agreement” and, with Licella Holdings Ltd taking the lead role, contributed funds into a Feasibility Study. Partner companies that are part of our team are Amcor Pty Ltd, Nestle Australia Ltd, LyondellBasell Australia Pty Ltd, IQRenew Pty Ltd and Coles Group Limited.

As part of the study, Envisage Works was commissioned to investigate the long-term availability of suitable plastic feedstocks for the Cat-HTR™ advanced recycling process and assess the local Australian demand for recycled packaging from major FMCG companies. This brand demand research was conducted in conjunction with AFGC (Australian Food and Grocery Council).

The findings of both the availability of suitable plastic feedstock and the brand demand for recycled content were extremely positive.

The study found it highly likely that our proposed Advanced Recycling facility using Cat-HTR™ technology with a 20,000 tonne/year capacity would have little trouble sourcing end-of-life plastic feedstock from Victoria (649,000 tonnes of plastics reaching end-of-life in 2019-20).

Additionally, plastic that has up until now been exported will no longer be exportable following the implementation of the federal Waste Export Ban on unprocessed waste plastics. Without significant further local processing this material will go to landfill. Landfill levies around Australia are also increasing with Victorian levies rising from \$166/tonne (1st July 2021) to \$188/tonne (1st July 2023), further discouraging the disposal of plastics to landfill.

There is strong desire for companies to partake in product stewardship schemes to ensure the material used for their products is recovered in a socially responsible way.

Local and international markets for 100% recycled content polypropylene (PP) and polyethylene (PE) resins are substantial, with the local market for Post-Consumer Recycled (PCR) resin into packaging conservatively estimated to reach 60,000–100,000 tonnes per year by 2025.

The Australian Government National Waste Policy Action Plan 2019 (NWP 2019) includes two targets particularly relevant to ARV’s Advanced Recycling technology.

Target 1 of the NWP 2019 aims to implement a ban on the export of waste plastic, paper, glass and tyres. The Council of Australian Governments plan for phasing out exports of waste plastic, paper, glass and tyres (Aus Gov 2020) outlines the schedule for banning the export of waste plastics from Australia.

In July 2021 ‘Phase 1’ of the Australian Government export bans came into effect, banning the export of mixed plastics that are not of a single polymer type and/or requiring further sorting, cleaning and processing before use in remanufacturing. In July 2022, the Australian Government intends to implement ‘Phase 2’ of the planned export bans for single resin/polymer plastics that have not been re-processed (e.g. cleaned and baled PET bottles).

Based on current generation rates, Australian Government estimates that around 200,000 tonnes of Australian plastics bound for exports will be impacted by the upcoming export bans. Without significant investment in recovery infrastructure for plastics, there is a significant risk that these banned exports will simply be disposed of in landfill.

Target 2 of the NWP 2019 aims for an average resource recovery rate of 80% by 2030 from all waste streams in the waste hierarchy. The Australian Government National Waste Report 2018 (NWR 2018) reported only 13% of plastics generated in Australia were recovered with the remainder assumed to be sent to landfill. This illustrates that there is an existing significant shortfall in Australia’s plastics recovery infrastructure.

To effectively implement the NWP 2019 targets, a substantial increase in Australia’s plastics recovery infrastructure capacity, capability and diversity of technology will be required.

In February 2020, the Victorian Government “Recycling Victoria” released a new economy policy (RV policy). The RV policy reports 587,000 tonnes of plastics waste was generated in Victoria, with around 23% (137,000 tonnes) recovered. The majority of the Victorian plastics recovery (62% or 85,000 tonnes) was “recovered” by exporting it. This export recovery pathway will cease in 2022, placing significant additional demand on Victorian plastics recovery capacity.

The Victorian Government has also committed to divert 80% of waste from landfill by 2030 with an interim target of 72% by 2025. Based on current generation rates, a 72% recovery rate of plastics (416,000 tonnes) would require an additional 360,000 tonnes of onshore plastics recovery by 2025. An 80% recovery rate would require an additional 413,000 tonnes of onshore recovery by 2030.

In April 2020, Infrastructure Victoria released “Advice on Recycling and Resource Recovery Infrastructure (IV 2020)” that aimed to direct the Victorian Government to areas in the waste sector that require significant increases in infrastructure capacity and capability. The projected shortfall in capacity of around 300,000 tonnes for plastics recycling processing capacity in Victoria by 2025 will require a significant and immediate investment in new capacity and technology.

Infrastructure Victoria 2020 also flags the following plastics infrastructure shortfalls:

- Plastics sorting capacity at materials recovery centres (MRFs)
- Stable off-take markets for recycled plastic products
- Capacity to process mixed residual plastics from MRFs

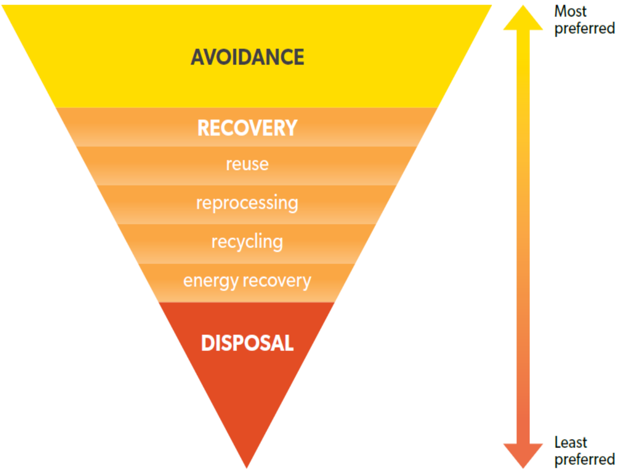
Currently the existing markets for recycled plastics include:

- Landfill: no value extraction
- Export: material value exported
- Mechanical recycling: if facility capacity and product markets exist to process
- Waste to Energy: material recovered as energy
- Reforming into products: limited off-take market

It is clear that the reason why so much material is currently directed to landfill or export is because Australia has no viable solutions to recycling large volumes of waste plastics. This is why a solution to how plastics can be recycled is necessary to target low value mixed plastics and create new product markets.

The technologies to achieve this must adhere with the best practices for resource recovery and adhere to the Waste Hierarchy.

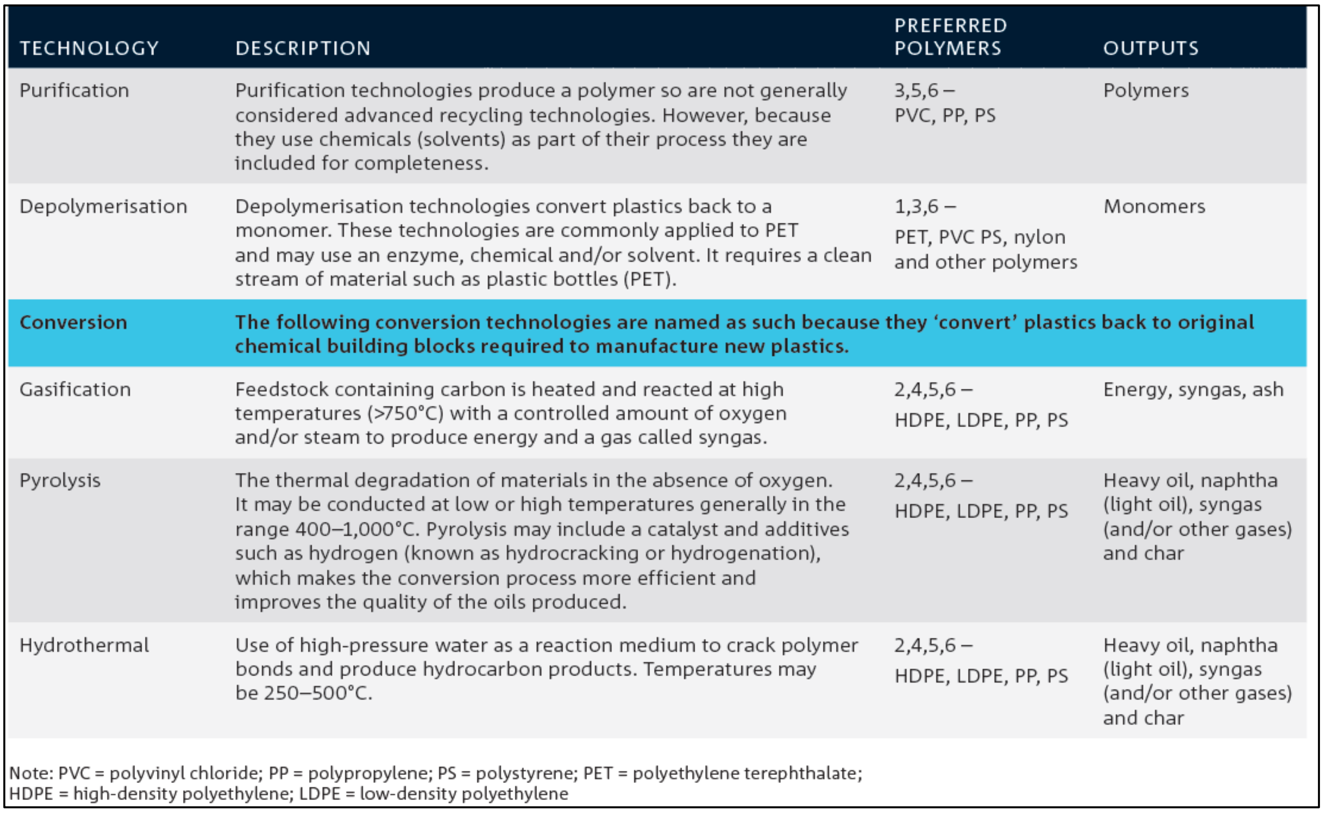
Figure B1.3: Waste Hierarchy



The introduction of Advanced Recycling for recycling waste plastic (especially flexible plastics) in Australia and the World is clearly needed. The challenge is for champions of the different types of Advanced Recycling technologies to establish themselves as being commercially viable.

B2. Advanced Recycling Alternative Technologies

Table B2.1 shown below was included in a CSIRO 2021 report titled “Advanced Recycling Technologies to Address Australia’s Plastic Waste”. This table summarizes the Advanced Recycling technologies that can be used for processing waste plastic.

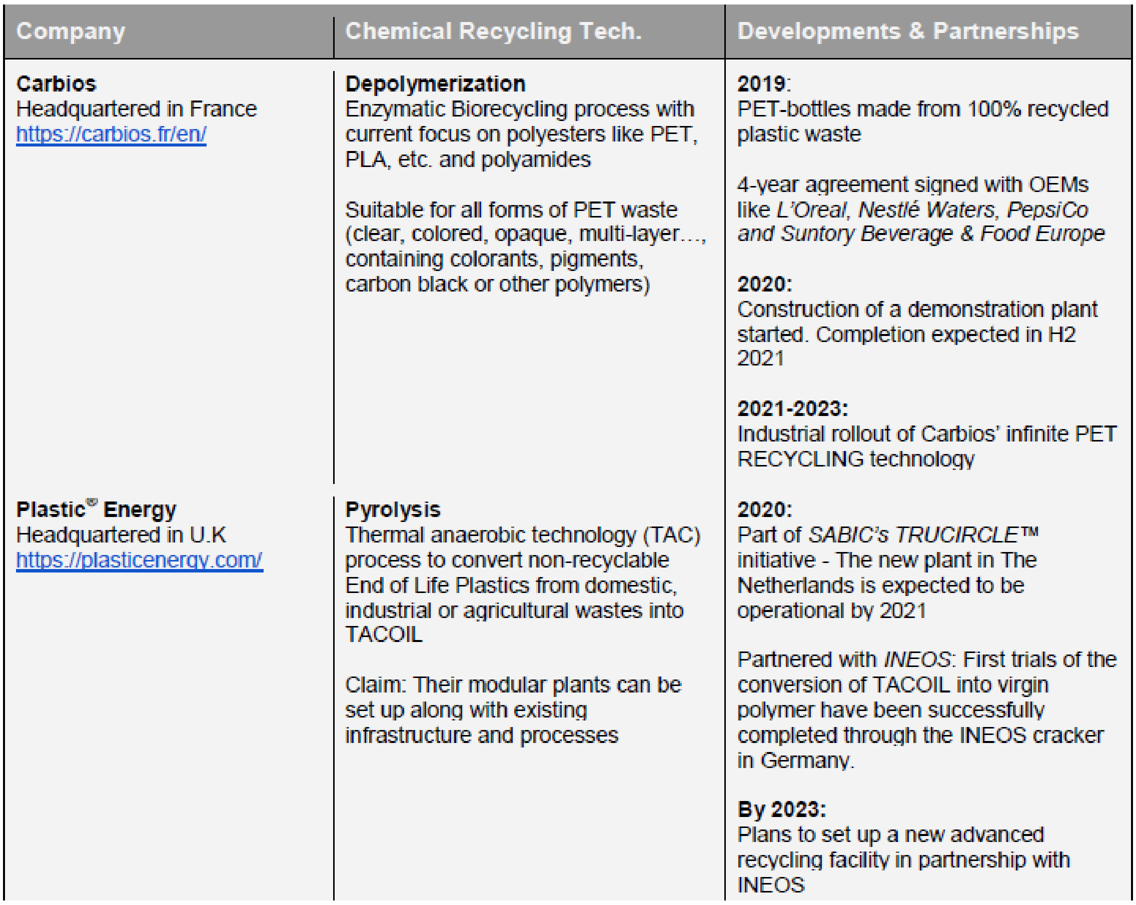


TECHNOLOGY	DESCRIPTION	PREFERRED POLYMERS	OUTPUTS
Purification	Purification technologies produce a polymer so are not generally considered advanced recycling technologies. However, because they use chemicals (solvents) as part of their process they are included for completeness.	3,5,6 – PVC, PP, PS	Polymers
Depolymerisation	Depolymerisation technologies convert plastics back to a monomer. These technologies are commonly applied to PET and may use an enzyme, chemical and/or solvent. It requires a clean stream of material such as plastic bottles (PET).	1,3,6 – PET, PVC PS, nylon and other polymers	Monomers
Conversion	**The following conversion technologies are named as such because they ‘convert’ plastics back to original chemical building blocks required to manufacture new plastics.**		
Gasification	Feedstock containing carbon is heated and reacted at high temperatures (>750°C) with a controlled amount of oxygen and/or steam to produce energy and a gas called syngas.	2,4,5,6 – HDPE, LDPE, PP, PS	Energy, syngas, ash
Pyrolysis	The thermal degradation of materials in the absence of oxygen. It may be conducted at low or high temperatures generally in the range 400–1,000°C. Pyrolysis may include a catalyst and additives such as hydrogen (known as hydrocracking or hydrogenation), which makes the conversion process more efficient and improves the quality of the oils produced.	2,4,5,6 – HDPE, LDPE, PP, PS	Heavy oil, naphtha (light oil), syngas (and/or other gases) and char
Hydrothermal	Use of high-pressure water as a reaction medium to crack polymer bonds and produce hydrocarbon products. Temperatures may be 250–500°C.	2,4,5,6 – HDPE, LDPE, PP, PS	Heavy oil, naphtha (light oil), syngas (and/or other gases) and char

Note: PVC = polyvinyl chloride; PP = polypropylene; PS = polystyrene; PET = polyethylene terephthalate; HDPE = high-density polyethylene; LDPE = low-density polyethylene

Table B2.1 Summary of advanced recycling technologies, polymer feedstocks and outputs

Table 2B.2 shows some of the “main players” worldwide in Advanced Recycling.



Company	Chemical Recycling Tech.	Developments & Partnerships
Carbios Headquartered in France https://carbios.fr/en/	**Depolymerization** Enzymatic Biorecycling process with current focus on polyesters like PET, PLA, etc. and polyamides Suitable for all forms of PET waste (clear, colored, opaque, multi-layer…, containing colorants, pigments, carbon black or other polymers)	**2019**: PET-bottles made from 100% recycled plastic waste 4-year agreement signed with OEMs like *L’Oreal, Nestlé Waters, PepsiCo and Suntory Beverage & Food Europe* **2020:** Construction of a demonstration plant started. Completion expected in H2 2021 **2021-2023:** Industrial rollout of Carbios’ infinite PET RECYCLING technology
Plastic® Energy Headquartered in U.K https://plasticenergy.com/	**Pyrolysis** Thermal anaerobic technology (TAC) process to convert non-recyclable End of Life Plastics from domestic, industrial or agricultural wastes into TACOIL Claim: Their modular plants can be set up along with existing infrastructure and processes	**2020:** Part of *SABIC’s TRUCIRCLE™* initiative - The new plant in The Netherlands is expected to be operational by 2021 Partnered with *INEOS*: First trials of the conversion of TACOIL into virgin polymer have been successfully completed through the INEOS cracker in Germany. **By 2023:** Plans to set up a new advanced recycling facility in partnership with INEOS

Licella Headquartered in Australia https://www.licella.com.au/	**Continuous hydrothermal liquefaction (HTL)** Patented technology, the Catalytic Hydrothermal Reactor (Cat-HTR™) uses water under high temperature & pressure to convert a blend of plastics, including PP, PS, LDPE, multilayer flexible packaging, bioplastics, etc. to oil and gas (raw material for developing new plastics) Claims: - The process takes 20 mins & doesn't require the waste feedstock to be dry - Has a very high yield i.e. 85% oil & a lower carbon footprint than pyrolysis or gasification due to a lower reaction temperature.	Tech. developed over the past 10 years and has already been extensively tested at a pilot plant in Australia **2018:** Collaboration set up with ReNew ELP & Neste **2020:** Partnered with BioLogiQ to accelerate the construction of 20,000 tons per year facility in Australia. BioLogiQ has limited-term exclusive rights to commercialize Cat-HTR™ in China. ReNew ELP building a new plant in the UK. Has the capacity to recycle 20,000 tons of end-of-life plastic per annum **Beyond 2020:** ReNew ELP further plans to add 3 more plants
Pyrowave® Headquartered in Canada https://www.pyrowave.com	**Depolymerization** Microwave catalytic technology designed specifically for PS, EPS, HIPS, which are converted into a liquid rich in monomers. Purified monomers can then be reprocessed into virgin polymers Claims: - Current yield can reach up to 95% in monomer production - Could possibly be used to process PP(plastic # 5) and PE (plastics # 2 and # 4) as well	**2020:** Collaboration set up with Styrenics Circular Solutions, joint industry initiative featuring INEOS Styrolution, Total, Trinseo and Versalis (Eni) Closed series B investment led by Michelin and Sofinnova Partners
Polystyvert Headquartered in Canada http://www.polystyvert.com	**Solvolysis** Low-temperature chemical process involves the dissolution of polystyrene including styrofoam (EPS) in a solvent (essential oil) followed by purification & separation. Claims: - Recycled PS retains the same properties as virgin PS - Effective removal of contaminants including Hexabromocyclododecane (HBCD) flame retardant	**2018:** Runner-up at the World Materials Forum 2018 Start-up Challenge Partnered with Total Refining & Chemicals Pilot Plant inaugurated **2020:** Chosen amongst Top 100 Technology Pioneers by World Economic Forum
Recycling Technologies Ltd Headquartered in U.K https://recyclingtechnologies.co.uk/	**Pyrolysis** (Machine) RT7000 machine uses thermal cracking in the absence of oxygen to produce an oil called Plaxx® (raw material for new plastics) Suitable for flexible films, multi-layered and laminated plastics, complex or even contaminated plastic Built to integrate with existing mechanical recycling infrastructure to increase the overall recycling capacity	**2019:** Part of Consortium along with Citeo, Total, Nestlé and Mars to develop Chemical Recycling in France **2020:** €10 million investment from Neste & Mirova JDA with INEOS Styrolution to advance the commercial recycling of PS. **By 2027:** They aim to produce 7 million tons of Plaxx per annum by installing 1,300 RT7000 machines worldwide

Feunix Ecogy Headquartered in The Netherlands https://fuenix.com/	**Pyrolysis** Ecogy® process 'cracks' the polymers in plastic to a molecular level Claim: Out of every kilo of plastic, 70% can be transformed into new plastic with half the CO_2 emissions	**2019:** Partnered with Dow Chemical for the supply of pyrolysis oil feedstock to produce new polymers at Dow's production facilities in NL **2020-2024:** Fuenix plans to launch a 2nd production line by the end of 2020, & is working with Dow on a large-scale plant slated for launch in 2023 or 2024.

Table B2.2 Companies developing Advanced Recycling technologies and commercial operations

B2.1 Why Advanced Recycling Victoria (ARV) believes that Licella's Advanced Recycling process using Cat-HTR Technology is BATT

The figure below shows the evolution of Advanced Recycling. Hydrothermal Liquefaction is the next generation Advanced Recycling technology.

The Evolution of Advanced Recycling – HTL is The Next Generation

As far back as the Viking era – **Gains maturity early 19th century**

PYROLYSIS

Converts feedstock to oil by heating it in the absence of oxygen.

WWII Onwards

GASIFICATION

Converts feedstock into gases at high temperatures (typically >700°C).

Began 1970s – **Licella begins continuous modern process Early 2000s**

HYDROTHERMAL LIQUEFACTION

Converts feedstock to synthetic crude oil using water under high temperature and pressure.

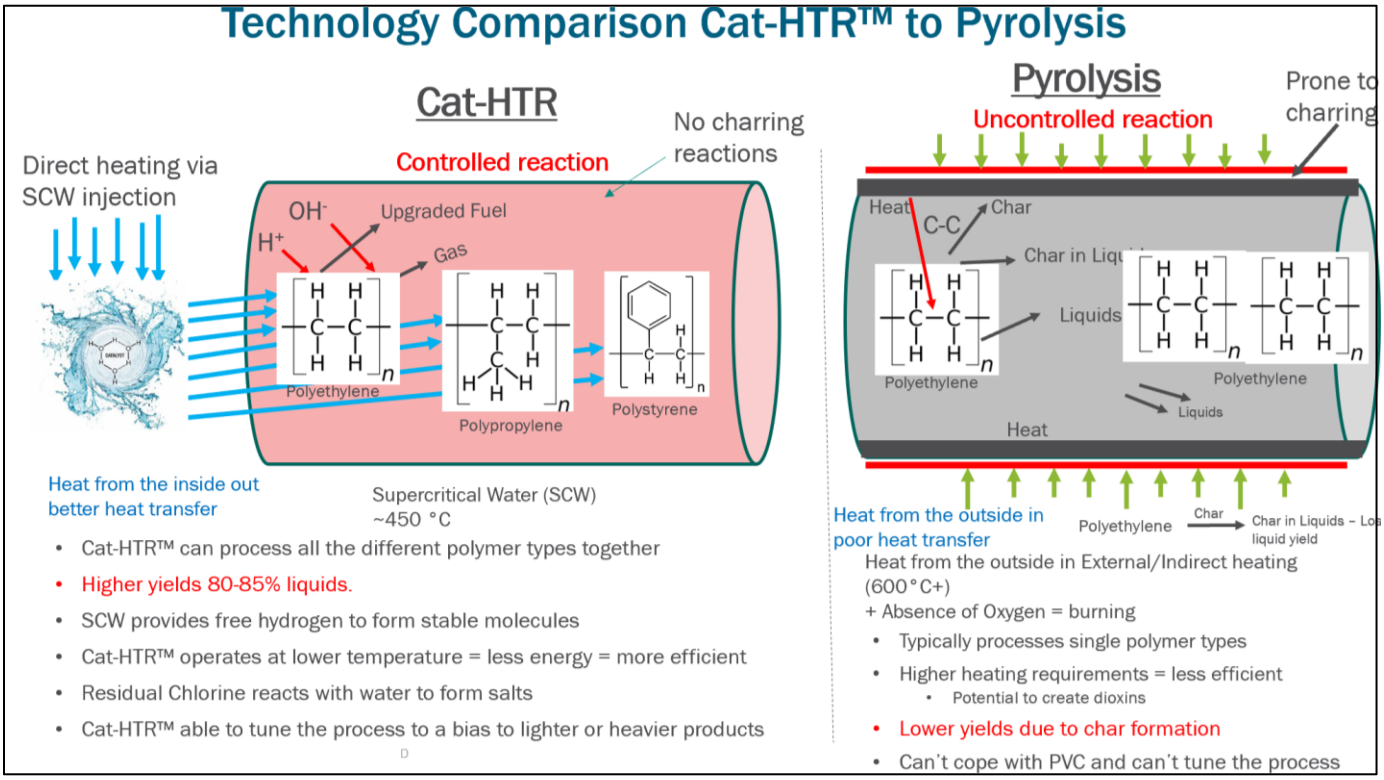
Figure B2-1 Evolution of Advanced Recycling

Whilst it appears that Pyrolysis and Hydrothermal Liquefaction in the form of Cat-HTR technology have similar outputs, there are significant differences as described below.

Cat-HTR technology offers significant advantages over earlier processes like pyrolysis and gasification.

- Supercritical water is used as the reaction medium, as opposed to other more toxic chemicals.
- During the process, the water molecules donate hydrogen atoms during the cracking process to the smaller hydrocarbon chains to create stable molecules. This means no additional hydrogen is required within the process.
- The plant is less susceptible to corrosion, to coking and to the production of char than comparably sized plants (e.g. pyrolysis technology) as the issues of thermal gradient don't exist i.e. the plastics are mixed with the supercritical water as opposed to the heat having to migrate from the outside in - see Figure B2.2 below.
- The process is robust to inorganic (ash and other solids) content in the feed plastic and to heteroatoms (e.g. oxygen, nitrogen, chlorine, bromine) in the feed plastic, a particular advantage for processing multi-layer film plastics.

- Low reaction temperatures (c.350-450°C), compared to pyrolysis (normally c.500-600+°C) and gasification (> c.700°C) require lower energy consumption.
- Reaction temperatures below that of incineration (waste to energy), and under that in which dioxins and other gaseous compounds of environmental concern are generated.
- High liquid yields of up to 85% for plastics (the balance being hydrocarbon gas that can be used in the process).
- Products produced are very low in sulphur.
- The process is tolerant of PVC with almost all chlorine removed either in plastics preparation or in the water phase as salts.
- Process can handle mixed plastic materials including multi-layer plastics (evidenced by the Cat-HTR winning the global Flexpax Recovery Challenge in 2019 for its unique ability to chemically recycle challenging multi-layer plastic packaging)[1].
- Cat-HTR can process "tramp" polyethylene terephthalate (PET), one of the most widely used plastic globally, which pyrolysis processes struggle to process.



Technology Comparison Cat-HTR™ to Pyrolysis

- Cat-HTR™ can process all the different polymer types together
- Higher yields 80-85% liquids.
- SCW provides free hydrogen to form stable molecules
- Cat-HTR™ operates at lower temperature = less energy = more efficient
- Residual Chlorine reacts with water to form salts
- Cat-HTR™ able to tune the process to a bias to lighter or heavier products

Heat from the outside in External/Indirect heating (600°C+)
+ Absence of Oxygen = burning

- Typically processes single polymer types
- Higher heating requirements = less efficient
  - Potential to create dioxins
- Lower yields due to char formation
- Can't cope with PVC and can't tune the process

Figure B2.2: Comparison of the Cat-HTR hydrothermal liquefaction technology and Pyrolysis

The following is another extract from the CSIRO 2021 report:

Hydrothermal processes are similar to pyrolysis technologies, but these processes operate with the addition of water and are more flexible regarding plastic feedstock compositions. Hydrothermal processes use hot compressed water as a reaction medium to convert complex organic compounds into smaller and simpler products (Qureshi et al. 2020). These conditions make the water a good solvent for dissolving organic compounds, although co-solvents and other materials such as biomass and catalysts are often added to improve the process. Most of the research into this process has centred on biomass

---

[1] https://renewelp.co.uk/news/renew-elp-win-the-flexpack-challenge-at-spc-impact-2019/

biological inputs, but hydrothermal processing has been identified as a promising option for plastics recycling due to the ability to process mixed plastic wastes (Shen 2020). Contamination from glass, metal, grit and stones must be removed, but in contrast to other processes, the plastic wastes do not need to be dried before processing, which can improve process economics (Qureshi et al. 2020). Hydrothermal processing is suitable for complex mixed wastes and hard to recycle plastics, including contaminated PET, carbon fibre reinforced plastics, printed circuit boards, polycarbonate, styrene-butadiene, polylactic acid and nylon. It can also tolerate other organic materials such as paper and food wastes. Processing wastes in the presence of water also stops unwanted side reactions, leading to high yields of stable hydrocarbon liquids with low gas formation (Chen, Jin & Wang 2019). The water also dissolves unwanted side products such as hydrogen chloride and oxygen containing materials. The main output is a complex synthetic oil that usually needs to be upgraded by standard refinery operations before it can feed into production of chemicals again.

Hydrothermal processing is particularly suitable for condensation polymers such as polyesters, polyethers, polycarbonates and polyamides that are also suitable for depolymerisation processes, due to their susceptibility to react with water under thermal and/or catalytic conditions (Pedersen, Thomas & Conti 2017). The recovery of monomers from polycarbonate and styrene-butadiene using hydrothermal processing, has been demonstrated at a laboratory scale (Pedersen, Thomas & Conti 2017). In addition, oil products that are very similar to naphtha and have excellent heating values (48–49 million joules per kilogram) have been recovered from PP using hydrothermal processing (Chen, Jin & Wang 2019).

The leading hydrothermal processing technology is the Licella Cat-HTR™ process (Licella Holdings, Australia), which has been demonstrated in pilot scale for processing mixed plastic wastes to recover a synthetic crude oil. This process is scaling up globally and will be adopted to process mixed plastic waste in the UK. Licella can add a distillation fractionation process to their recycled polymer oil (RPO), which will produce high-quality intermediate products (e.g. an ultra-low sulphur heavy oil and naphtha) and intermediate products with minimal contaminants (such as chlorine).

In summary, some of the key advantages of Licella technology are that it:

- *has efficient heat transfer and operates at a comparatively low temperature, 450°C, which is associated with producing lower char than other processes*
- *accepts PET (which can clog pipes and contaminate products in pyrolysis processes)*
- *is tolerant of contamination (e.g. paper, cardboard) and is therefore good for processing multilayer plastics packaging*
- *can process thermoset plastics*
- *is tolerant of some chlorine (from PVC), which washes out with water as a salt.*

ARV, with the backing of companies such as Amcor, LyondellBasell, iQRenew and Licella, believes that Licella's Cat-HTR technology is a world-leading best practice Advanced Recycling technology for processing end-of-life plastic. As such, ARV intends to establish its initial facility using Cat-HTR technology in Australia at Altona, Victoria.

B3. Information about the Advanced Recycling Process using Licella's Cat-HTR Technology

Recycling end-of-life plastics is problematical in comparison with recycling other material streams. The presence of filler sand colouring within plastic and the use of multi-layer packaging comprised of different polymer types and other material such as paper, food and trace-metals, limits the extent to which plastics can be mechanically recycled. At present a significant proportion of end-of-life plastic is combusted in waste-to-energy facilities or sent to landfill.

The most common post-consumer end-of-life plastics are polypropylene (PP), polyethylene (PE), and polyethylene terephthalate (PET). Table B3.1 contains a summary of the end-of-life plastic types.

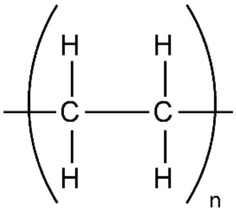
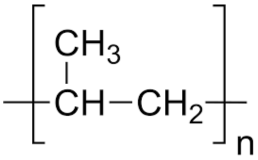
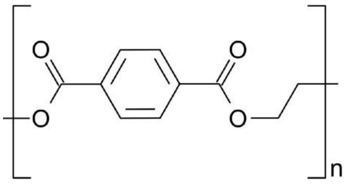
Type of Plastic	Structure	Applications
Polyethylene		Most common plastic, with around 80 million tonnes being produced annually. Its primary useis in packaging (plastic bags, plastic films, geomembranes, containers including bottles, etc.)
Polypropylene		Second-most widely produced commodity plastic, with a variety of applications to include packaging for consumer products,plastic parts for various industriesincluding the automotive industry
Polyethylene Terephthalate		Polyethylene terephthalate is the most common thermoplastic polymer resin of the polyester family and is used in fibres for clothing, containers for liquids andfoods

Table B3.1 End-of-Life Plastic Types

ARV's Advanced Recycling using Cat-HTR technology is able to chemically recycle this waste plastic.

Cat-HTR uses supercritical water as its process medium. Above the critical point (373 °C and 218 bar), no liquid phase of water exists and the water behaves like a dense gas, having the diffusivity of a gas while retaining the solvating power of a liquid.

Effectively, the very hot, dense supercritical water acts as an energy source, solvent and a chemical moderator which breaks down the long chain hydrocarbon polymers. The moderating role includes incorporation of hydrogen from the water to stabilize the new hydrocarbon liquid products. After these depolymerisation reactions are complete, the process is depressurised, and the products separated into the individual product streams.

Gases, which make up 15% of the products, are recovered for re-use within the process, while the liquid oil product is separated from the water and transferred to product storage tanks.

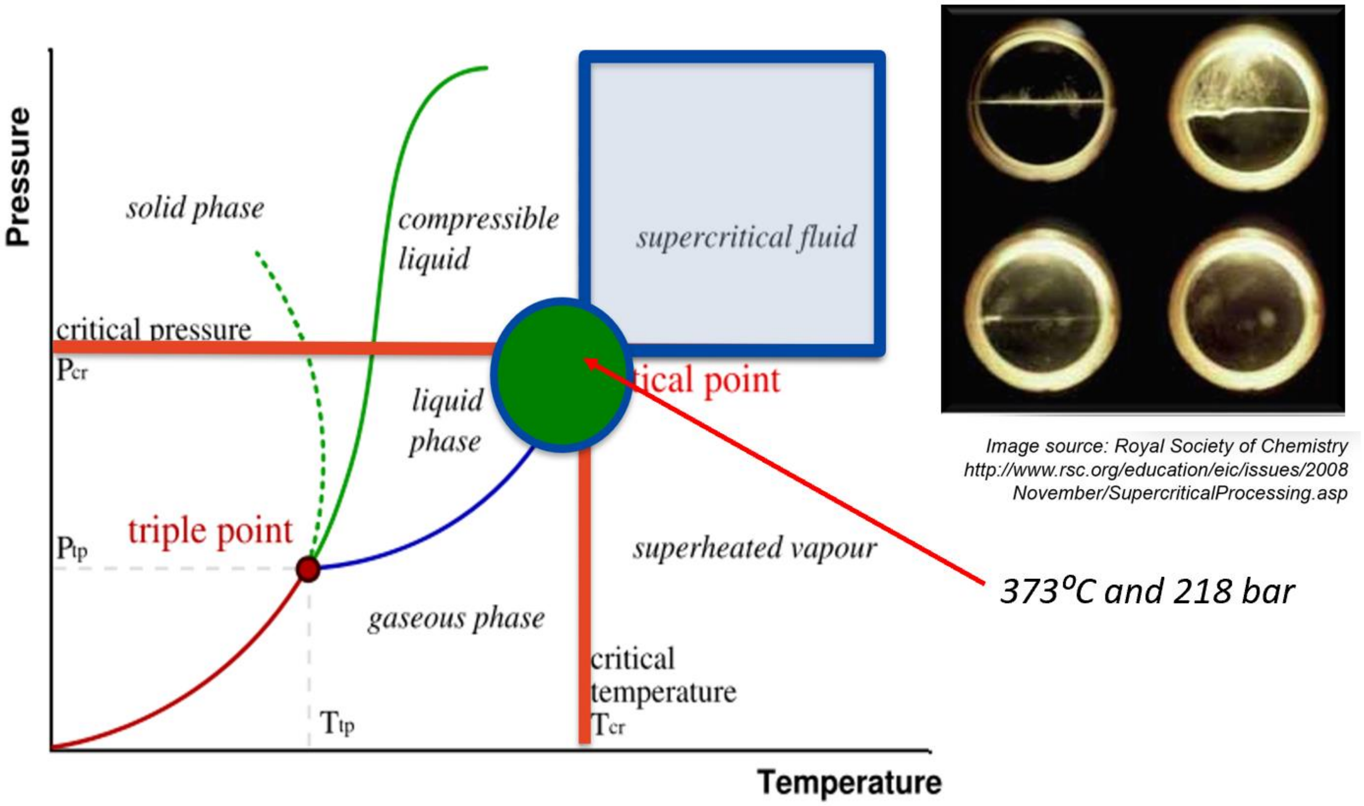


Image source: Royal Society of Chemistry http://www.rsc.org/education/eic/issues/2008 November/SupercriticalProcessing.asp

Figure B3.1: Phase diagram of water, showing supercritical phase

An overview of the Cat-HTR process is shown in Figure B3.2 detailing the key elements of the process.

After preparation, the waste plastic is fed to a proprietary process which pressurises and heats the feedstock, ready for secondary heating via supercritical water injection. The energy for supercritical water generation is provided by the hydrocarbon process gas which is a product of the reaction. A final temperature adjustment to reaction temperature will be undertaken by a gas fired or electric heater.

The combined fluid, now at reaction temperature, will flow through the 'Cat-HTR' reactors that hold the reaction at stable conditions for a specific residence time to ensure sufficient depolymerisation and hydrothermal conversion to occur. The Cat-HTR process consists of hydrothermal upgrading of waste plastics which breaks the plastic's carbon to carbon bonds to form shorter chain hydrocarbons. This is achieved by combining supercritical steam with molten plastic under high temperature and pressure. The open ends of the resultant molecule are completed by hydrogen taken from the water molecules present.

The products from the Cat-HTR reactor are pressure reduced by a let-down valve into a flash column. The majority of the products, along with steam, are flashed off as a vapour passing upwards through a conventional oil refinery type distillation column. These fractions are removed at different temperature cuts and heights within the column, allowing continuous production.

The distillation process results in the following outputs:

- Process Gas consisting mainly of C1-C4 hydrocarbons
- Wastewater – distilled and separated from the oil fraction
- Plasticrude oil
- Heavy Fraction residue (similar to bitumen). This Heavy Fraction makes up 1-4% of incoming feedstock and can be reused in bitumen applications and is made up of:
    - "Heavy" oil from the base of the flash column

  - Insoluble ash and contaminants present within the feedstock that is periodically purged from the base of the continuous flow reactors.

Process gas will be recovered and used as fuel within steam generating boilers; a high-pressure boiler for producing very high temperature and pressure supercritical steam for the hydrothermal process and a low-pressure boiler for producing steam for the deaerator and storage tank heating. The design intent is that the process gas produced will be combusted within the steam generators or sold as a process gas to neighbouring industrial sites. Recent price hikes in natural gas make this more likely.

Should there be excess process gas in Stage 1 operations then it will not be stored but flared. Two flares are included in the facility design – one for start-up and a second for emergency operation to prevent over pressurisation of the process.

Wastewater from the flash distillation column will be pH neutralised using sodium hydroxide dosing. This water will then be held in a wastewater storage tank allowing any remaining oil products to separate prior to passing through a wastewater treatment plant that will remove contaminants and allow it to be discharged into the Greater Western Water tradewaste line.

A periodic reactor purge will manage insoluble ash and contaminants present within the feedstock. The contaminants will settle at the base of the continuous flow reactors. Reactor purge will utilise a sequence of valves to safely remove the contaminant material to another pressure vessel.

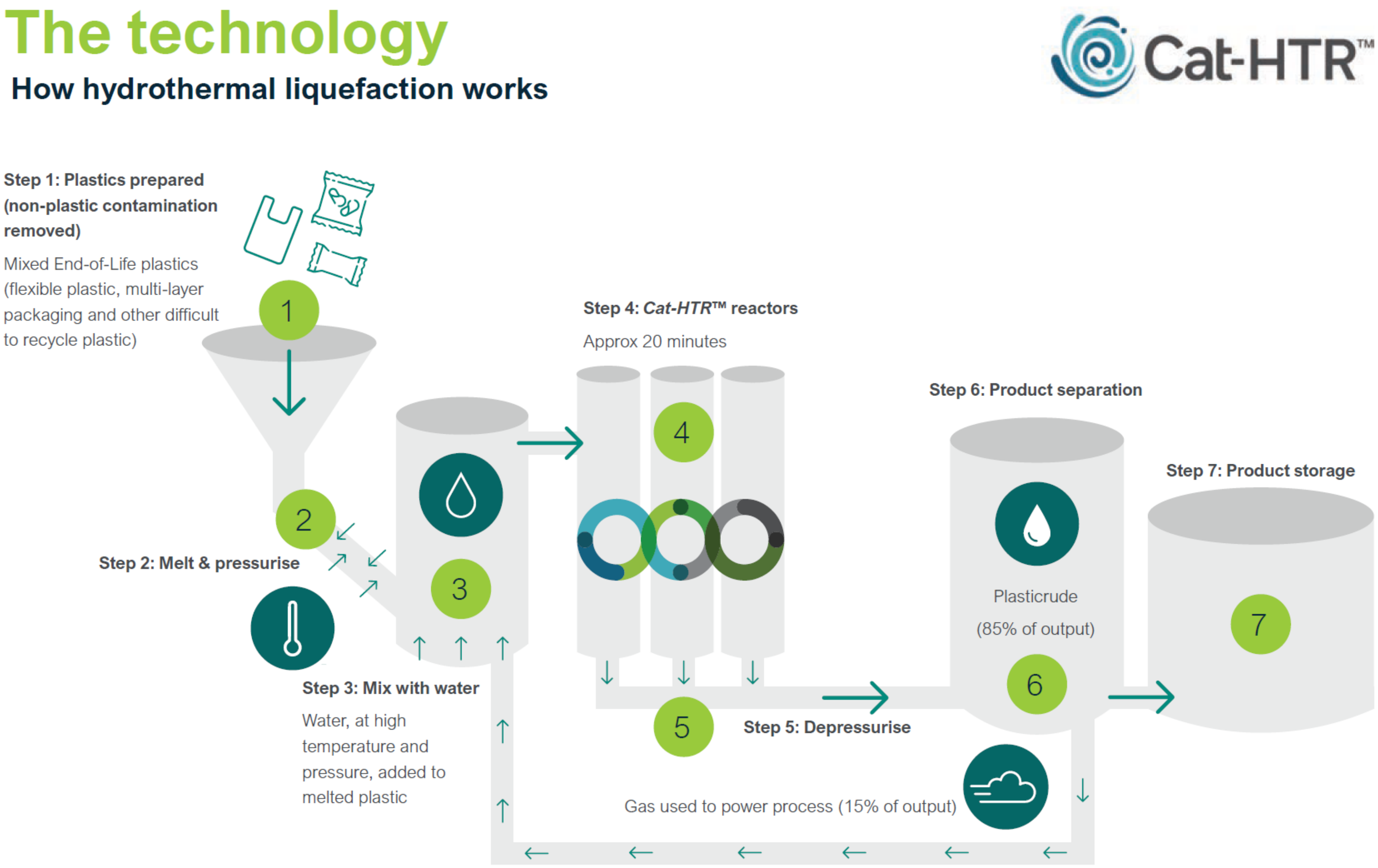
The main elements comprising the Cat-HTR process are:

- plastic inclusion into the Cat-HTR process
- mixing and heating
- pressure let-down
- condenser
- product cooling and storage
- wastewater treatment
- steam generation
- reactor units
- flash column
- flare
- tanker loading
- utilities.

External to the main process equipment, auxiliary systems are included in the facility such as an emergency flare, deaeration, water polishing, compressed air and utilities such as electricity, natural gas and site drainage systems. The plant will be controlled via trained process operators in a centralised control room that will allow for remote monitoring and operation of the process. An on-site laboratory will undertake regular sampling. Maintenance personnel will undertake plant maintenance.

The ARV Altona facility will recover high value petrochemicals that can be used as feedstocks for the plastics industry. There is no limit to the number of times plastics can pass through the advanced recycling process, unlike with conventional mechanical recycling technologies.

The ARV facility has Cat-HTR modules that will each process 20,000tpy of waste plastic. The Altona site can increase production by having more modules constructed.



The technology

How hydrothermal liquefaction works

Step 1: Plastics prepared (non-plastic contamination removed)

Mixed End-of-Life plastics (flexible plastic, multi-layer packaging and other difficult to recycle plastic)

Step 2: Melt & pressurise

Step 3: Mix with water

Water, at high temperature and pressure, added to melted plastic

Step 4: ***Cat-HTR™*** **reactors**

Approx 20 minutes

Step 5: Depressurise

Gas used to power process (15% of output)

Step 6: Product separation

Plasticrude

(85% of output)

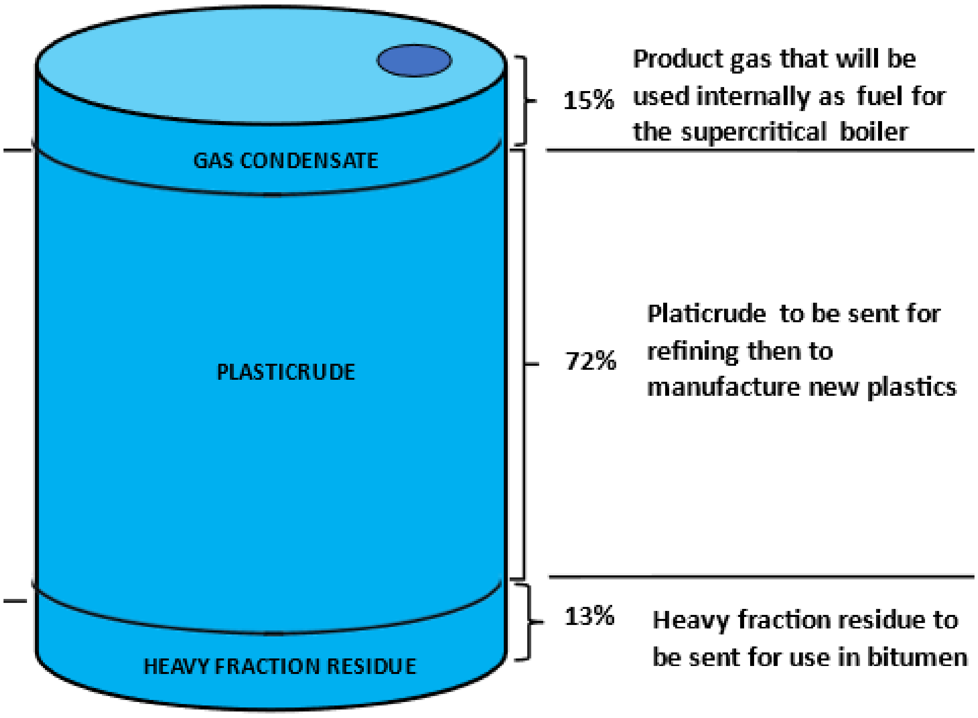
Step 7: Product storage

Figure B3.2 Cat-HTR Process Flow Chart

B3.1 Mass Balance for Advanced Recycling using Cat-HTR technology

The following shows the Mass Balance for ARV Altona Project Cat-HTR technology:

Input	Output
1 tonne of waste plastic feedstock	**150kg Process Gas (15%)**
	720kg Plasticrude Oil (72%)
	130kg Heavy Fraction Bitumen (13%)



B3.2 Recycling “waste” oil from process start-up, shutdown and water treatment plant.

There will be very minor quantities of oil produced in the Cat-HTR facility that will not be suitable for immediate sale as a product. It will be necessary to recycle and re-process this oil.

Sub-standard oil production will occur:

- During Cat-HTR process start-up
- During Cat-HTR process shutdown
- In wastewater after the supercritical mixture is depressurized and distilled into products. The water component will be sent to the Water Treatment Plant- any oil retained will be separated off.

Sub-standard oil will be collected and pumped initially to a "slops" tank. The "slops" mix will be passed through a centrifugal pump and the resulting oil concentrate injected back into the Cat-HTR process. In this way it is planned to maximise oil production with minimal waste.

This sub-standard oil recycling process will be engineered and installed at the UK Mura Technologies facility so its effectiveness reviewed before being installed at the Altona facility.

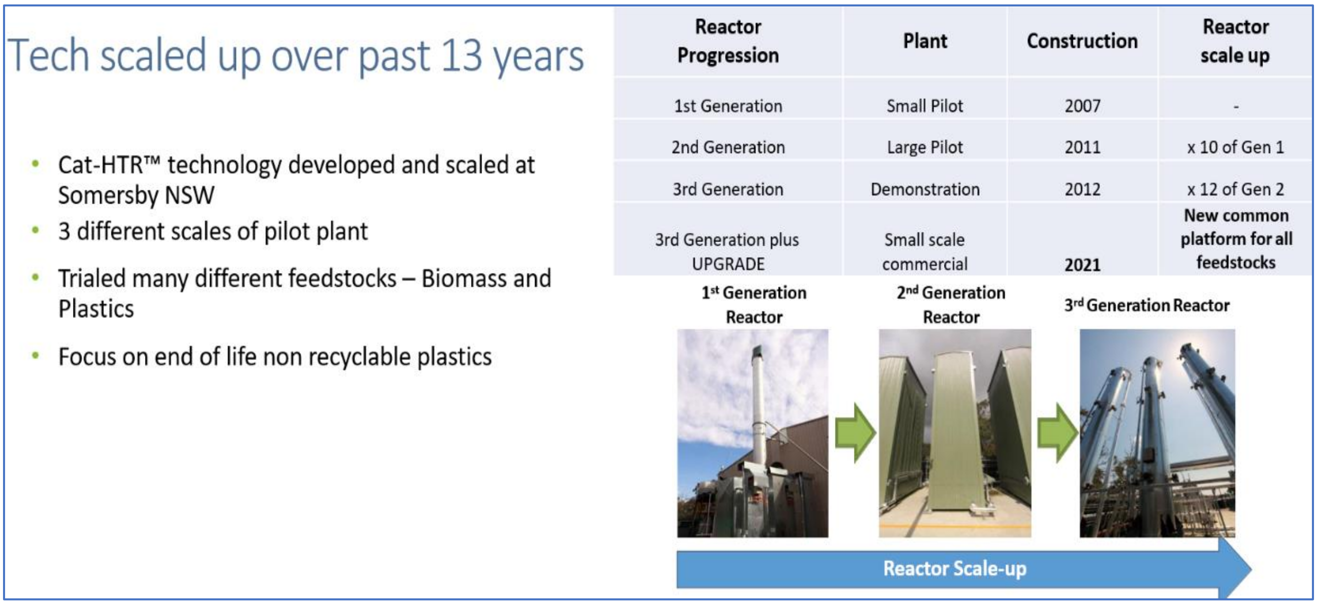
There will be some very minor waste occurring when products are separated from the superheated water and some oily substances stay in the water. This will be understood better when the UK Project commences production. Oily substances will be removed at the site Water Treatment Plant. It may be possible to recycle this waste back into the Cat-HTR process.

B3.3 Development of Licella's Cat-HTR technology

Licella's development facility is located in Somersby, NSW. Two operating pilot plants denoted as the Small Pilot Plant (SPP) and Large Pilot Plant (LPP), have been operated to trial a range of processes and feedstocks. Over 328 individual pilot runs and 2800 hrs operation have occurred over these plants.

The Cat-HTR technology has been under development at Somersby since 2008 with an original focus on hydrothermal conversion of lignite and biomass feedstocks. With a growing concern over the management of waste, end-of-life feedstocks have become a focus with proof-of-concept trials conducted in the period of 2016 to 2019. The timing and capacity parameters of the pilot plants are shown below

With the support of an awarded Accelerated Commercialisation grant by the Australian Government in 2017-2019, Licella was able to test a range of representative feedstocks, design, fabricate and operate a batch distillation unit (BDU) (See Figure 3.4) capable of processing 200 kg product batches. This has enabled Licella and partners to develop off-taker partnerships for joint venture projects in Australia, Canada and United Kingdom.



Tech scaled up over past 13 years

- Cat-HTR™ technology developed and scaled at Somersby NSW
- 3 different scales of pilot plant
- Trialed many different feedstocks – Biomass and Plastics
- Focus on end of life non recyclable plastics

Reactor Progression	Plant	Construction	Reactor scale up
1st Generation	Small Pilot	2007	-
2nd Generation	Large Pilot	2011	x 10 of Gen 1
3rd Generation	Demonstration	2012	x 12 of Gen 2
3rd Generation plus UPGRADE	Small scale commercial	**2021**	**New common platform for all feedstocks**

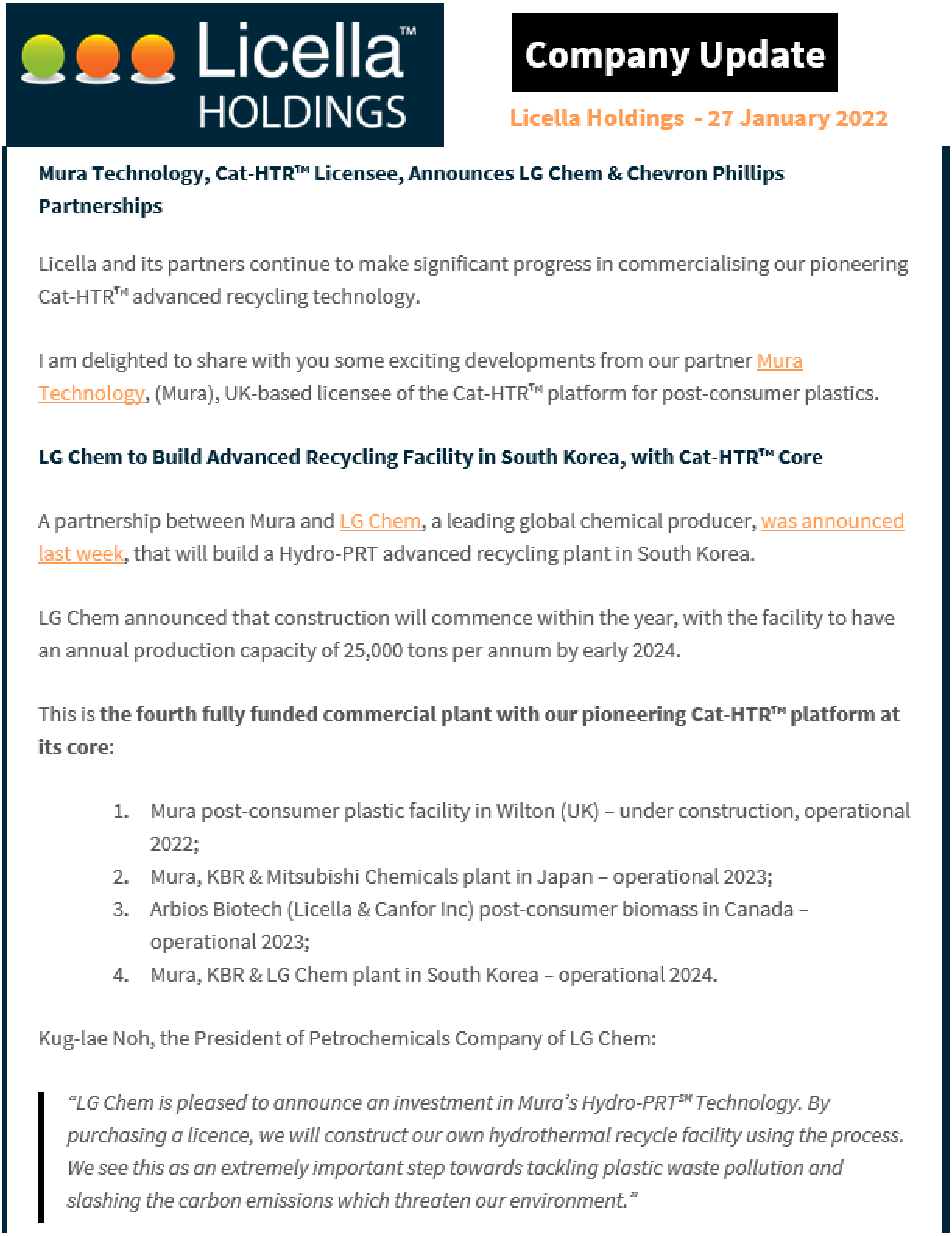
Figure B3.4: Scale up timeframe for Licella's Cat-HTR pilot plants

Figure B3.5: Photos of Licella Small Pilot Plant (SPP), Somersby, NSW

Figure B3.6: Photo of Licella Large Pilot Plant (LPP), Somersby, NSW

Figure B3.7: Licella batch distillation column unit (BDU) at Somersby, NSW

3.4 World-wide establishment of facilities using Licella's Cat-HTR technology



Licella™ HOLDINGS

Company Update

Licella Holdings - 27 January 2022

Mura Technology, Cat-HTR™ Licensee, Announces LG Chem & Chevron Phillips Partnerships

Licella and its partners continue to make significant progress in commercialising our pioneering Cat-HTR™ advanced recycling technology.

I am delighted to share with you some exciting developments from our partner Mura Technology, (Mura), UK-based licensee of the Cat-HTR™ platform for post-consumer plastics.

LG Chem to Build Advanced Recycling Facility in South Korea, with Cat-HTR™ Core

A partnership between Mura and LG Chem, a leading global chemical producer, was announced last week, that will build a Hydro-PRT advanced recycling plant in South Korea.

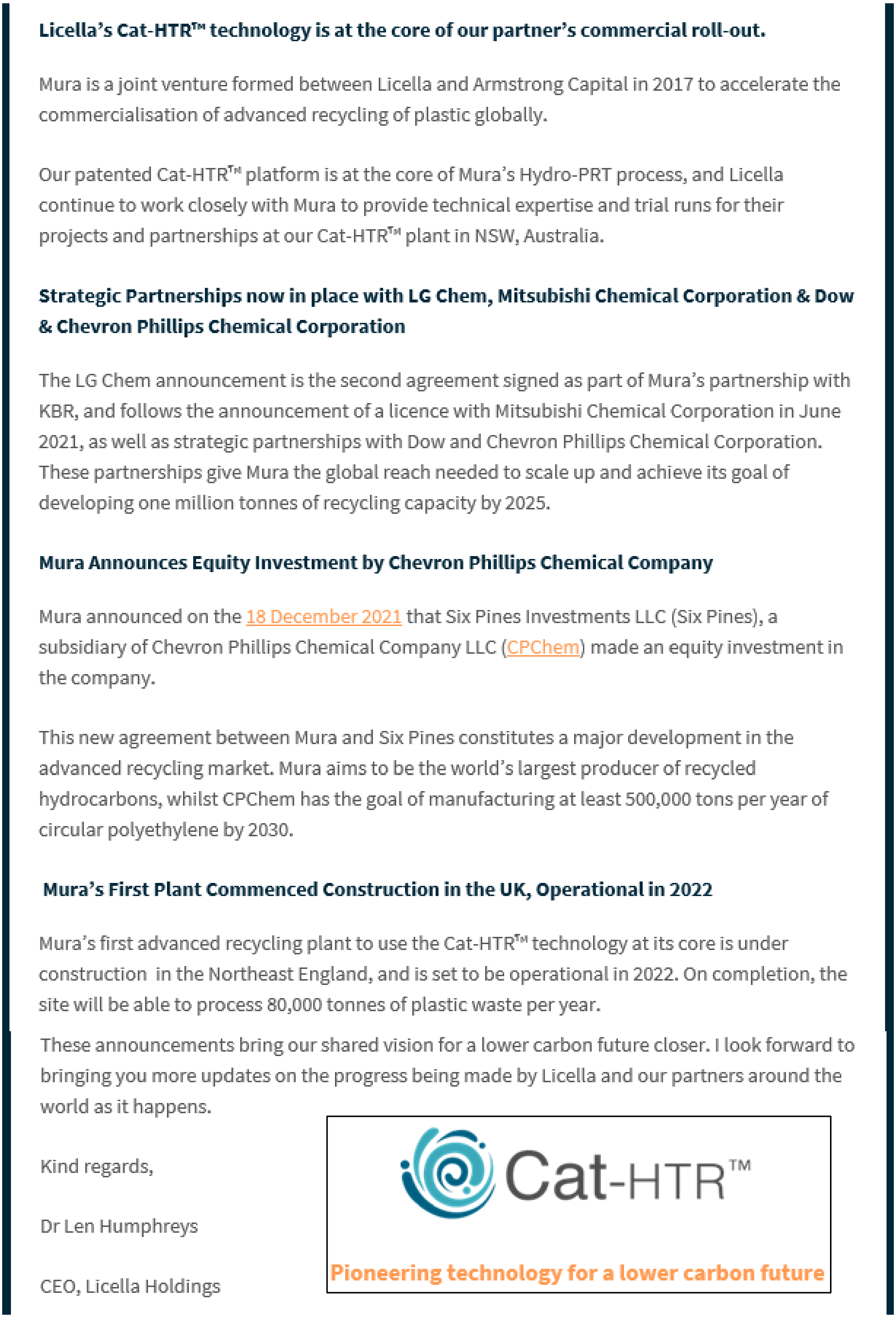
LG Chem announced that construction will commence within the year, with the facility to have an annual production capacity of 25,000 tons per annum by early 2024.

This is **the fourth fully funded commercial plant with our pioneering Cat-HTR™ platform at its core:**

1. Mura post-consumer plastic facility in Wilton (UK) – under construction, operational 2022;
2. Mura, KBR & Mitsubishi Chemicals plant in Japan – operational 2023;
3. Arbios Biotech (Licella & Canfor Inc) post-consumer biomass in Canada – operational 2023;
4. Mura, KBR & LG Chem plant in South Korea – operational 2024.

Kug-lae Noh, the President of Petrochemicals Company of LG Chem:

> *"LG Chem is pleased to announce an investment in Mura's Hydro-PRT℠ Technology. By purchasing a licence, we will construct our own hydrothermal recycle facility using the process. We see this as an extremely important step towards tackling plastic waste pollution and slashing the carbon emissions which threaten our environment."*



Licella's Cat-HTR™ technology is at the core of our partner's commercial roll-out.

Mura is a joint venture formed between Licella and Armstrong Capital in 2017 to accelerate the commercialisation of advanced recycling of plastic globally.

Our patented Cat-HTR™ platform is at the core of Mura's Hydro-PRT process, and Licella continue to work closely with Mura to provide technical expertise and trial runs for their projects and partnerships at our Cat-HTR™ plant in NSW, Australia.

Strategic Partnerships now in place with LG Chem, Mitsubishi Chemical Corporation & Dow & Chevron Phillips Chemical Corporation

The LG Chem announcement is the second agreement signed as part of Mura's partnership with KBR, and follows the announcement of a licence with Mitsubishi Chemical Corporation in June 2021, as well as strategic partnerships with Dow and Chevron Phillips Chemical Corporation. These partnerships give Mura the global reach needed to scale up and achieve its goal of developing one million tonnes of recycling capacity by 2025.

Mura Announces Equity Investment by Chevron Phillips Chemical Company

Mura announced on the 18 December 2021 that Six Pines Investments LLC (Six Pines), a subsidiary of Chevron Phillips Chemical Company LLC (CPChem) made an equity investment in the company.

This new agreement between Mura and Six Pines constitutes a major development in the advanced recycling market. Mura aims to be the world's largest producer of recycled hydrocarbons, whilst CPChem has the goal of manufacturing at least 500,000 tons per year of circular polyethylene by 2030.

Mura's First Plant Commenced Construction in the UK, Operational in 2022

Mura's first advanced recycling plant to use the Cat-HTR™ technology at its core is under construction in the Northeast England, and is set to be operational in 2022. On completion, the site will be able to process 80,000 tonnes of plastic waste per year.

These announcements bring our shared vision for a lower carbon future closer. I look forward to bringing you more updates on the progress being made by Licella and our partners around the world as it happens.

Kind regards,

Dr Len Humphreys

CEO, Licella Holdings

Cat-HTR™

Pioneering technology for a lower carbon future

C. BATT for Site Operations

C1.0 Site suitability for establishing the first Australian Advanced Recycling facility using Cat-HTR technology

C1.1 Site Location and Access

The decommissioned Dow Chemical site at 541-583 Kororoit Creek Road, Altona was selected as the preferred site for the Advanced Recycling facility. Twelve sites were considered.

The Dow Chemical site has the following attributes that made it preferable to other sites

- Close proximity to Viva Refinery and Qenos and LyondellBasell plastics manufacturers.
- Excellent truck access with close freeway networks and local roads supporting truck deliveries and outputs.
- Excellent site infrastructure with electrical power, industrial water, potable water, trade-waste water and natural gas available. Also, some buildings and product tanks can be refurbished for ongoing use.
- Good site industrial infrastructure with internal roads and storm drainage already constructed.
- Large buffer zone of 1.3km to the closest residential areas.
- Local council SUZ3 land zoning which is dedicated to use by industries involved with the use, manufacture and storage of petrochemicals
- Ample development area for the both the proposed Stage 1 operations and possible additional future expansion stages

Figure C4.1 shows the location of the site.

The site location also offers the potential to sell offtake process gas and product to immediate neighbouring industries.

The Project site has access from the Kororoit Creek Road public highway which is a four-lane carriageway with a centre-road median strip. The site access point has its own traffic lights and a dedicated incoming right-hand turning lane. Traffic departing the site can only do so when the traffic lights stop travel on Kororoit Creek Rd and allow site exit.

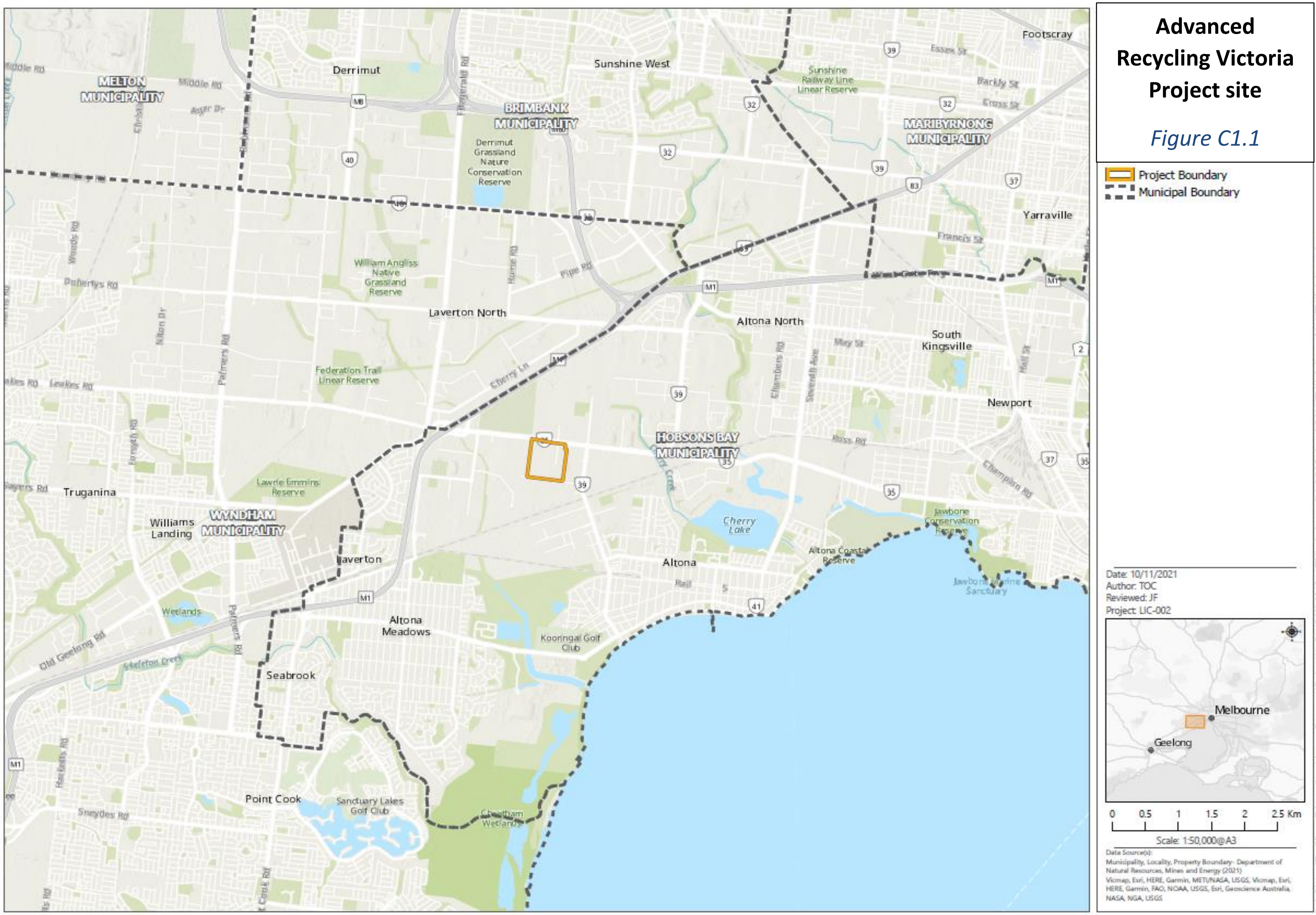
The Project site is 1.5km east from the Melbourne-Geelong freeway. Kororoit Creek Rd has entry and exit points to the freeway. The freeway connects through the Melbourne Ring-Road Freeway access to all major freeways and highways around Melbourne including the Geelong-Western Districts, Ballarat-Adelaide, Bendigo-Mildura, Wodonga-Albury-Sydney and Dandenong-Gippsland freeways. A network of internal roads provide access to the site once in the Project Area.

C1.2 Summary of ARV Stage 1 establishment

The Stage 1 ARV facility will receive 20,000 tonnes of end-of-life plastic feedstock per year. Initially only 1 Cat-HTR module will be built and operated, with a view for additional Cat-HTR modules to be built in the medium term. Project expansion involving the establishment of additional stages and Cat-HTR modules will be incorporated into Project EPA licencing by way of new licencing applications.

In Stage 1 it is planned to establish the following infrastructure:

- All utilities including:
    - Electrical power supply including HV switching and all site power distribution
    - Potable water supply pipelines
    - Recycled industrial water supply pipelines
    - Tradewaste discharge water lines incorporating sewerage discharge pipelines
    - Communications



Advanced Recycling Victoria Project site

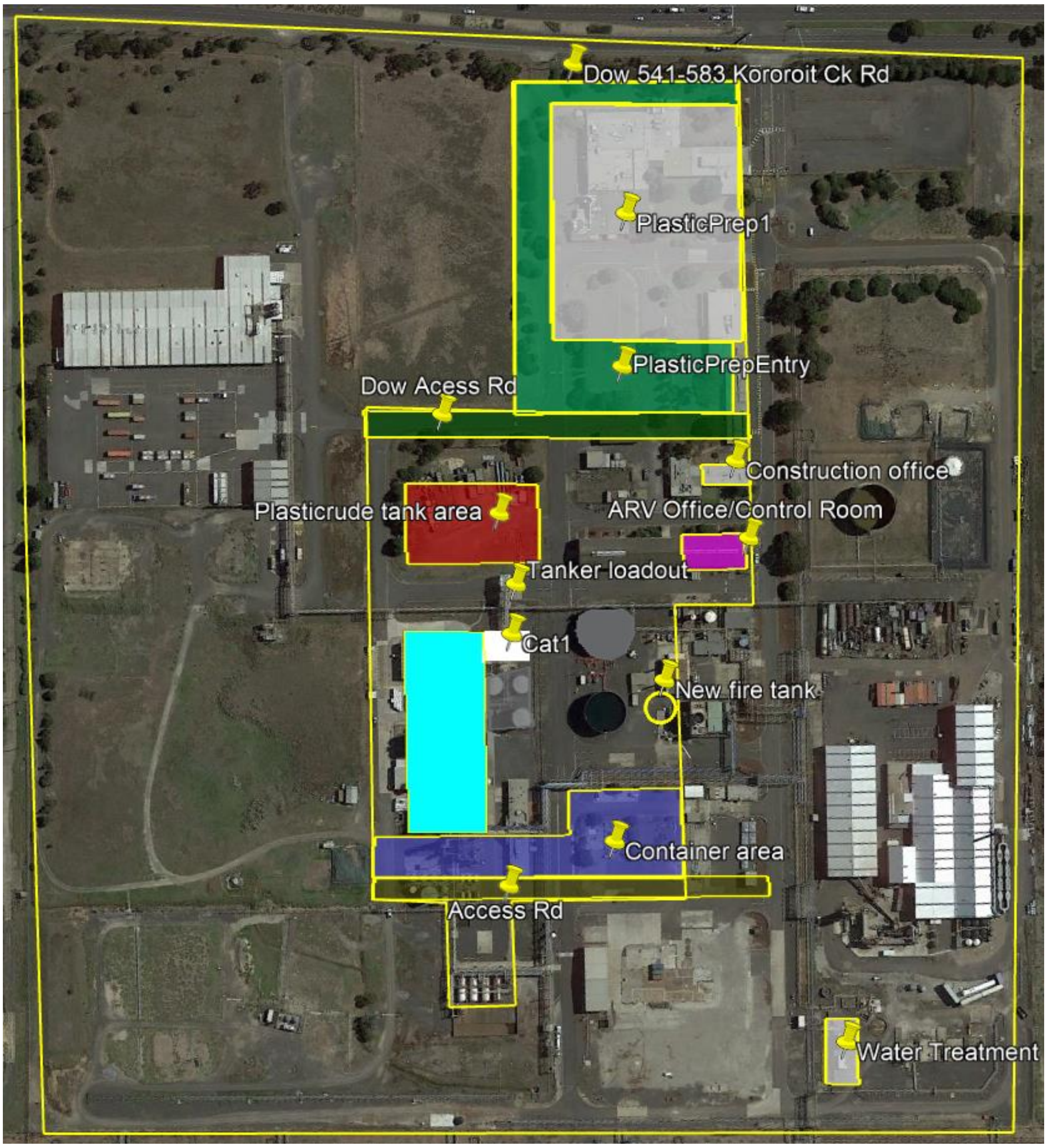
Figure C1.1

Date: 10/11/2021
Author: TOC
Reviewed: JF
Project: LIC-002

Data Source(s):
Municipality, Locality, Property Boundary- Department of Natural Resources, Mines and Energy (2021)
Vicmap, Esri, HERE, Garmin, METI/NASA, USGS, Vicmap, Esri, HERE, Garmin, FAO, NOAA, USGS, Esri, Geoscience Australia, NASA, NGA, USGS

- Offices and Control Room
- Workshops
- Staff carparking
- 1 x Cat-HTR module including supercritical steam generator
- Plastics Preparation shed, plant and equipment
- Pipe-racking for utilities and services
- Product storage tanks
- Truck tanker loading station
- Emergency services infrastructure and equipment
- Container storage area for both incoming feedstock containers and outgoing empty containers
- Water treatment plant
- Flaring for excess product gas
- Flaring for emergency process gas dumping
- Solar panels on all suitable sheds and buildings

Figure C1.2 showing the proposed site Stage 1 layout.



C1.3 Community and Stakeholder Engagement

Licella engaged Capire Consulting Group to plan and deliver a range of community and stakeholder engagement activities. The purpose of the engagement is to understand community and stakeholder concerns and issues with the proposed facility and identify options to mitigate those concerns through the proposal. The objectives of the engagement were to:

- Determine the technical, economic, and environmental benefits of a local advanced recycling industry
- Build community and stakeholder understanding of the Cat-HTR™ technology, advanced recycling and how this contributes to a circular economy
- Build trust in Licella and their partners
- Identify community and stakeholder concerns early in the development of the proposal
- Engage with key stakeholders to develop a baseline of what issues need to be addressed in the Development Licence application process
- Work with key stakeholders to develop options which mitigate community concerns and issues to the greatest extent possible.

Appendix 2 contains the community and stakeholder engagement summary report.

A summary of the key messages from initial conversations with these stakeholders included:

- Most community and stakeholder representatives are supportive of finding a local solution to soft plastics recycling
- Establishing trust and credibility within the community and environmental groups was considered paramount to success
- Fundamental concerns about the volumes of plastics still in circulation that end up in the environment
- Key concerns about cumulative local air quality impacts from industry on local community
- Concerns about the practicality and reliability of people taking their plastics to collection points for recycling and the manual extraction on assembly lines.

Plant size:	Quality Requirements								Plant Demand				Annual working quantity		
20kt	Pressure (barg)				Temperature (°C)				Demand Units				Units		
Utility	Design Rating	Normal Operating	Minimum	Maximum	Design	Normal Operating	Minimum	Maximum		Normal Operating/ Average	Minimum	Maximum		Annual Average consumption	Peak Load Hours per annum
Electricity	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	MW	2.8	0.25	3.8	MWh	22,075	0
Potable Water	10.00	6.00	4.00	8.00	Ambient	Ambient	Ambient	Ambient	m^3/hr	0.1	0.05	10	m^3	1,028	24
Industrial Water (Process Water) (Note 8)	10.00	6.00	4.00	8.00	Ambient	Ambient	Ambient	Ambient	m^3/hr	3	0.05	10	m^3	25,092	144
Waste Water / Washdown/drainage (Note 1) Outgoing	N/A	N/A	N/A	N/A	40	10	0	40	m3/hr	0.4	0	10	m3	4,594	144
Waste Water / Process Effluent (Note 1) Outgoing	N/A	N/A	N/A	N/A	40	10	10	40	m3/hr	1.8	0	2	m3	14,191	0
Demin Water (Note 10)	10.00	6.00	4.00	8.00	Ambient	Ambient	Ambient	Ambient	m^3/hr	2	1	10	m^3	15,858	9
Natural Gas - Site Requirment - (Note 4)	1.00	0.35	0.35	0.50	32	0	-25	32	MW	0.005	0.005	2.50	MWh	99	24
Hydrogen (Note 13)	50	35	30	40	N/A	N/A	N/A	N/A	Nm^3/hr	0	0	0	Nm^3	0	0
Compressed Air (note 12)									Nm^3/hr				Nm^3		0
Instrument Air	10	7	N/A	10	N/A	N/A	N/A	N/A	Nm^3/hr	2.5	1.00	5.00	Nm^3	19,830	24
Process Air (note 6)	10	8	N/A	10	N/A	N/A	N/A	N/A	Nm^3/hr	320	25	320	Nm^3	2,522,880	0
Nitrogen	10	7	N/A	10	N/A	N/A	N/A	N/A	Nm^3/hr	10	5	120	Nm^3	87,480	72
LP Steam (note 11)	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	kg/hr	300	0	400	kg	2,394,000	72
MP Steam (note 14)	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	kg/hr	0	0	0	kg	0	0
HP Steam (note 15)	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	kg/hr	0	0	0	kg	0	0
Site Rain Water Drainage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	m^3/hr	To be determined for the site			m^3	To be determined for the site	
Sewerage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Nm^3/hr	0.1	0.05	10	Nm^3	1,028	24
Firewater - Note 9	10.00	6.00	4.00	10.00	32	15	-15	32	m^3/hr	0	0	350	m^3	0	0

Notes 90%

1 Pumped to the site water treatment plant then discharged into GWW tradewaste line.

3 Electrical Load - Normal includes a process loading factor **Peak load working assumptions**

5 Cooling Water is a Closed Loop - the value provided is the size of the Cooling Water recirculation Pump - flow into the system is only required for top up and first/ post maintenance fill.

6 Process air is for the Material Prep Plant. Demand will vary depending on MPP design.

7 Natural Gas values given are at site boundary assuming there is a let down system upstream, if let down system is required on site then values for P & T will change.

8 Industrial Water usage (normal) is dependent on time of year (summer = 3 other periods = 0.1. Site location dependent).

9 Fire assessment to be completed to confirm requirements/conditions. On site tanks & pumps required if low reliability or pressure in connection/source.

10 Demin water max demand is when filling/topping up closed loop cooling network

11 If a steam source is available and utilised on the plant, the quality needs to be checked of available sources

12 Compressed Air is used to generate instrument and process air.

13 Hydrogen demand is only required if Hydrotreater is included. Purity required is 99.9% minimum

14 MP Steam is required for upgrading package only

15 HP Steam is generated with upgrading package only

Normal working assumptions		Unit
Online efficiency	90%	
Online days	328.5	Days
Online Hours	7884	Hours
Peak load working assumptions		
Startups/Shutdowns per year		3

Table C1.1 Utilities Summary for Stage 1 Altona Advanced Recycling of waste plastic using Cat-HTR technology

C2. Collection of feedstock waste plastic

This Project has not only considered the Advanced Recycling of waste plastic using Cat-HTR technology but also the creation of the upstream waste plastic collection. There is an increasing shift for industry to recycle plastics, with major companies that use plastic in their products wanting the material to be recycled in a socially responsible way.

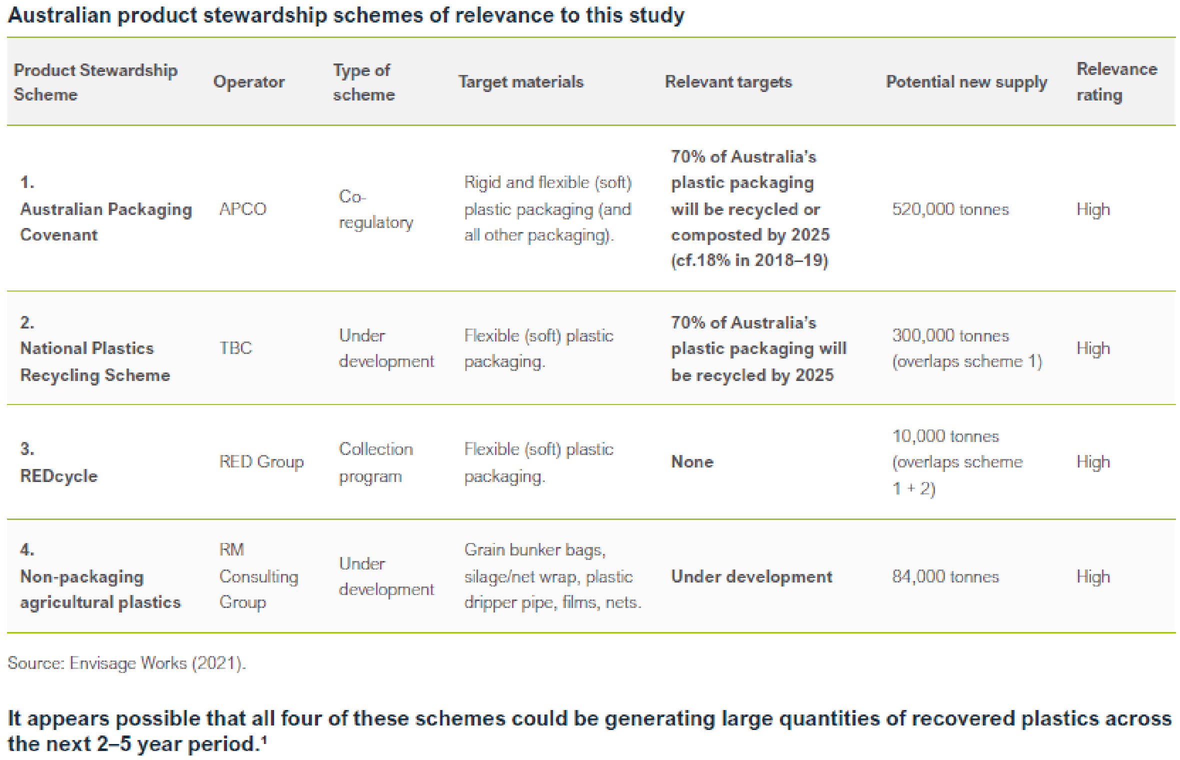
It is impossible to implement plastic stewardship schemes without appropriate technology to process the waste material recovered.

C2.1 Collection schemes for soft plastics

- The best-known product stewardship scheme for End-of-Life plastics in Australia is the REDCycle soft plastics collection bins in supermarkets. The scheme has collected over 2.95 billion pieces of plastic since it launched in 2011.
- Similar schemes exist for a variety of agricultural plastics.
- The AFGC is developing a National Plastics Recycling Scheme (NPRS), which aims to collect and recycle nearly 190,000 tonnes of plastic packaging per annum by 2025.
- The CurbCycle company is operating the Curby program with the NSW Central Coast Council. Residents are using a large plastic bag to collect their waste soft plastics. The large plastic bag is placed in the household recycling bin and separated from other recyclables at the iQRenew MRF and bundled for advanced recycling. This plastic has already been used in advanced recycling trials.

C2.2 New potential supply of soft plastics from these schemes

The four high relevance schemes highlighted by Envisage Works (in the table below) will generate around 850,000 tonnes of 'new' recovered plastics if they achieve their stated targets. This waste plastic would normally go to landfill.



Australian product stewardship schemes of relevance to this study

Product Stewardship Scheme	Operator	Type of scheme	Target materials	Relevant targets	Potential new supply	Relevance rating
1. Australian Packaging Covenant	APCO	Co-regulatory	Rigid and flexible (soft) plastic packaging (and all other packaging).	**70% of Australia's plastic packaging will be recycled or composted by 2025 (cf.18% in 2018–19)**	520,000 tonnes	High
2. National Plastics Recycling Scheme	TBC	Under development	Flexible (soft) plastic packaging.	**70% of Australia's plastic packaging will be recycled by 2025**	300,000 tonnes (overlaps scheme 1)	High
3. REDcycle	RED Group	Collection program	Flexible (soft) plastic packaging.	**None**	10,000 tonnes (overlaps scheme 1 + 2)	High
4. Non-packaging agricultural plastics	RM Consulting Group	Under development	Grain bunker bags, silage/net wrap, plastic dripper pipe, films, nets.	**Under development**	84,000 tonnes	High

Source: Envisage Works (2021).

It appears possible that all four of these schemes could be generating large quantities of recovered plastics across the next 2–5 year period.[1]

Table C2.1 - four high relevance schemes highlighted by Envisage Works

C2.3 Advanced recycling is a scalable solution for these difficult to recycle plastics

With new product stewardship schemes under development, and the opportunity to expand ones already in place, we must consider the recycling capacity in place.

The proposed ARV facility using Cat-HTR™ technology will process the vast majority of the plastics collected by the schemes listed in the table above, including plastics that are difficult to recycle mechanically, such as soft plastic packaging.

Expanding these schemes in parallel to building the advanced recycling infrastructure necessary to recycle them is essential to ensure the additional plastics collected are not sent to landfill or waste-to-energy facilities.

Suppliers of waste plastic for Cat-HTR processing will be contracted to supply feedstock that meets the following specifications:

Parameter	Value	Comments
Material size	<40 mm	Largest dimension. Applies to rigid and flexible scrap plastics.
Water	<10%	This is total moisture (water) from all sources.
PE and/or PP	>75%	These are the target polymers and must be more than 75% of the input. This value excludes any plastics additives. Glass fibre reinforced plastics are excluded.
PET, PS, PA and/or ABS	<15%	Non-target polymers.
PVC, PVDC, PVDF and/or chlorinated PE	<0.2%	Total halogens (F, Cl and Br) ≤0.1%. Organochlorides are unacceptable contaminants to refiners or other applications.
Paper and cardboard	<10%	The process can tolerate paper however it is a dead load reducing plant production capacity.
Organics – solids – cellulose, textiles and/or leather	<10%	Assumed polyamide or polyester based textiles.
Organics – washable – detergents, grease and food	<1%	Nitrogen containing compounds undesirable as they affect final oil quality.
Metals – ferrous	~0%	Minimise by feedstock supplier. Presence of particles >5mm diameter can cause damage to plant equipment leading to significant downtime.
Metals – non-ferrous	~0%	Copper, aluminium, brass. Minimised by feedstock supplier. Vapour deposited OPP aluminium (e.g. liner in chip pack films) is acceptable.
Silicones	<1%	-
Inorganic materials – large	~0%	Includes stone, glass, ceramics. Minimise by feedstock supplier. Stones can increase risk of equipment jamming and must be reduced as much as practical. Fine glass acceptable in small amounts but will contribute to increased wear.
Inorganic materials – fine	<1%	Includes sand, grit, dirt.
Inorganic materials – ash	<10%	Total ash from all sources.

Table C2.2 - waste plastic for Cat-HTR processing specifications

The collection of waste plastic for Advanced Recycling using Cat-HTR technology will be a new activity in waste management that will involve creating new upstream supply chains. Whilst it appears that collecting at least 20,000 tonnes per year of waste plastic for ARV Stage 1 operations will be highly likely, for Stage 2 onwards the complete waste management industry will need to be upgraded and upskilled. Companies already undertaking waste plastic collection that have expressed interest in the

Project include REDCycle, CurbCycle, iQRenew, Cleanaway, Violia and CityWaste.

To a large extent the upgrading and upskilling of the waste plastic upstream collection has not happened because there has been no large-scale industrial process that can process the waste plastic that could be collected.

Waste plastic that is collected for Advanced Recycling using Cat-HTR technology will be baled in preparation for transportation to site.

C3.0 Transportation and storage of feedstock waste plastic to site prior to Advanced Recycling processing

There are a few means of transporting large volumes of waste plastic, these being:

- Baled plastic loaded onto tautliners
- Loose plastic loaded into tip trucks
- Baled plastic loaded into shipping containers

Of these, for the ARV Advanced Recycling Project, having “Baled plastic loaded into shipping containers” is the best option.

Discussions have been held with iQRenew MRF operators who use containers for transporting waste plastics. When loaded, 40ft containers hold 20 tonnes of baled plastic.

In summary:

- The use of shipping containers for waste plastic feedstock transportation and on-site storage provides an efficient, safe and low risk solution for managing waste plastic feedstock compared to just transporting individual plastic bales or loose plastic stockpiles.
- Waste plastic will be baled, loaded, transported and stored in 40ft shipping containers – 20 tonnes per container.
- Litter management and fire safety management are effective when containers are used.
- Shipping containers will be transported and stored at site with a maximum of 5 days feedstock supply (15 full containers) stored at site.

C4.0 Preparation of feedstock waste plastic for Advanced Recycling

C4.1 Plastics preparation processing

The front end of the Advanced Recycling facility will be a plastics preparation processing line.

ARV is considering if this activity will be contracted out or will be carried out “in-house” for Stage 1 of the project.

It is expected that the plastics preparation process line will be configured to process waste plastic at a throughput rate of 5 tonnes per hour.

The plastics preparation line will comprise the following:

- Plastics reception and handling
- Course shredder reducing particle size to approximately 40mm
- Belt magnet ferrous metal recovery
- Eddy current separator to remove non-ferrous metals (aluminium)
- Density separator to remove rigid plastics, grit, stones, pieces of wood, etc
- Dry cleaner system to abrade and remove fine material (soils, some paper, etc.)
- Near Infra-Red separator to selectively reject unsuitable plastic (PVC etc.)
- Fine shredder to ensure plastic pieces are below 40mm size
- Floor storage bins

The equipment used for the plastics preparation line is industry standard. Figure C4.2 shows the plastics preparation process line - the numbers on the diagram are the tonnage rates.

iQRenew has established a plastics Preparation line at Tuggarah, NSW, using this technology. It is now in operation doing feedstock plastics preparation for “waste-to-energy” operations in NSW. ARV will co-ordinate the design of the plastics preparation with iQRenew and industry consultants.

Fig C4.1 Pics of iQRenew’s Tuggarah Plastics Preparation facility

C4.2 Managing and minimizing halogens in the Cat-HTR process

The Plastics Preparation process removes most PVC and PVDC. This is achieved through the use of near-infrared sorters in the plastics preparation process line.

However, it is understood that small fragments of PVC or PVDC may still enter the Cat-HTR process. When this does happen, chlorine and other halogens stay in the water phase as salts. Licella proved this in a pilot plant trial where plastic feedstock was “spiked” with PVC and PVDC plastics see Appendix 3 “Chlorine balance on spiked run”.

1. The plastics preparation process is built to target the removal of PVC through the near-infrared plastics separation process. The majority of PVC is removed during plastics preparation.
2. Any PVC and PVDC that does enter the Cat-HTR process is “scrubbed” from the product stream. Most chlorine and any rogue halogens that make it to the Cat-HTR process will remain in the water phase as salts.
3. Licella has used the Somersby pilot plants to test the effect of PVC and resultant chlorine in the Cat-HTR process and has proved that chlorine remains in the water phase as salts.

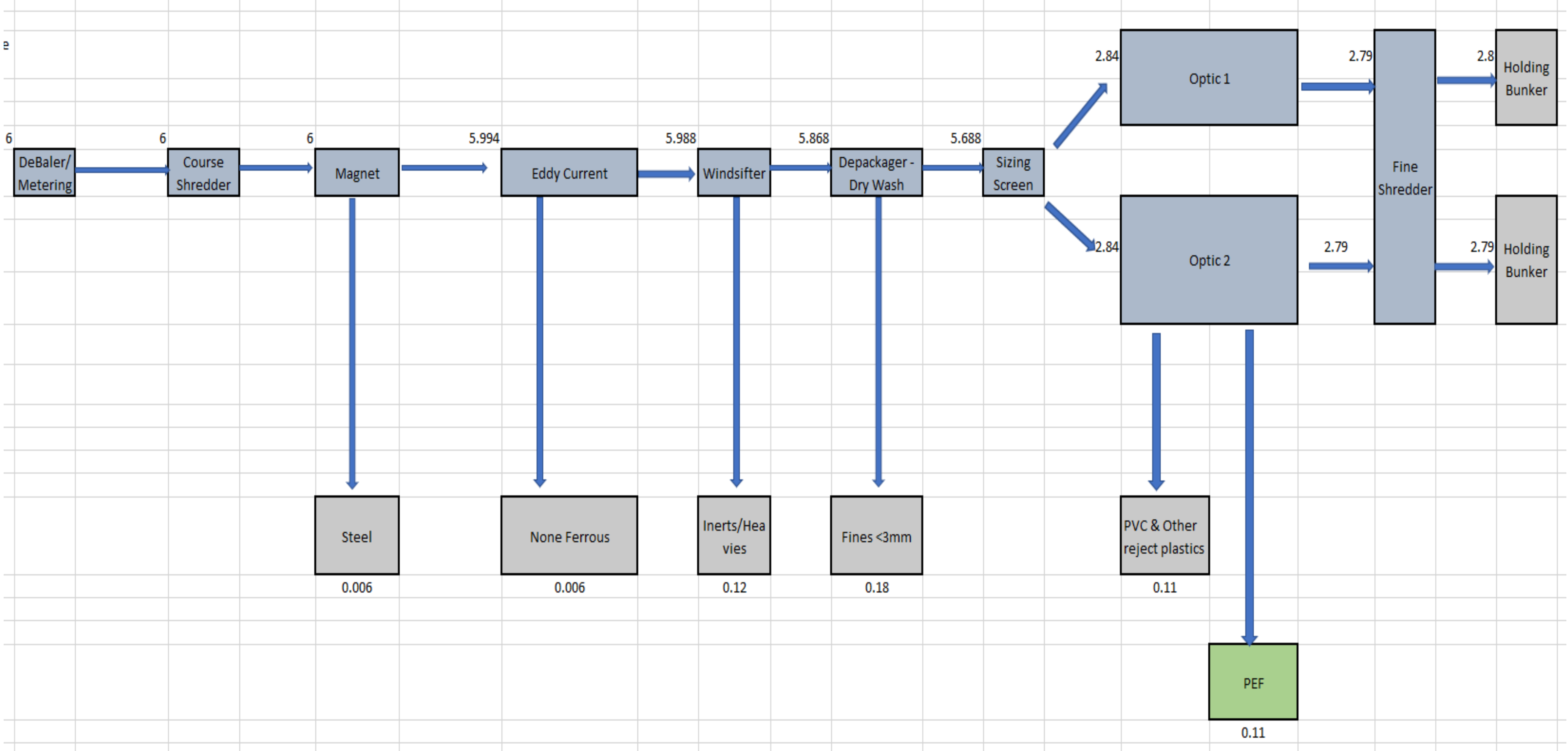


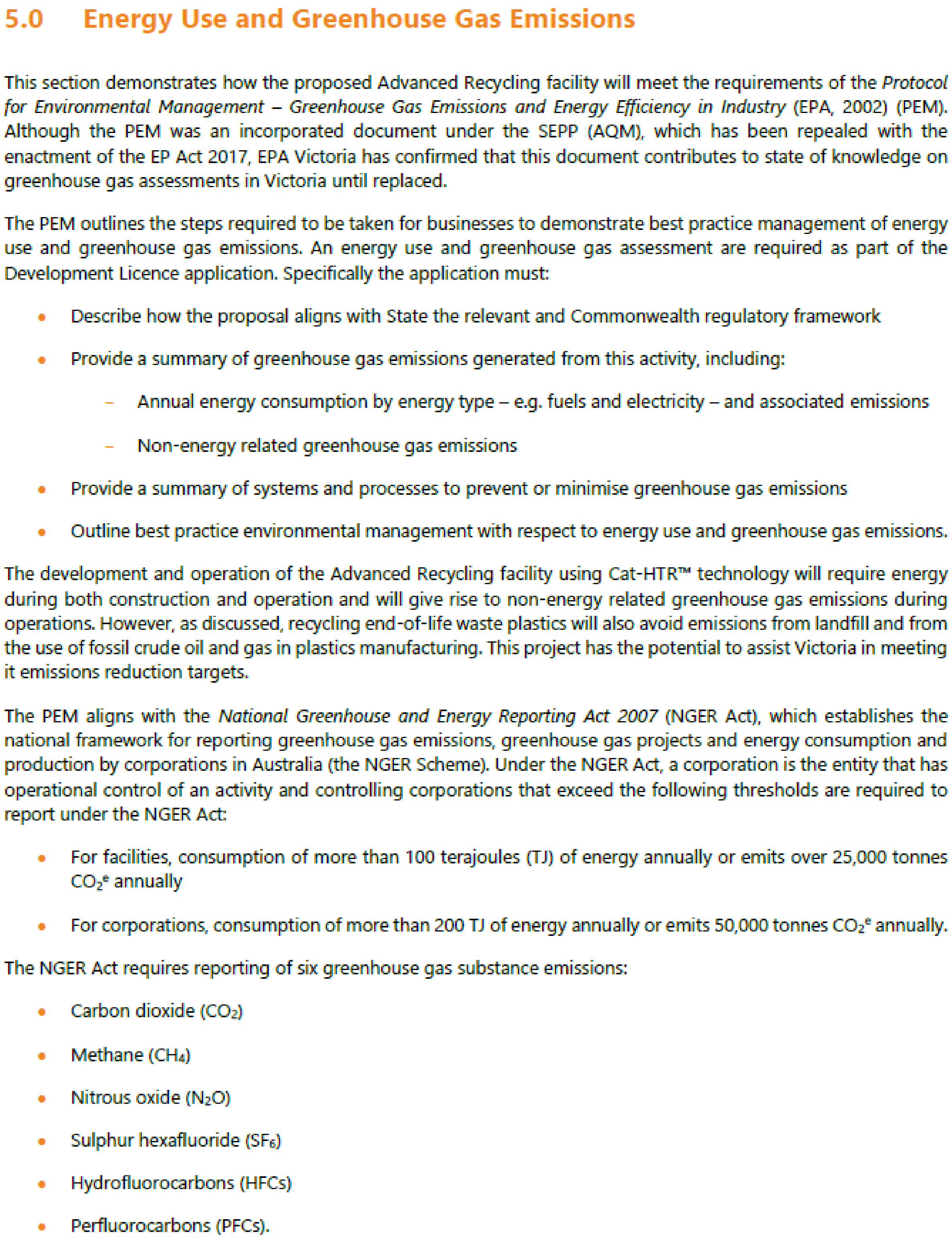
Figure C4.2 Plastics preparation process line – numbers showing tonnage throughput rates

C5.0. Minimizing GHG production from Advanced Recycling operations

It is estimated that Stage 1 operations will produce 3,571t CO_2^e GHG equivalent per year.

A comparable industry to the Altona Advanced Recycling facility using Cat-HTR technology is a Waste-to-Energy (WtE) facility that incinerates rubbish to produce electricity. Based on findings from the "Zero Waste Europe" organization published in 2020, a WtE facility will produce between 0.7t to 1.7t of CO_2^e for each tonne of waste it consumes. Taking a mid-point of 1.2 CO_2^e for a WtE facility's GHG emissions, if such a facility was to incinerate 20,000 tonnes of waste plastic in a year, then it would produce (1.2 x 20,000) = 24,000t of CO_2^e

GHG production at the Altona facility has been covered in Chapter 5 of the submission already issued to EPA Victoria "Development Licence Application Supporting Documentation - Altona Advanced Recycling Facility Using Cat-HTR™ Technology". It is reproduced here.



5.0 Energy Use and Greenhouse Gas Emissions

This section demonstrates how the proposed Advanced Recycling facility will meet the requirements of the *Protocol for Environmental Management – Greenhouse Gas Emissions and Energy Efficiency in Industry* (EPA, 2002) (PEM). Although the PEM was an incorporated document under the SEPP (AQM), which has been repealed with the enactment of the EP Act 2017, EPA Victoria has confirmed that this document contributes to state of knowledge on greenhouse gas assessments in Victoria until replaced.

The PEM outlines the steps required to be taken for businesses to demonstrate best practice management of energy use and greenhouse gas emissions. An energy use and greenhouse gas assessment are required as part of the Development Licence application. Specifically the application must:

- Describe how the proposal aligns with State the relevant and Commonwealth regulatory framework
- Provide a summary of greenhouse gas emissions generated from this activity, including:
    - Annual energy consumption by energy type – e.g. fuels and electricity – and associated emissions
    - Non-energy related greenhouse gas emissions
- Provide a summary of systems and processes to prevent or minimise greenhouse gas emissions
- Outline best practice environmental management with respect to energy use and greenhouse gas emissions.

The development and operation of the Advanced Recycling facility using Cat-HTR™ technology will require energy during both construction and operation and will give rise to non-energy related greenhouse gas emissions during operations. However, as discussed, recycling end-of-life waste plastics will also avoid emissions from landfill and from the use of fossil crude oil and gas in plastics manufacturing. This project has the potential to assist Victoria in meeting it emissions reduction targets.

The PEM aligns with the *National Greenhouse and Energy Reporting Act 2007* (NGER Act), which establishes the national framework for reporting greenhouse gas emissions, greenhouse gas projects and energy consumption and production by corporations in Australia (the NGER Scheme). Under the NGER Act, a corporation is the entity that has operational control of an activity and controlling corporations that exceed the following thresholds are required to report under the NGER Act:

- For facilities, consumption of more than 100 terajoules (TJ) of energy annually or emits over 25,000 tonnes CO_2^e annually
- For corporations, consumption of more than 200 TJ of energy annually or emits 50,000 tonnes CO_2^e annually.

The NGER Act requires reporting of six greenhouse gas substance emissions:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Sulphur hexafluoride (SF_6)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs).

According to the State and Territory Greenhouse Gas Emissions Inventories 2019 report (the latest available), Victoria's total greenhouse gas emissions in 2019 were 91.33 Mt CO_2^e (Australian Government Department of Industry, Energy and Resources 2021). Of these, 86.99 Mt CO_2^e were related to energy (including energy industries, transport, fugitive emissions and other energy activities).

5.1 Scope of the Energy Use and Greenhouse Gas Assessment

The scope includes energy use and greenhouse gas emissions associated with the construction and operation of the Advanced Recycling facility, considering the material sources of emissions. The assessment compares the proposed future operation of the facility, using primarily process gas, with a baseline where waste is sent to landfill and operation of the facility using utility natural gas. The boundary of this scope includes all material sources (and sinks) of emissions within the construction and operation (annually) of the proposed Cat-HTR™ plant.

The greenhouse gas assessment was prepared in accordance with:

- The Greenhouse Gas Protocol (GHG Protocol) issued by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI)
- AS ISO 14064-1:2006 Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals.

Although the NGER Act requires reporting on six greenhouse gas substances as identified in Section 5.2.1, the Cat-HTR™ facility is not anticipated to emit SF_6, HFCs or PFCs. As such, the greenhouse gas substances associated with the proposed facility only include:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O).

Sulphur oxides (SOx), which are indirect greenhouse gases, would be emitted by the process, albeit at <1% of the air quality criteria.

In accordance with the GHG Protocol, emissions sources were categorised as follows:

- Scope 1 – greenhouse gas emissions created directly by a person or business from sources that are owned or controlled by that person or business (direct emissions).
- Scope 2 – greenhouse gas emissions created because of the generation of electricity, heating, cooling or stream that is purchased and consumed by a person or business. These are indirect emissions as they arise from sources that are not controlled by the person or business consuming the electricity.
- Scope 3 – greenhouse gas emissions that are generated in the wider community because of a person or business's activities. These are indirect emissions as they arise from sources that are not owned or controlled by that person or business, but they exclude Scope 2 emissions.

Energy related greenhouse gas emissions include those resulting from the consumption of electricity or fuels. Non-energy related greenhouse gas emissions include those that result from processes undertaken by the person or business (e.g., emissions from chemical reactions or direct releases of greenhouse gases from activities such as land clearing) and incidental emissions (e.g., use of products).

Greenhouse gases are generally measured as tonnes (t) of carbon dioxide equivalent (CO_2^e). This represents the amount of greenhouse gases emitted as an equivalent amount of CO_2 which has a global warming potential of one. For example, one tonne of CH_4 released into the atmosphere will cause the same amount of global warming as 25 tonnes of CO_2. Therefore, one tonne of CH_4 is expressed as 25 t CO_2^e (Department of the Environment and Energy (DoEE) 2019).

5.2 Potential Emissions Sources

Table 5.1 outlines the potential construction energy and non-energy related greenhouse gas emissions for the Cat-HTR™ facility.

Table 5.1 Potential sources of construction-related greenhouse gas emissions

Source	Greenhouse gases	Included in assessment	Scope		
			1	2	3
Energy Related					
Construction fuel – excavated material haulage	CO_2, CH_4, N_2O	No – site excavation not required			●
Construction fuel – earthworks and civil works	CO_2, CH_4, N_2O	No – no earthworks, only minor civil works required.	●		●
Material deliveries	CO_2, CH_4, N_2O	Yes			●
Embedded emissions – construction materials*	CO_2, CH_4, N_2O	Yes			●
Non-energy related					
Loss of carbon in stored vegetation	CO_2	No – no vegetation clearing required	●		

Table 5.2 outlines the potential operational energy and non-energy related greenhouse gas emissions for the Cat-HTR™ facility.

Table 5.2 Potential sources of operational-related greenhouse gas emissions

Source	Greenhouse gases	Included in assessment	Scope		
			1	2	3
Energy Related					
Emissions associated from combustion of waste – fossil sources	CO_2, CH_4, N_2O	Yes	●		
Emissions associated from combustion of waste – biogenic sources	CH_4, N_2O	No – no biogenic waste sources will be processed	●		
Emissions from natural gas combusted	CO_2, CH_4, N_2O	Yes	●		
Emissions from on-site diesel generators	CO_2, CH_4, N_2O	No – no diesel generators required	●		●

Source	Greenhouse gases	Included in assessment	Scope		
			1	2	3
Emissions associated with fuel used in operation of on-site equipment used to handle waste	CO_2, CH_4, N_2O	No – no fuel powered equipment	●		●
Emissions from use of grid electricity during operation	CO_2, CH_4, N_2O	Yes		●	
Emissions associated with transport of waste from point of generation to waste transfer point	CO_2, CH_4, N_2O	No – outside scope			●
Emissions associated with transport of waste from waste processing point to site (truck)	CO_2, CH_4, N_2O	No – outside scope			●
Emissions associated with transport of product from site (truck – diesel post 2004)	CO_2, CH_4, N_2O	Yes – product off-take	●		
Avoided emissions resulting from displaced grid electricity	CO_2, CH_4, N_2O	No – no displaced grid electricity		●	
Non-energy related					
Avoided emissions, diverting waste from landfill	CH_4	Yes			●
Avoided emissions, hydrocarbon extraction to make plastics	CO_2, CH_4	Yes			●
Emissions associated with landfilling of waste/residues	CH_4	Yes			●

Some greenhouse gas emissions have been deemed immaterial because of the likely insignificant quantity of these emissions. These include:

- Scope 1:
  - Maintenance vehicle fuel consumption has been deemed immaterial.
- Scope 2:
  - Purchased electricity during construction of the Cat-HTR™ facility is expected to be minimal. Generators would likely be used to power most plant and equipment during construction. This has been assessed under stationary energy (Scope 1)
- Scope 3:
  - Employees travel to and from site
  - International delivery of plant, equipment and materials.

5.3 Emissions Factors

Where it is not possible or practical to directly measure or model greenhouse gas emissions from processes related to an activity, emissions factors are used as a substitute. Standard emissions factors for a range of common emissions-generating activities are published in various, recognised and approved guidelines. Emissions factors used for the assessment of potential greenhouse gas emissions from the Cat-HTR™ facility were obtained from three sources, namely:

- National Greenhouse Accounts (NGA) Factors (August 2021)
- Greenhouse Gas Protocol
- Infrastructure Sustainability Council of Australia (ISCA) Materials Calculator.

Process-related emissions of CO_2 and CH_4 were modelled (Synergetics, 2021). The CH_4 component will be entirely within the process gas, which will be captured for reuse or sale. The exception being if process gas is required to be flared for safety reasons. The baseline for waste sent to landfill (CH_4), combustion of fuel during construction, embedded emissions in construction materials (i.e., the emissions generated during their extraction, processing and manufacture) and emissions associated with use of natural gas was established using relevant emissions factors as detailed in Table 5.3.

Table 5.3 Emissions factors

Activity	Emissions factor	Reference
Process emissions – Cat-HTR™	Scope 1 CO_2 – modelled CH_4 - derived	Modelled – Synergetics (2021) Derived – Process gas monitoring Cat-HTR™ pilot
Landfill (baseline) – end-of-life plastics	Scope 3 CH_4 – 40 kg CO_2^e / t	GHG Protocol – Technical Guidance for Calculating Scope 3 Emissions (v1.0; 2013)
Natural gas consumption	Scope 1 CO_2 – 51.4 kg CO_2^e / GJ CH_4 – 0.1 kg CO_2^e / GJ N_2O – 0.03 kg CO_2^e / GJ Scope 3 5.52×10^{-4} t C/m^3	NGA 2021 Table 2 NGA 2021 Table 38
Electricity (purchased)	Scope 2 0.79 kg CO_2^e / kWh	NGA 2021 Table 5
Wastewater disposal	Scope 3 0.5 kg CO_2^e / m^3	GHG Protocol – Technical Guidance for Calculating Scope 3 Emissions (v1.0; 2013)
Materials - steel	Scope 3 2.336 kg CO_2^e / kg	ISCA Materials Calculator

Please note that some emissions factors will change over the operational life of the Cat-HTR™ facility, including:

- The composition of waste for processing at the site will differ in terms of quantity of waste combusted, the fossil content and the amount of process/waste gas produced. This variation has not been accounted for.
- Electricity purchased from the grid will likely become less carbon intensive over the lifetime of the proposal, meaning that whilst the quantity of electricity offset will remain steady, the emissions offset will decrease. The results use the current Victoria electricity emissions GHG factor to demonstrate the magnitude of the offset at approximately year 1 of operation.

5.4 Assessment based on Design and Processing Information Available

The greenhouse gas assessment was undertaken based on the currently available information for the proposal. Several assumptions were made relevant to the calculation of greenhouse gas emissions, including that the following would not occur:

- Inefficient use of materials, fossil fuels and electricity during construction or operation
- Construction delays causing additional consumption of materials and fossil fuels
- Accidental release of natural/process gas during operation of the boilers
- Unacceptable quality of materials from the manufacture of construction components leading to additional resource consumption.

If any of these assumptions prove incorrect, emissions may increase beyond those estimated in this report.

5.5 Energy Use and Greenhouse Gas Emissions (Energy Related)

It is estimated that the Advanced Recycling facility will use about 20,475 MWhr/year of electricity.

If the Advanced Recycling facility was to purchase electricity generated from fossil fuel power generation from the Victorian grid (which is a worst-case scenario), the greenhouse gas emissions associated with this would be about 22,295 t CO_2^e/year.

However, Advanced Recycling Victoria intend to purchase and use 100% renewable energy, which therefore avoids these 22,295 t CO_2^e/year greenhouse gas emissions.

5.6 Non-energy Related Greenhouse Gas Emissions

The main sources of non-energy related greenhouse gas emissions would be from the combustion of gases used in gas-fired plant and equipment (e.g., supercritical boiler, low-pressure boiler). A secondary, but much lower, source of non-energy related emissions would be associated with the transport of product from site. Non-energy related greenhouse gas emissions would be primarily CO_2 and NOx, noting that Cat-HTR™ process temperatures are anticipated to impede significant CH_4 production.

Greenhouse gas emissions associated with the generation of supercritical water were calculated assuming that gas fuel usage will be 1,198 t / year. This assumed usage rate is based on the boiler specifications and data from the ReNewELP UK plant and an annual operating period of 328.5 days. Because the exact nature of emissions from combustion of process gas are unknown, the calculation is based on natural gas use and emissions factors. This has been benchmarked using process gas analysis from Licella's NSW pilot plant, extrapolated to the scale of the proposed Altona Advanced Recycling facility.

For product transport related greenhouse gas emissions, the calculations assumed that 17,597 t of product would be produced annually (Lifecycles, 2021), and that this product would be transferred from site using 55 tonne b-double tankers. To calculate fuel usage of these vehicles a benchmark fuel efficiency of 70L/100 km (ARTSA Institute) and the maximum distance of carriage would be 100 km. It was assumed that product would be used domestically within the greater Melbourne region. Transport of product any further than this would diminish the benefits of the 'circular economy' of the proposal.

Emissions associated with wastewater treatment and disposal were based on the annual water consumption estimate of 25 ML (see section 6.0), and emissions factors provided in the GHG Protocol – Technical Guidance for Calculating Scope 3 Emissions (v1.0, 2013). Embodied emissions in steel used in the construction of the Advanced Recycling facility (the most significant construction material) were calculated using the ISCA Materials Calculator and assumed a total quantity of steel used during construction of about 90 t.

5.7 Summary of Greenhouse Gas Emissions

Table 5.4 provides the worst-case greenhouse gas emissions from the proposed Cat-HTR™ facility.

Table 5.4 Worst-case greenhouse gas emissions

Scope	Description	Estimated emissions t CO_2^e / year
Scope 1	Diesel use (construction vehicles, plant and equipment); diesel use (product off-take tankers); natural/process gas combustion	3,665
Scope 2	The Cat-HTR™ facility was estimated to use 16,800 MWhr / year purchased electricity	22,295
Total annual scope 1 and scope 2 emissions – NGER Reporting		***25,960***
Scope 3	Wastewater disposal	6,665
	Embodied emissions - steel	210

The greenhouse gas emissions presented in Table 5.4 are based on several assumptions that represent the worst-case. These include:

- Use of 100% diesel fuel in construction plant and equipment and product off-take vehicles
- Use of 100% Victorian fossil fuel generated grid electricity
- Use of 100% pipeline natural gas to energise gas-fired plant and equipment.

Based on these assumptions, estimated total annual scope 1 and scope 2 greenhouse gas emissions for the Cat-HTR™ facility are 25,960 t CO_2^e/year, which is above the NGER annual reporting threshold of 25,000 t CO_2^e/year. Emissions from purchased grid electricity make up most of these emissions.

This will not be the case though, as discussed. Advanced Recycling Victoria have already committed to:

- Using (purchasing) 100% renewable energy to power the Altona Cat-HTR™ Facility
- Specify, where practicable, the use of biodiesel in construction plant and equipment, and in product off-take tankers.

Table 5.5 presents the re-calculating annual greenhouse gas emissions for the Cat-HTR™ facility based on these assumptions.

Table 5.5 Anticipated greenhouse gas emissions

Scope	Description	Estimated emissions t CO_2^e / year
Scope 1	100% Biodiesel use (construction vehicles, plant and equipment); diesel use (product off-take tankers); natural/process gas combustion	3,571
Scope 2	Use of 100% renewable energy	0
Total annual scope 1 and scope 2 emissions – NGER Reporting		***3,571***
Scope 3	Wastewater disposal	6,665
	Embodied emissions - steel	210

Based on the likely scenario (Table 5.5) assumptions, (100% renewable electricity; 100% use of biodiesel), estimated total annual scope 1 and scope 2 greenhouse gas emissions for the Advanced Recycling facility are 3,571 t CO_2^e/year

Upstream emissions associated with the extraction and distribution of natural gas were not considered in this assessment. Advanced Recycling Victoria intend on only using pipeline natural gas during initial start-up and shut down. The remainder of the time the facility will run on the process gas generated through the Cat-HTR™ process. Emissions associated with the use of process gas were assumed to be the same as those for the use of natural gas, as it is expected that the two will have very similar properties. However, it is important to note that the intended use of process gas provides an additional benefit of avoiding upstream emissions associated with the extraction and distribution of natural gas.

Based on this assessment Advanced Recycling Victoria will not be required to report (under NGER) operational emissions associated with the proposed facility as they are unlikely to emit over 25,000 t CO_2^e annually. However, even with a commitment of using 100% renewable energy, Advanced Recycling Victoria will likely have to report based on consumption of more than 100 TJ of energy annually.

As discussed, the other benefit of the Cat-HTR™ process is that it diverts end-of-life plastics from landfill. The GHG Protocol provides an emissions factor for landfill (baseline) – end-of-life plastics of 40 kg CO_2^e / t. This is across the lifetime of plastics within landfill, which could be anywhere between 10 to 100 years, depending on the type of plastic and landfill conditions. However, as a crude comparison, diverting 20,000 t of end-of-life plastics from landfill, has the potential to avoid 860 t CO_2^e / year.

5.8 Best Practice Energy and Greenhouse Gas Management

The best practice energy use and greenhouse gas emissions management has considered the mitigation hierarchy and integration of economic, social and environmental considerations. The nature of the construction and operation of the proposal means that the avoidance of greenhouse gas emissions is not feasible. As such, the best practice management has considered measures to reduce the duration, intensity and amount of greenhouse gas emissions and impacts related to the proposal. Best practice management measures to be considered during operation and construction of the proposal are specified in Table 5.6.

Table 5.6 Best practice environmental management – energy and greenhouse gases

Environmental Management Measure - energy and greenhouse gases
Using monitoring data from the ReNew ELP Cat-HTR™ plant in the UK (which will be operational before the design of the proposed Altona Cat-HTR™ plant is finalised) to inform the final design of the proposed Altona Cat-HTR™ plant.
Using low embodied energy materials where they are of comparable quality, utility, availability and cost. Using fuel efficient plant and equipment where practicable during construction.
Using 100% renewable electrical energy to power the Advanced Recycling facility.
Using biofuels in all or some construction plant and equipment. Using sustainable materials in construction – i.e., reclaimed, recycled material
Energy efficiency - include environmental standards and performance in selection criteria (and cost benefit analysis) for the tendering and award of key packages associated with equipment, plant and machinery to reduce greenhouse gas emissions in construction, operation and decommissioning
Source local materials – materials including those provided by suppliers would be sourced locally where practicable

The best practice management measures detailed in Table 5.6 would minimise the projects emissions footprint. It is important to note however, other aspects of the project, as discussed throughout this document, that would be considered best practice management, including:

- The use of process gas to energise the Cat-HTR™ boilers and other gas-powered systems, which avoids upstream emissions associated with the extraction and distribution of natural gas
- The operation of the Advanced Recycling facility would divert 20,000tpa of end-of-life plastic from landfill or from being incinerated, avoiding a significant greenhouse gas emissions associated with this
- The products of the Cat-HTR™ process – "plasticrude" and wax bitumen – can be used in the creation of new plastics, road construction etc. which would displace new fossil fuel extraction.

The LCA (Lifecycles, 2021) also concluded that:

- For every tonne of residual plastic waste processed, the Cat-HTR™ technology provides a saving of 1.8 t CO_2^e emissions compared to waste-to-energy, which presents a better environmental outcome and demonstrates why residual plastic should not be sent to waste-to-energy facilities.
- The Advanced Recycling facility would produce a synthetic crude oil thus displacing conventionally extracted crude oil that would otherwise be imported to Australia. Producing crude oil through the Cat-HTR™ reactor would reduce greenhouse gas emissions by 64% compared to importation of conventional crude oil. This would also have a flow-on effect on the downstream supply chain, reducing the footprint of polymers produced from Cat-HTR™ products.

C6.0 Industrial water supply for Advanced Recycling operations

There are two choices for the supply of water for the Advanced Recycling operations:

Option 1: The use of potable water. This is the water that is supplied to all residences throughout Melbourne. Potable water is water that has been treated so that it is fit for human consumption as drinking water. The supply of potable water is dependent upon rain catchment dams around Melbourne – this means that if Melbourne endures drought conditions, then there could be restrictions on the supply of potable water, especially if potable water is being used for industrial use.

Option 2: The use of recycled industrial water. Greater Western Water (GWW) is the water supply body that manages all water supply in the Altona region. GWW has an industrial water supply line in an easement to the south of the Dow Altona site that services nearby industrial sites such as the Qenos and Dow sites. The GWW supply of recycled industrial water is not subject to restrictions caused by drought conditions because the water is sourced from the GWW wastewater treatment plant.

Discussions held with GWW indicate that the recycled industrial water is of a high quality and is suitable for the Cat-HTR process. There is available capacity in the GWW industrial water system to allow connection to the ARV Advanced Recycling facility.

Figure C6.1: Altona site plan showing the location of the pipeline easement and GWW pipelines

In summary:

- It is best to not use potable water for large industrial uses because this water is needed for community use.
- The use of recycled industrial water for ARV's Advanced Recycling facility will mean that there is no impact on potable water usage for the rest of the community.
- Greater Western Water (GWW) produces 100% recycled industrial water at its Altona water treatment plant. Their industrial water supply line passes by the Dow Altona site and is available for use.
- Using GWW recycled industrial water minimizes operational risks for the Advanced Recycling facility because GWW has a very large volumes of recycled industrial water.
- A Recycled Industrial Water supply contract will be signed between ARV and GWW for water supply to the Advanced Recycling facility.

C7.0 Discharge of wastewater from Advanced Recycling operations

All industrial wastewater (as distinct to stormwater runoff) that is to be discharged from the site will initially be directed into a site Water Treatment Plant.

Industrial wastewater will enter the site Water Treatment Plant from the following site uses:

- Industrial water that is separated from hydrocarbon products during the Cat-HTR process. This will be the main source of discharge water.
- Site water from bunded industrial areas from either washdown work or from rain catchment into the bunded areas.

Typical water analysis from untreated discharge from the Cat-HTR process is shown in Table 10.1.

Points relating to the discharge of industrial water are:

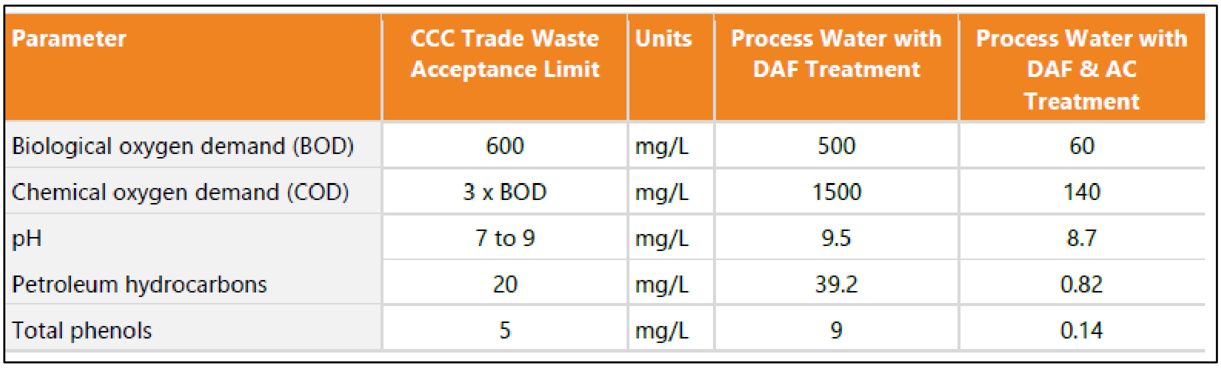
- GWW has effluent water standards that must meet before any wastewater it is discharged into the GWW tradewaste line.
- ARV will construct an onsite Water Treatment Plant that will treat wastewater from the Cat-HTR process to meet the GWW tradewaste discharge standards so that site wastewater can be discharged into the GWW tradewaste line.
- In Stage 1 of the ARV Advanced Recycling Project, it is more cost effective to discharge site process wastewater rather than treating it so that it can be recycled on site. In Stage 2 planning, the possibility of recycling wastewater onsite will be examined.
- The site wastewater discharged into the GWW tradewaste line will be processed at GWW's Altona water treatment plant and recycled as Industrial water. So, in fact, the use of GWW's industrial water and tradewaste lines enables water to be recycled for the Advanced Recycling process.
- Separate to the discharge of Advanced Recycling wastewater, ARV will discharge site sewerage directly into the GWW tradewaste line in accordance with GWW guidelines. Site sewerage will also therefore be recycled for re-use as Industrial water.

C7.1 Site Water Treatment

Figure C7.1 shows a design flow diagram for a site water treatment plant. The main components of this design are:

- Dissolved air flotation (DAF)
- Filtration through activated carbon (AC)

The following Table C7.1 shows a trial carried out on Cat-HTR wastewater at the Somersby pilot plant:



Parameter	CCC Trade Waste Acceptance Limit	Units	Process Water with DAF Treatment	Process Water with DAF & AC Treatment
Biological oxygen demand (BOD)	600	mg/L	500	60
Chemical oxygen demand (COD)	3 x BOD	mg/L	1500	140
pH	7 to 9	mg/L	9.5	8.7
Petroleum hydrocarbons	20	mg/L	39.2	0.82
Total phenols	5	mg/L	9	0.14

Table C7.1 Composition of process wastewater samples from the Somersby (NSW) pilot plant

The design and operation of the Site Water Treatment Plant is a relatively straight forward process and involves using standard plant and equipment. The affiliate company Mura Technologies will be establishing a similar water treatment plant at the UK advanced recycling facility and this will be in operation in 2022 enabling ARV to review the water treatment plant design and operational effectiveness prior to the ARV facility becoming operational.

It is planned to send “tramp” oil collected at the separation of water from oil back into the “slops” tank at the Cat-HTR facility so that it can be recycled back into the oil product.

C7.2 Greater Western Water (GWW) Tradewaste water quality requirements

The site water treatment plant will treat water so that it can be discharged into the GWW Tradewaste line. Water that enters into the GWW Tradewaste line is sent to the GWW Altona Water Treatment Plant where it is treated and then either recycled back into the Recycled Industrial Water line or discharged into the sea.

Appendix 4 gives the GWW Tradewaste water Approved Acceptance Criteria. These are the site water discharge quality levels that will be met before ARV’s site water is discharged.

Table C7.2 Sample analysis for untreated wastewater from Cat-HTR

Sample Name	SE214038.001
Description	Water Sample - PW-202
Sample Date	25/11/2020
Matrix	Water

Job Number	**Method Name**	**Analyte Name**	**Units**	**Reporting Limit**	**Result**	**mg/L**	
SE214038	VOCs in Water	Benzene	µg/L	0.5	**2200**	**2.2**	
SE214038	VOCs in Water	Toluene	µg/L	0.5	**18000**	**18**	
SE214038	VOCs in Water	Ethylbenzene	µg/L	0.5	**8800**	**8.8**	
SE214038	VOCs in Water	m/p-xylene	µg/L	1	**4400**	**4.4**	
SE214038	VOCs in Water	o-xylene	µg/L	0.5	**1600**	**1.6**	
SE214038	VOCs in Water	Total Xylenes	µg/L	1.5	**6100**	**6.1**	
SE214038	VOCs in Water	Total BTEX	µg/L	3	**35000**	**35**	
SE214038	VOCs in Water	Naphthalene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	d4-1,2-dichloroethane (Surrogate)	%	0	**96**		
SE214038	VOCs in Water	d8-toluene (Surrogate)	%	0	**95**		
SE214038	VOCs in Water	Bromofluorobenzene (Surrogate)	%	0	**100**		
SE214038	VOCs in Water	Dichlorodifluoromethane (CFC-12)	µg/L	5	<5000	5	max
SE214038	VOCs in Water	Chloromethane	µg/L	5	<5000	5	max
SE214038	VOCs in Water	Vinyl chloride (Chloroethene)	µg/L	0.3	<300	0.3	max
SE214038	VOCs in Water	Bromomethane	µg/L	10	<10000	10	max
SE214038	VOCs in Water	Chloroethane	µg/L	5	<5000	5	max
SE214038	VOCs in Water	Trichlorofluoromethane	µg/L	1	<1000	1	max
SE214038	VOCs in Water	Acetone (2-propanone)	µg/L	10	**65000**	**65**	
SE214038	VOCs in Water	Iodomethane	µg/L	5	<5000	5	max
SE214038	VOCs in Water	1,1-dichloroethene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Acrylonitrile	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Dichloromethane (Methylene chloride)	µg/L	5	<5000	5	max
SE214038	VOCs in Water	Allyl chloride	µg/L	2	<2000	2	max
SE214038	VOCs in Water	Carbon disulfide	µg/L	2	<2000	2	max
SE214038	VOCs in Water	trans-1,2-dichloroethene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	MtBE (Methyl-tert-butyl ether)	µg/L	2	<2000	2	max
SE214038	VOCs in Water	1,1-dichloroethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Vinyl acetate	µg/L	10	<10000	10	max
SE214038	VOCs in Water	MEK (2-butanone)	µg/L	10	<10000	10	max
SE214038	VOCs in Water	cis-1,2-dichloroethene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Bromochloromethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Chloroform (THM)	µg/L	0.5	<0.5	0.0005	max
SE214038	VOCs in Water	2,2-dichloropropane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,2-dichloroethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,1,1-trichloroethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,1-dichloropropene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Carbon tetrachloride	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Dibromomethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,2-dichloropropane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Trichloroethene (Trichloroethylene,TCE)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	2-nitropropane	µg/L	100	<100000	100	max
SE214038	VOCs in Water	Bromodichloromethane (THM)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	MIBK (4-methyl-2-pentanone)	µg/L	5	<5000	5	max
SE214038	VOCs in Water	cis-1,3-dichloropropene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	trans-1,3-dichloropropene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,1,2-trichloroethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,3-dichloropropane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Dibromochloromethane (THM)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	2-hexanone (MBK)	µg/L	5	<5000	5	max
SE214038	VOCs in Water	1,2-dibromoethane (EDB)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Tetrachloroethene (Perchloroethylene,PCE)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,1,1,2-tetrachloroethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Chlorobenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Bromoform (THM)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	cis-1,4-dichloro-2-butene	µg/L	1	<1000	1	max
SE214038	VOCs in Water	Styrene (Vinyl benzene)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,1,2,2-tetrachloroethane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,2,3-trichloropropane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	trans-1,4-dichloro-2-butene	µg/L	1	<1000	1	max
SE214038	VOCs in Water	Isopropylbenzene (Cumene)	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Bromobenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	n-propylbenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	2-chlorotoluene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	4-chlorotoluene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,3,5-trimethylbenzene	µg/L	0.5	**1500**	**1.5**	
SE214038	VOCs in Water	tert-butylbenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,2,4-trimethylbenzene	µg/L	0.5	**770**	**0.77**	
SE214038	VOCs in Water	sec-butylbenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,3-dichlorobenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,4-dichlorobenzene	µg/L	0.3	<300	0.5	max
SE214038	VOCs in Water	p-isopropyltoluene	µg/L	0.5	<500	0.5	max

Job Number	Method Name	Analyte Name	Units	Reporting Limit	Result	mg/L	
SE214038	VOCs in Water	1,2-dichlorobenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	n-butylbenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,2-dibromo-3-chloropropane	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,2,4-trichlorobenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Hexachlorobutadiene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	1,2,3-trichlorobenzene	µg/L	0.5	<500	0.5	max
SE214038	VOCs in Water	Total VOC	µg/L	10	**100000**	**100**	
SE214038	Volatile Petroleum Hydrocarbons in Water	TRH C6-C9	µg/L	40	**120000**	**120**	
SE214038	Volatile Petroleum Hydrocarbons in Water	Benzene (F0)	µg/L	0.5	**2200**	**2.2**	
SE214038	Volatile Petroleum Hydrocarbons in Water	TRH C6-C10	µg/L	50	**130000**	**130**	
SE214038	Volatile Petroleum Hydrocarbons in Water	TRH C6-C10 minus BTEX (F1)	µg/L	50	**95000**	**95**	
SE214038	Volatile Petroleum Hydrocarbons in Water	d4-1,2-dichloroethane (Surrogate)	%	0	**96**		
SE214038	Volatile Petroleum Hydrocarbons in Water	d8-toluene (Surrogate)	%	0	**95**		
SE214038	Volatile Petroleum Hydrocarbons in Water	Bromofluorobenzene (Surrogate)	%	0	**100**		
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH C10-C14	µg/L	50	**69000**	**69**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH C15-C28	µg/L	200	**10000**	**10**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH C29-C36	µg/L	200	**8800**	**8.8**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH C37-C40	µg/L	200	**2700**	**2.7**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH >C10-C16	µg/L	60	**56000**	**56**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH >C10-C16 - Naphthalene (F2)	µg/L	60	**56000**	**56**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH >C16-C34 (F3)	µg/L	500	**14000**	**14**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH >C34-C40 (F4)	µg/L	500	**6100**	**6.1**	
SE214038	TRH (Total Recoverable Hydrocarbons) in Water	TRH C10-C40	µg/L	320	**91000**	**91**	
SE214038	Total Phenolics in Water	Total Phenols	mg/L	0.01	**17**	**17**	
SE214038	Free Cyanide in water	Free Cyanide	mg/L	0.004	<0.004	0.004	
SE214038	Anions by Ion Chromatography in Water	Nitrate Nitrogen, NO3-N	mg/L	0.005	**0.061**	**0.061**	
SE214038	Nitrite in Water	Nitrite Nitrogen, NO2 as N	mg/L	0.005	**0.008**	**0.008**	
SE214038	Nitrite in Water	Total Oxidised Nitrogen, NOx-N	mg/L	0.005	**0.069**	**0.069**	
SE214038	TKN Kjeldahl Digestion by Discrete Analyser	Total Kjeldahl Nitrogen	mg/L	0.05	**120**	**120**	
SE214038	Ammonia Nitrogen by Discrete Analyser (Aquakem)	Ammonia Nitrogen, NH_3 as N	mg/L	0.01	**93**	**93**	
SE214038	Ammonia Nitrogen by Discrete Analyser (Aquakem)	Ammonia, NH_3	mg/L	0.01	**110**	**110**	
SE214038	Ammonia Nitrogen by Discrete Analyser (Aquakem)	Ammonium, NH4	mg/L	0.01	**120**	**120**	
SE214038	Total Phosphorus by Kjeldahl Digestion DA in Water	Total Phosphorus (Kjeldahl Digestion) as P	mg/L	0.02	**0.06**	**0.06**	
SE214038	pH in water	pH**	No unit	0	**8.6**		
SE214038	Total and Volatile Suspended Solids (TSS / VSS)	Total Suspended Solids Dried at 103-105°C	mg/L	5	**8**	**8**	
SE214038	Forms of Carbon	Total Organic Carbon as NPOC	mg/L	0.2	**360**	**360**	
SE214038	BOD5	Biochemical Oxygen Demand (BOD5)	mg/L	5	**1200**	**1200**	
SE214038	COD in Water	Chemical Oxygen Demand	mg/L	10	**2700**	**2700**	
SE214038	Oil and Grease in Water	Oil and Grease	mg/L	5	**51**	**51**	
SE214038	Metals in Water (Dissolved) by ICPOES	Tin, Sn	mg/L	0.05	<0.05	0.05	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Cadmium, Cd	µg/L	0.1	**2.1**	**0.002**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Copper, Cu	µg/L	1	**8**	**0.008**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Chromium, Cr	µg/L	1	**2**	**0.002**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Zinc, Zn	µg/L	5	**32**	**0.032**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Arsenic, As	µg/L	1	<1	0.001	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Aluminium, Al	µg/L	5	**16**	**0.016**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Antimony, Sb	µg/L	1	<1	0.001	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Cobalt, Co	µg/L	1	**1**	0.001	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Iron, Fe	µg/L	5	**34**	**0.034**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Lead, Pb	µg/L	1	<1	0.001	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Manganese, Mn	µg/L	1	**11**	**0.011**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Molybdenum, Mo	µg/L	1	**5**	**0.005**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Nickel, Ni	µg/L	1	**25**	**0.025**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Selenium, Se	µg/L	1	<1	0.001	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Silver, Ag	µg/L	1	<1	0.001	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Tin, Sn	µg/L	1	**2**	**0.002**	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Tungsten, W	µg/L	1	<1	0.001	
SE214038	Trace Metals (Dissolved) in Water by ICPMS	Vanadium, V	µg/L	1	<1	0.001	
SE214038	Mercury (dissolved) in Water	Mercury	mg/L	0.0001	<0.0001	0.0001	
SE214038	Alcohols in Water	1-butanol	mg/L	1	<1	1	
SE214038	Alcohols in Water	1-hexanol	mg/L	1	<1	1	
SE214038	Alcohols in Water	1-butoxy-2-propanol	mg/L	1	<1	1	
SE214038	Alcohols in Water	1-propanol	mg/L	1	**20**	**20**	
SE214038	Alcohols in Water	2-butoxyethanol	mg/L	0.02	<0.02	0.02	
SE214038	Alcohols in Water	2-ethyl hexanol	mg/L	1	<1	1	
SE214038	Alcohols in Water	ethanol	mg/L	1	**10**	**10**	
SE214038	Alcohols in Water	isobutanol	mg/L	1	<1	1	
SE214038	Alcohols in Water	isopropanol	mg/L	1	**33**	**33**	
SE214038	Alcohols in Water	methanol	mg/L	1	**160**	**160**	

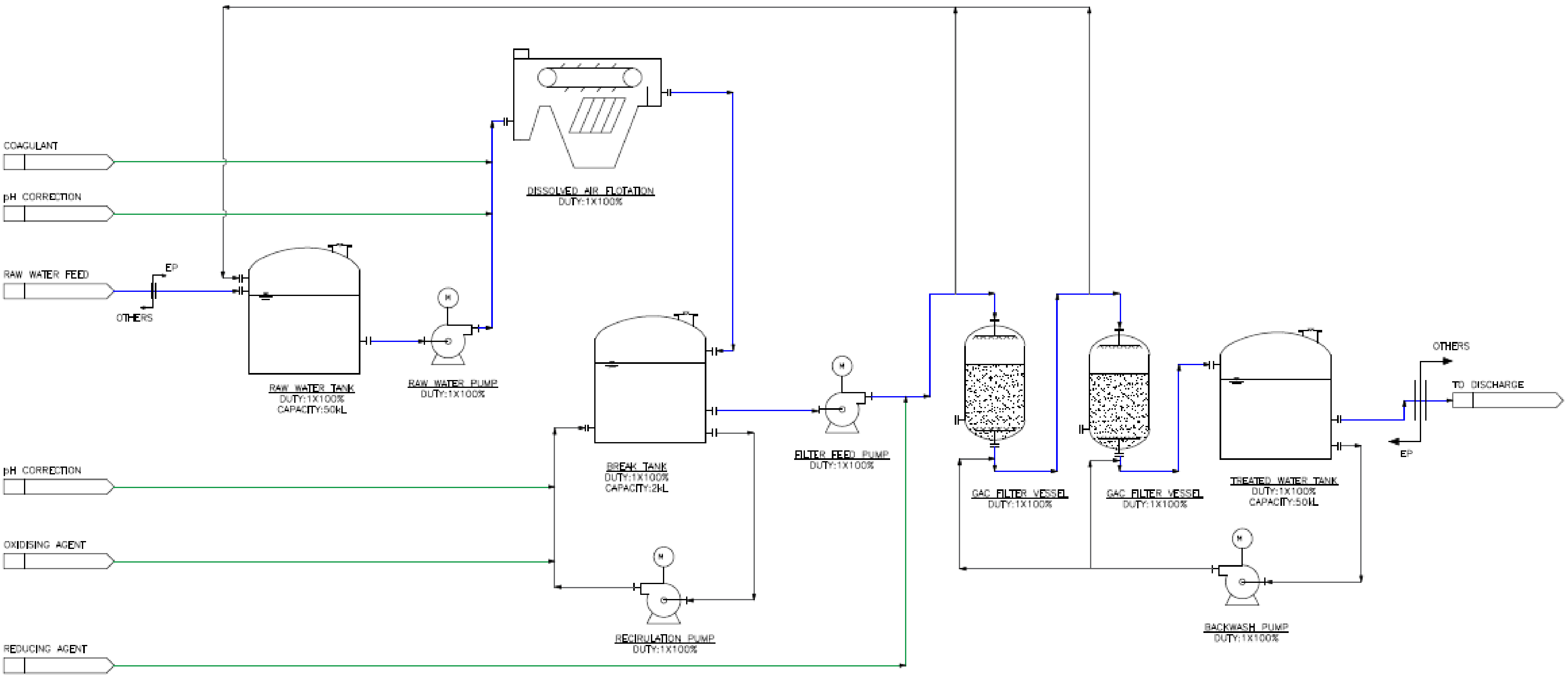


Figure C7.1 Design flow diagram for a site water treatment plant

C8.0 Generation of heat in site boilers for the Cat-HTR process

The ARV Stage 1 facility will have two boilers, these being

- A supercritical steam generator that will produce steam at up to 550 deg Celsius. This steam is used for the Cat-HTR process.
- A standard boiler that will produce steam for activities such as Product Tank steam heating and steam cleaning site capability.

There are two forms of energy that could be used for heating water in boilers, these being:

- Using electrical power
- Using a hydrocarbon gas

When the Altona Advanced Recycling facility using Cat-HTR technology is operational then a Process Gas will be manufactured when the waste plastic is processed and long hydrocarbon chains are “snipped”.

Given that the Process Gas will be manufactured in the Cat-HTR process then it makes sense to use this gas in the advanced recycling process.

The Process Gas has an energy of 38MJ/kg which is similar to natural gas.

However, to get the Cat-HTR process underway, it will be necessary to commence boiler heating using natural gas. Upon the Cat-HTR process completing start-up, the natural gas flow can be reduced and turned off and the newly manufacture Process Gas can then be used as the fuel used for boiler heating.

Natural gas will be used as fuel for the boilers:

- When the Cat-HTR process is in start-up mode
- When the Cat-HTR process is in shutdown
- If there is a shortage of Process Gas for boiler heating any reason.

Natural Gas has energy of around 42MJ/kg.

It is expected that in Stage 1 operations when 60.6 tonnes of waste plastic feedstock is being processed per day that 9.09 tonnes per day of Process Gas will be manufactured. It is expected that over half of this gas will be used for boiler heating. Any excess Process Gas will be sold to neighbouring industries or, if there is still excess Process Gas, it will be flared as a last resort.

In Stage 1 operations the small quantity of Process Gas being manufactured does not justify any additional processing of the gas. However, for Stage 2 operations, the compression of Process Gas into lighter oil products will be considered and evaluated.

Appendix 5 shows the analysis of 5 x samples of Process Gas. These samples were taken at the Licella Cat-HTR facility, Somersby NSW.

C9.0 Combustion of Process Gas and methods for exhaust flue gas treatment

C9.1 Use of Process Gas

The process gas that is manufactured during the Cat-HTR process will be utilised in:

- The high-pressure supercritical steam generator that discharges treated flue gases.
- A low-pressure steam generating boiler that discharges flue gases.
- An enclosed flare designed for plant start up and emergency over pressure protection of the low-pressure system. Any excess Process Gas that is not used at site may also be flared using this device.
- A conventional open flare for extreme emergency operations protecting the high-pressure system from over pressurisation.

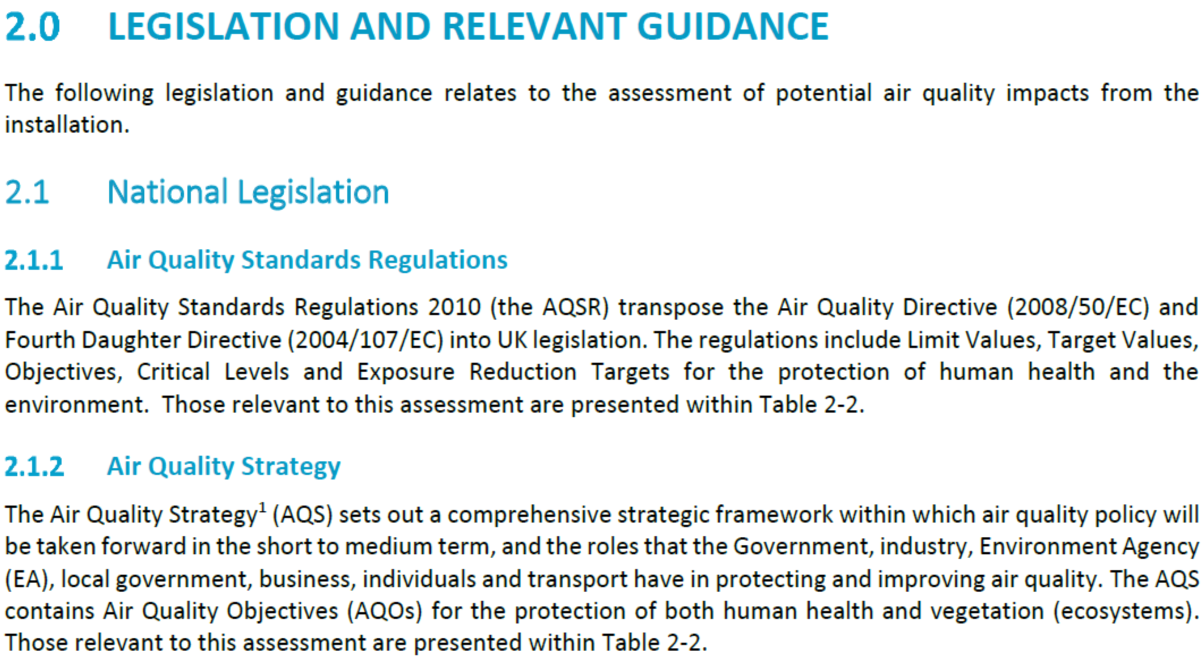
The boilers will also be able to operate using natural gas. Once fully operational it is the intent that fuel for the boilers will be switched to the Process Gas, supplemented by natural gas as required.

C9.2 Exhaust gas emissions assessment in the UK Cat-HTR facility

ReNew Wilton Ltd prepared an Environmental Permit (EP) for the Wilton Hydrothermal Upgrading Facility in Redcar, Wilton Centre, Redcar, Teesside, TS10 4RG UK, which contained an Air Emissions Risk Assessment (AERA) undertaken in accordance with UK Environment Agency guidance. This facility will be processing 20ktpa of feedstock plastic which is the same amount of feedstock that the Altona Advanced Recycling facility will be processing in Stage 1.

The UK Advanced Recycling facility has received environmental approval for proceeding to construction and operations. It is scheduled to commence commissioning in November 2022.

The description of the UK legislation that the UK Advanced Recycling facility must comply with is described in Section 2 of the UK Facility Air Emissions Risk Assessment and is as follows:



2.0 LEGISLATION AND RELEVANT GUIDANCE

The following legislation and guidance relates to the assessment of potential air quality impacts from the installation.

2.1 National Legislation

2.1.1 Air Quality Standards Regulations

The Air Quality Standards Regulations 2010 (the AQSR) transpose the Air Quality Directive (2008/50/EC) and Fourth Daughter Directive (2004/107/EC) into UK legislation. The regulations include Limit Values, Target Values, Objectives, Critical Levels and Exposure Reduction Targets for the protection of human health and the environment. Those relevant to this assessment are presented within Table 2-2.

2.1.2 Air Quality Strategy

The Air Quality Strategy[1] (AQS) sets out a comprehensive strategic framework within which air quality policy will be taken forward in the short to medium term, and the roles that the Government, industry, Environment Agency (EA), local government, business, individuals and transport have in protecting and improving air quality. The AQS contains Air Quality Objectives (AQOs) for the protection of both human health and vegetation (ecosystems). Those relevant to this assessment are presented within Table 2-2.

2.1.3 Local Air Quality Management

Section 82 of the Environment Act 1995 (Part IV) requires local authorities to periodically review and assess the quality of air within their administrative area. The reviews have to consider the present and future air quality and whether any AQALs prescribed in regulations are being achieved or are likely to be achieved in the future.

Where any of the prescribed standards are not likely to be achieved the authority concerned must designate an Air Quality Management Area (AQMA). For each AQMA the local authority has a duty to draw up an Air Quality Action Plan (AQAP) setting out the measures the authority intends to introduce to deliver improvements in local air quality in pursuit of the standards. As such, Local Authorities (LAs), have formal powers to control air quality through a combination of LAQM and by use of their wider planning policies.

Defra has published technical guidance for use by local authorities in their LAQM work[2]. This guidance, referred to in this report as LAQM.TG(16), has been used where appropriate in the assessment presented here.

2.1.4 Protection of Nature Conservation Sites

Sites of nature conservation importance at a European, national and local level, are provided environmental protection from developments, including from atmospheric emissions.

The Conservation of Habitats and Species Regulations 2010 introduces the precautionary principle for protected areas, i.e. that projects can only be permitted to proceed; having ascertained that there will be no adverse effect on the integrity of the designated site. It requires an assessment to determine if significant effects (alone or in combination) are likely, followed by an 'appropriate assessment' by the competent authority, if necessary.

Similarly, the Countryside and Rights of Way (CRoW) Act 2000 provides protection to Sites of Special Scientific Interest (SSSIs) to ensure that developments are not likely to cause them damage.

Locally important sites (such as National Nature Reserves (NNR), Local Nature Reserves (LNR), Local Wildlife Sites (LWS) or Sites of Importance for Nature Conservation (SINCs) and Ancient Woodland (AW)) are also protected by legislation to ensure that developments do not cause significant pollution.

2.2 Regulation of Industrial Emissions

2.2.1 Medium Combustion Plant Directive

The Medium Combustion Plant Directive[3] (MCPD) regulates pollutant emissions from the combustion of fuels in plants with a rated thermal input equal to or greater than 1 Megawatt thermal (MWth) and less than 50 MWth.

Due to the low thermal input of the two gas fired boillers (each less than 2MW) with significantly less than 3t/h of combusted fuel, the combustion plants at the site falls under the MCPD regulations. The flare stack is used for emergency and overpressure flaring is exempt from emissions compliance under the MCPD.

2.2.2 Emission Limit Values to Air

As mentioned above, the combustion plant at the site will be regulated under MCPD. Table 2-1 presents the applicale ELVs for the combustion plant.

Table 2-1
MCPD Emission Limit Values

Pollutant	Emission Limits (mg/Nm^3) (a)	
	Natural gas	Gaseous Fuels other than natural gas
Sulphur dioxide (SO_2)	N/A	35
Oxides of nitrogen (NOx)	100	200

Table Notes:

a) Concentrations referenced to temperature 273 K, pressure 101.3 kPa, 3% oxygen, dry gas.

---

[1] The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, DEFRA. July 2007

[2] Department for Environment, Food and Rural Affairs (DEFRA): Local Air Quality Management Review and Assessment Technical Guidance LAQM.TG(16), 2016.

2.2.3 Environmental Permitting

In England, the Environmental Permitting (England and Wales) Regulations (2018) transpose the MCPD in UK legislation. The proposed installation would be regulated by the EA under the Environmental Permitting (EP) Regulations which includes regulating emissions to air.

Guidance Notes produced by Defra provide a framework for regulation of installations and additional Technical Guidance Notes produced by the EA are used to provide the basis for Environmental Permit conditions as regards releases to air and mitigation measures.

Of particular relevance to the assessment of air quality impacts is the EA's '*air emission risk assessment for your environmental permit*' guidance[4] (referred to as the AERA guidance throughout this report). The purpose of this guidance is to assist operators to assess risks to the environment and human health when applying for a permit under the EP Regulations. This guidance sets out Environmental Assessment Levels (EALs) which are taken from the AQS and AQSR but also includes EALs for additional pollutants derived from occupational exposure limits (OEL) and maximum exposure levels (MEL) presented in HSE EH40[5]. Those relevant to this assessment are presented within Table 2-2 below.

2.3 Environmental Standards

The environmental standards for air, taken from the legislation and guidance outlined above, for the protection of human health and sensitive ecological receptors are presented in the sections below.

2.3.1 Standards for Protection of Human Health

The standards applied in this assessment, taken from the AQSR, AQS and AERA guidance are set out in Table 2-2 below.

Table 2-2
Relevant Standards (µg/m³)

Pollutant		Annual Standard (µg/m³)	Short Term Standard (µg/m³)	Ref
Nitrogen dioxide	(NO_2)	40	200 (1-hour) not to be exceeded more than 18 times per year	AQSR
Sulphur dioxide	(SO_2)	---	266 (15-minute) not to be exceeded more than 35 times per year	AQS
			350 (1-hour) not to be exceeded more than 24 times per year	AQSR
			125 (24-hour) not to be exceeded more than 3 times per year	AQSR
Ammonia	(NH_3)	180	2,500 (1-hour)	AERA

The regulations[6] state that exceedances of the objectives should be assessed in relation to "the quality of the air at locations which are situated outside of buildings or other natural or man-made structures, above or below ground, and where members of the public are regularly present". LAQM.TG(16) provides guidance on relevant exposure locations that are summarised in Table 2-3 below.

---

[3] Directive 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants.

[4] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit

Table 2-3
Relevant Public Exposure

Averaging Period	Relevant Locations	AQO's should apply at:	AQO's don't apply at:
Annual mean	Where individuals are exposed for a cumulative period of 6 months in a year	Building facades of residential properties, schools, hospitals etc.	Facades of offices Hotels Gardens of residences Kerbside sites
24-hour mean	Where individuals may be exposed for eight hours or more in a day	As above together with hotels and gardens of residential properties	Kerbside sites where public exposure is expected to be short term
8-hour mean	Where individuals may be exposed for eight hours or more in a day	As above together with hotels and gardens of residential properties	Kerbside sites where public exposure is expected to be short term
1-hour mean	Where individuals might reasonably expected to spend one hour or longer	As above together with kerbside sites of regular access, car parks, bus stations etc.	Kerbside sites where public would not be expected to have regular access
15-minute mean	All locations where members of the public might reasonably be exposed for a period of 15-minutes or longer		-

2.3.2 Standards for the protection of Ecosystems and Vegetation

Environmental Quality Standards exist for nature conservation sites known as Critical Levels (for airborne concentrations) and Critical Loads (for deposition of nitrogen or acid forming compounds).

Critical Levels (CLe)

CLe's are a quantitative estimate of exposure to one or more airborne pollutants in gaseous form, below which significant harmful effects on sensitive elements of the environment do not occur, according to present knowledge. CLe's for the protection of vegetation and ecosystems are specified within relevant European air quality directives and corresponding UK air quality regulations (see Table 2-4).

Table 2-4
Critical Levels for the Protection of Vegetation and Ecosystems

Pollutant	Concentration ($\mu g/m^3$)	Habitat and Averaging Period
Ammonia (NH_3)	1	Annual mean. Sensitive lichen communities & bryophytes and ecosystems where lichens & bryophytes are an important part of the ecosystem's integrity
	3	Annual mean. For all higher plants (all other ecosystems)
Sulphur dioxide (SO_2)	10	Annual mean. Sensitive lichen communities & bryophytes and ecosystems where lichens & bryophytes are an important part of the ecosystem's integrity
	20	Annual mean. For all higher plants (all other ecosystems)
Nitrogen oxides (NO_x)	30	Annual mean (all ecosystems)
	75	Daily mean (all ecosystems)

---

[5] HSE (2011) EH40/2005 Workplace Exposure Limits.

[6] The Air Quality (England) Regulations 2000 No. 928

The UK Advanced Recycling facility is required to meet the UK air emission standards.

As mentioned earlier in this BATT report, the Altona Advanced Recycling facility will be constructed using the UK Advanced Recycling facility's Cat-HTR module design.

Section 5 of the UK Facility Air Emissions Risk Assessment had the following information regarding air emissions and this data is deemed to be relevant to the Altona facility:

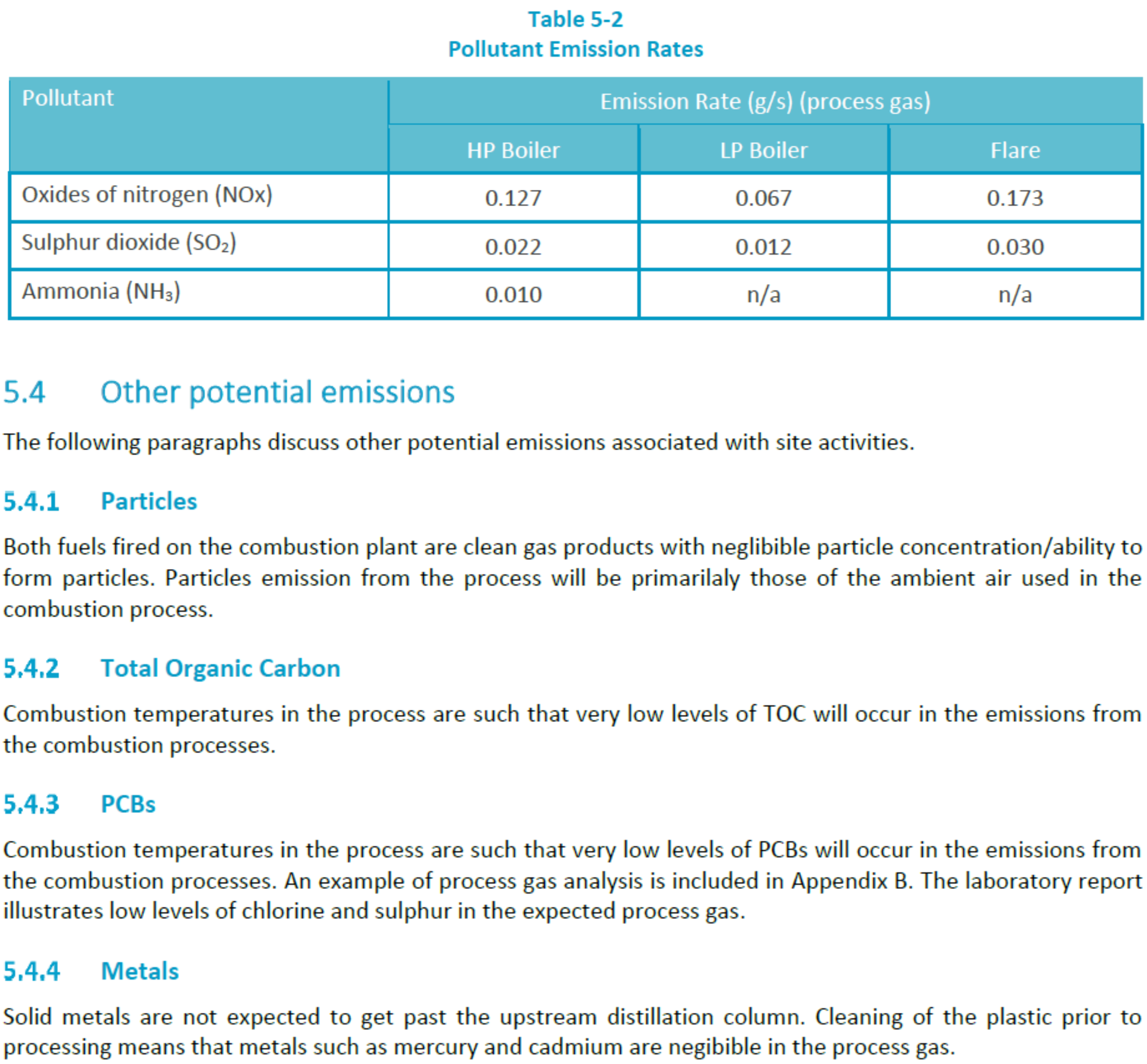


Table 5-2
Pollutant Emission Rates

Pollutant	Emission Rate (g/s) (process gas)		
	HP Boiler	LP Boiler	Flare
Oxides of nitrogen (NOx)	0.127	0.067	0.173
Sulphur dioxide (SO_2)	0.022	0.012	0.030
Ammonia (NH_3)	0.010	n/a	n/a

5.4 Other potential emissions

The following paragraphs discuss other potential emissions associated with site activities.

5.4.1 Particles

Both fuels fired on the combustion plant are clean gas products with neglibible particle concentration/ability to form particles. Particles emission from the process will be primarilaly those of the ambient air used in the combustion process.

5.4.2 Total Organic Carbon

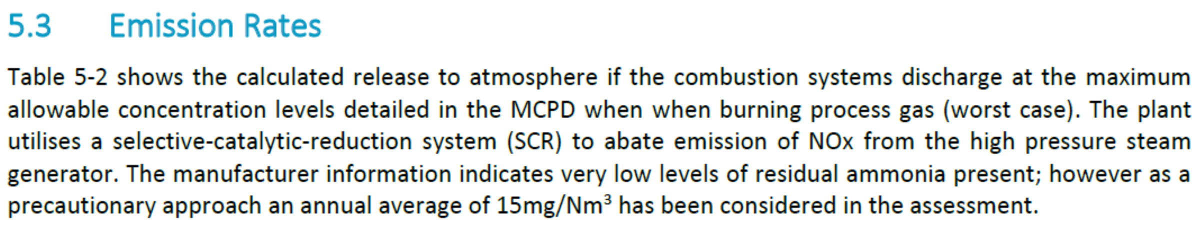
Combustion temperatures in the process are such that very low levels of TOC will occur in the emissions from the combustion processes.

5.4.3 PCBs

Combustion temperatures in the process are such that very low levels of PCBs will occur in the emissions from the combustion processes. An example of process gas analysis is included in Appendix B. The laboratory report illustrates low levels of chlorine and sulphur in the expected process gas.

5.4.4 Metals

Solid metals are not expected to get past the upstream distillation column. Cleaning of the plastic prior to processing means that metals such as mercury and cadmium are negibible in the process gas.



5.3 Emission Rates

Table 5-2 shows the calculated release to atmosphere if the combustion systems discharge at the maximum allowable concentration levels detailed in the MCPD when when burning process gas (worst case). The plant utilises a selective-catalytic-reduction system (SCR) to abate emission of NOx from the high pressure steam generator. The manufacturer information indicates very low levels of residual ammonia present; however as a precautionary approach an annual average of 15mg/Nm^3 has been considered in the assessment.

As mentioned in the UK report Section 5.3, whilst "Boiler Manufacturer information indicates very low levels of residual ammonia present; however, as a precautionary approach, an annual average of 15mg/Nm3 has been considered in the assessment". In the Altona Air Emissions modelling a similar stance will be taken with respect to modelling NH_3.

C9.3 Exhaust gas emissions assessment in the Altona Cat-HTR facility

For the Altona Advanced Recycling facility, the situation at this point in time regarding considerations of exhaust emissions for the Altona Advanced Recycling facility is that there is no representative "operational data" regarding the proposed air emissions from the Cat-HTR facility after the Process Gas is combusted in a boiler because:

- All trials of Cat-HTR operations at the Licella Somersby NSW facility have used natural gas for water heating.
- Process Gas from Cat-HTR trials at Somersby has not been combusted via the boiler hence the Somersby boiler flue gas has not been suitable for emissions analysis. Due to the short and intermittent nature of pilot plant Cat-HTR operations, the Process Gas is currently combusted via a separate on-site flare/afterburner system. Process Gas analysis is performed on pre combustion samples only.
- Even if longer term Somersby Cat-HTR operations could be undertaken, the boiler at Somersby is not suitable for syngas combustion and would not be representative of the boiler to be used in the UK and Altona.

For this BATT report, as a means of examining the potential for harmful air emissions emanating from the Stage 1 Cat-HTR facility, a Risk Assessment was conducted as per EPA's publication Guideline for Assessing and Monitoring Air Pollution in Victoria (GAMAPV), that considered:

- ➢ Feedstock quality at collection.
- ➢ Feedstock preparation and removal of contaminants
- ➢ Product Gas manufacture
- ➢ Combustion of Product Gas

This Risk Assessment is included with this BATT report as Appendix 5 and it found Very Low levels of risk that uncontrolled amounts of harmful fumes would be produced during combustion of the Process Gas. The justification for this is:

- The selection of sources of waste plastic feedstock will be scrutinised and QA tested so that it is unlikely that there will contaminants or harmful additives in the delivered feedstock plastic that will result in the Process Gas having "difficult-to-deal-with" gasses in its exhaust fumes.
- Due to the dominant liquid phase present in the hydrothermal processes, the majority of remnant contaminants or additives will remain in the water phase and not report to the Process Gas.

As well:

- Experience will be gained from the UK Cat-HTR facility operations that will commence in 2022 as to any types of issues with managing the manufacture of Process Gas such that there are minimal problems with exhaust fumes.
- If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers.

ARV plans to work with ReNew Wilton Ltd in the UK to conduct monitoring of the air emissions from the Cat-HTR facility when it is operational to get accurate data as to what pollutant gasses are released. If required, the Altona Advanced Recycling facility can add/design exhaust scrubbers to suit the pollutants encountered. Such monitoring would include the flowing pollutants:

- ❖ NOx

- SOx
- Ammonia
- Volatile organic compounds
- Dioxins including PCBs such as polychlorinated dibenzodioxins (PCDD), polychlorinated dibenzofurans (PCDF), polychlorinated phenols (PCPh) and polychlorinated benzene (PCBz).
- Furans
- Any other gaseous compounds of environmental concern.

ARV can state that flue gas emissions at the Altona Advanced Recycling will meet the UK air emission standards and regulations delayed in Section 12.2.

C9.4 Exhaust emissions of particulates

Due to the water that is used in the Cat-HTR process, any particulate matter that is present will be trapped in the water phase and not in the Process Gas that is released. The Process Gas that is used as fuel in the boilers is consequently free of particulate matter.

C9.5 Dioxins and furans and determining if they are present in the emissions of Process Gas exhaust fumes

Supercritical steam will be generated to meet the required reaction temperatures of the Cat-HTR process will be in the range of 350 deg to 400 deg C.

Whilst it is expected that dioxins and furans will not be created when Process Gas is combusted to generate the required supercritical steam, evidence of this will be verified from air emissions taken upon the UK Advanced Recycling facility using Cat-HTR technology becoming operational in 2022.

Should dioxins and furans be found in the UK facility exhaust flue gas then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Wet Lime Scrubbers and Packed Bed Scrubbers that will greatly reduce the emissions of dioxins and furans.

C9.6 BATT for air emissions modelling for the Altona Cat-HTR facility

The BATT for assessing the dispersion of air emissions at an industrial site requires a method that considers and takes into account:

- Noxious levels and volumes of air emissions at the discharge point to atmosphere
- The location of the discharge point and its influence on airflow from topography and site structures such buildings
- The proximity of the industrial site to residential areas and neighbouring sites
- Year-round atmospheric conditions such as wind directions, wind strength and ambient temperatures that will influence emission dispersions.

The US American Meteorological Society and Environmental Protection Agency Regulatory Model (AERMOD[8]) is an air emissions dispersion model used throughout the world that is considered BATT for air emissions modelling. The modelling incorporates:

- Identification of sensitive receptors and compilation of the existing air quality baseline
- Quantification of emissions from the installation
- Atmospheric dispersion modelling to determine process contribution to ground level

concentrations and calculate deposition rates

- Assessment of impacts by comparison to standards for protection of human health and ecological receptors.

Air emission dispersion modelling for the Altona site has used the AERMOD dispersion modelling.

The Altona Advanced Recycling Project air emissions modelling has been conducted twice:

First Run Air Emissions Modelling was conducted using air emissions data that was used for the UK Mura Technologies Project. This Project has had its air emissions modelling accepted as suitable by the UK Environmental Agency.

Second Run Air Emissions Modelling was conducted using the maximum acceptable air emission levels for an EU Municipal Waste Incinerator. The reasons for conducting a Second Run Air Emissions Model were:

- Because Advanced Recycling using Cat-HTR Technology has not yet been carried out on a commercial scale, there is as yet no actual data on the air emissions that will be discharged to atmosphere when:
    - Waste plastics are processed in large volumes on a continuous basis using Cat-HTR technology
    - Process Gas is collected and used as a boiler fuel
    - The actual facility boilers use the Process Gas.
- Because there is no actual Cat-HTR Technology air emissions data, it was felt that substituting the maximum allowable EU air emissions for noxious gasses emitted from a Municipal Waste Incinerator as the air emissions from the Altona facility would allow the modelling of a “worst-case” scenario for the Altona facility to be undertaken. Whilst the waste types being incinerated at an EU Municipal Waste Incinerator are substantially more varied and noxious than that expected at the Altona facility, should the Second Run air emissions modelling nevertheless show minimal impact to Human Health, then it is a reasonable assumption to make that the Altona Advanced Recycling air emissions will be substantially less noxious than those resulting from this Second Run model.

Results from the First Run Air Emissions Modelling

First Run Air Emissions Modelling (for which the full report is included as Appendix 7) shows the gas emissions at the point of discharge for NOx, SOx and NH_3 in the table below:

Emissions for other gasses are at such a low level that it is difficult to detect them.

Table 4 - Modelled maximum GLC showing maximum level for any gridded receptor[13].

Substance	Assessment criteria		Facility emission only		Background only		Facility with background	
	Averaging period	GLC (ppm)	Modelled value (ppm)	% of criterion	Recorded value (ppm)	% of criterion	Modelled value (ppm)	% of criterion
NO_x	1 hour	0.12	0.0056	4.6%	0.052	43%	0.055	45%
	1 Year	0.03	0.00042	1.4%	.010	34%	0.011	36%
SO_2	1 hour	0.2	0.00044	0.22%	0.062	31%	0.062	31%
	1 day	0.08	0.00018	0.23%	0.019	24%	0.019	24%
	1 year	0.02	0.000041	0.21%	.0026	13%	.0027	13%
NH_3	1 hour	4.6	0.0015	0.03%	-	-	-	-
	1 day	1.7	0.00035	0.02%	-	-	-	-
	1 year	0.1	0.00009	0.09%	-	-	-	-

The air emissions modelling shows that NOx emissions are present at levels higher than other contaminant air emissions such as SOx, Ammonia or other chemical compounds. Untreated, NOx levels are expected to be at 4.6% of the 1-hour allowable limits for a distance of around 550m from the site exhaust stacks. The diagram below is also taken from the Appendix 7 report and shows the emissions dispersion contour area.

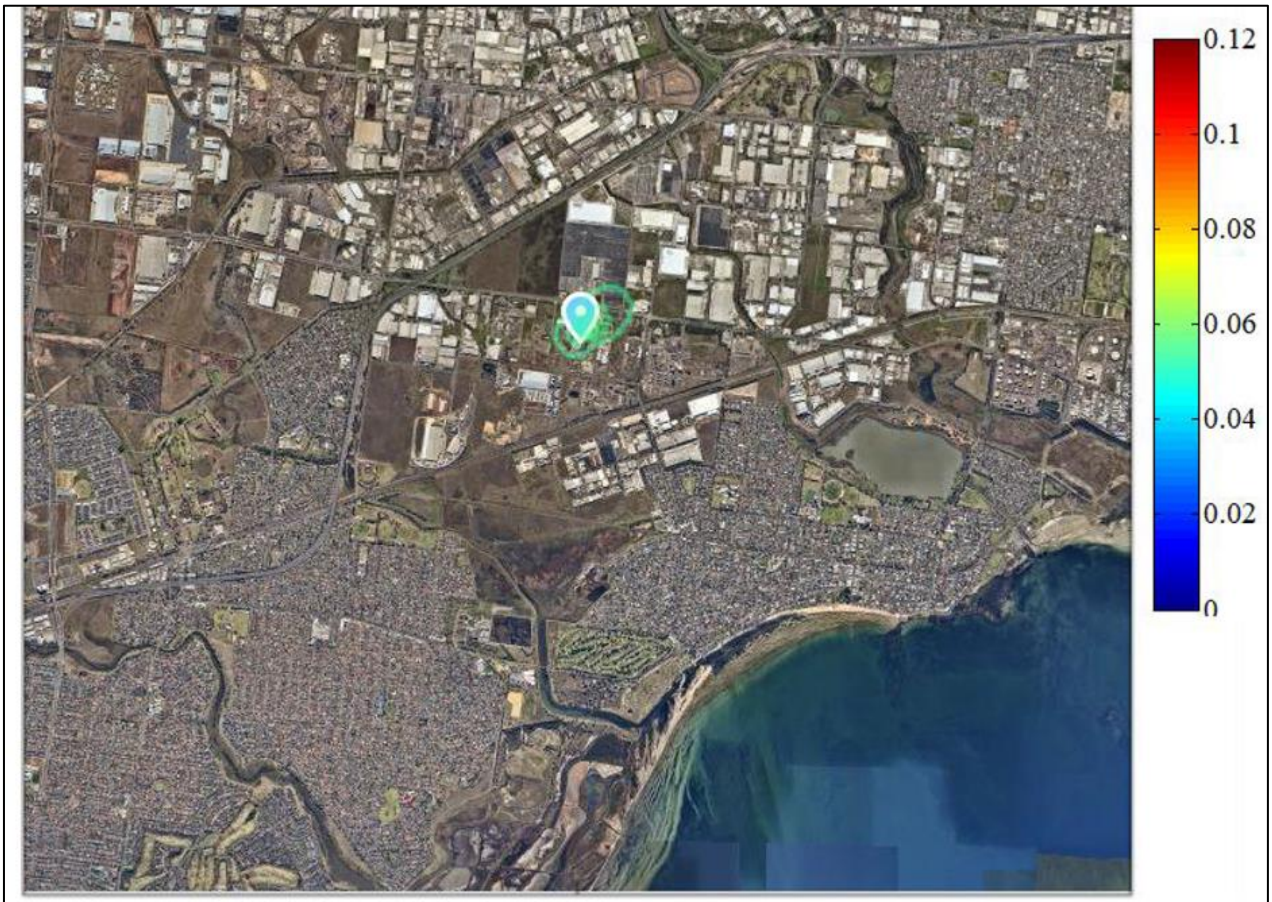


Figure 5 - Contours of highest 1 hour averaging period NO_2 GLC, including background, in ppm. The top contour level (red = 0.12 ppm) on the scale corresponds to the relevant criterion and does not occur on the plot due to the low GLC. The GLC is nearly uniform due to the low contribution of the site compared to the background.

It is possible to reduce the noxious gas levels emitted from the Project exhaust stacks even further by “scrubbing” the exhaust emissions and capturing noxious gasses. Two different types of exhaust scrubbing techniques are being considered for the Altona Project, these being:

- The addition of a Catalytic Converter to boiler exhaust flumes that can remove 80% of NOx thereby dropping expected NOx levels to 0.92% of the 1-hour allowable limits within the 550m radius zone of the exhaust flumes
- The addition of a Packed Bed Wet Scrubber which is effective for removing a range of emission contaminants but is only around 50% effective with treating NOx contaminants. A Packed Bed Scrubber would drop expected NOx levels to 2.3% of the 1-hour allowable limits.

Upon the UK Advanced Recycling facility becoming operational, ARV will work with Mura Technologies and conduct air emission sampling and analysis. Based on these results, the type and design of flue gas scrubbing for the Altona Advanced Recycling facility will be decided and installed.

Results from the Second Run Air Emissions Modeling

Second Run Air Emissions Modelling (for which the full report is included as Appendix 8) shows the gas emissions at the point of discharge for various gasses and particulates in the table below:

Table 3 - Modelled maximum GLC showing maximum level for any gridded receptor[11].

Substance	Assessment criteria			Facility emission only		Background only		Facility with background	
	Averaging period	APAC	Units	Modelled value	% of criterion	Recorded value	% of criterion	Modelled value	% of criterion
NO_x	1 hour	0.08	ppm	0.0036	4.5%	0.040	49%	0.042	52%
	1 Year	0.015	ppm	0.00042	2.8%	0.0096	64%	0.0099	66%
SO_2	1 hour	0.075	ppm	0.00065	0.87%	0.036	48%	0.036	48%
	1 day	0.02	ppm	0.00032	1.6%	0.018	88%	0.018	89%
NH_3	1 hour	3200	µg/m³	0.61	0.019%	-	-	-	-
	1 day	1184	µg/m³	0.30	0.43%	-	-	-	-
	1 year	70	µg/m³	0.070	0.10%	-	-	-	-
Cd	1 hour	18	µg/m³	0.0012	0.007%	-	-	-	-
	1 day	0.03	µg/m³	0.00060	2.0%	-	-	-	-
	1 year	0.005	µg/m³	0.00014	2.8%	-	-	-	-
CO	8 hours	9	ppm	0.0022	0.024%	-	-	-	-
Dioxins	1 year	0.00004	µg/m³	5.62E-10	0.001%	-	-	-	-
HCl	1 hour	2100	µg/m³	0.37	0.018%	-	-	-	-
	1 year	20	µg/m³	0.042	0.21%	-	-	-	-
HF	1 day	2.9	µg/m³	0.030	1.0%	-	-	-	-
Hg	1 year	1	µg/m³	0.00014	0.014%	-	-	-	-
$PM_{2.5}$	1 day	25	µg/m³	0.15	0.60%	34	140%	34	140%
	1 year	8	µg/m³	0.035	0.44%	7.4	93%	7.5	93%
PM_{10}	1 day	50	µg/m³	0.15	0.30%	140	280%	140	280%
	1 year	20	µg/m³	0.035	0.18%	23	110%	23	110%

As with the First Run Air Emissions Modelling, NOx emissions levels are the highest of the gasses emitted.

Particulates are very low and are only problematic when the background level is high at times when bushfire smoke is present.

In fact, whilst this Second Run Air Emissions Modelling shows particulates being emitted from the Cat-HTR process, due to the water scrubbing of the Process Gas, particulates are negligible.

Figure 2 - Contours of highest 1 hour averaging period NO_2 GLC based on 2017[13] data, including background, in ppm. A 10 km by 10 km area around the site is shown. The top contour level (red = 0.12 ppm) on the scale corresponds to the relevant criterion, and does not occur on the plot due to the low GLC. The GLC is nearly uniform (ranging from 0.040 to 0.042) due to the low contribution of the site compared to the background.

C10.0 The technique for inserting plastics into the Cat-HTR process

In the development of the Cat-HTR technology, Licella has investigated various means of inserting plastics into the depolymerization process. The Cat-HTR process requires plastic to be added to super-heated water at high temperature and pressure. There are limited ways of achieving this.

Licella's Cat-HTR pilot plants have trialed and now use a proprietary process that compresses and pressurizes waste plastics prior to the plastic stream being inserted into the Cat-HTR module.

C11.0 Methods for product handling and storage – Process Gas

During the Cat-HTR process, the products leaving the reactor will be pressure reduced by a let-down valve into a flash column. The majority of the products, along with steam, are flashed off as a vapour passing upwards through a conventional oil refinery type distillation column. These fractions are removed at different temperature cuts and heights within the column, allowing continuous production.

The distillation process results in the manufacture of a Process Gas consisting mainly of C1-C4 hydrocarbons. Gas will be directed into a low-pressure temporary holding "buffer" gas tank from where it will be sent to receival locations, these being either boilers, nearby industrial sites or flaring.

In Stage 1 of the Altona Advanced Recycling Project, most Process Gas will be used in boiler heating or sold to neighbouring industrial sites. Any excess Process Gas will be flared off.

Points relating to manufactured Process Gas are:

1. For Stage 1 Advanced Recycling operations, it is planned to process 60.6 tonnes per day of waste plastic. This will produce 9.09 tonnes per day of product gas.
2. Design details of the boilers are still being determined but it appears that most of the Process Gas will be used for boiler heating.
3. If there is any excess Process Gas, then it is planned to offer this for sale to neighbouring businesses including EnviroPacific who use natural gas for their soil decontamination business.
4. Beyond the sale of Process Gas, for Stage 1 if there is any excess Process Gas above what is used for boiler heating and for sale, then the excess Process Gas will be flared off.
5. In Stage 2 operations consideration will be given to compressing Process Gas so that additional Plasticrude Oil can be manufactured. Given the low waste plastic feedstock throughput in Stage 1, it is not cost-effective for establishing a gas pressurization facility in this Stage.

The Stage 1 planned maximum tonnages of gas production are well below the levels that would trigger any WH&S consideration for the Altona Advanced Recycling facility being designated as a "Major Hazard" facility.

C12.0 Methods for product handling and storage- Plasticrude and Heavy Fraction oils

In the Cat-HTR process, the products leaving the reactor will be pressure reduced by a let-down valve into a flash column. The majority of the products, along with steam, are flashed off as a vapour passing upwards through a conventional oil refinery type distillation column. These fractions are removed at different temperature cuts and heights within the column, allowing continuous production.

The distillation process results in the manufacture of:

1. Plasticrude oil

- Heavy Fraction residue (similar to bitumen) – from the base of the flash column.

From separation at the distillation column both of these oil products will be pumped to their own holding tanks. It is intended to refurbish existing tanks at the Dow site so they can be used as oil product storage tanks at the Altona Advanced Recycling facility.

Refurbished product tanks will have the following features:

- The product tanks will be fully refurbished including wall thickness testing, replacement of steel wall sections if necessary and repainting. Dow product tanks at the Dow site are shown in Figure 15.1. Detailed engineering for the tank refurbishment will be carried out following Project financial approval.
- Tanks will be fitted with:
    - Internal steam heated pipes to keep the oils above 100 deg to prevent water condensation
    - External wall insulation
    - Internal floating rooves that will minimize any leakage of fumes. A typical design of a tank with a floating roof is shown in Figure 15.2. Design of the floating rooves for the tanks at the Dow site will be completed upon the Project getting the financial approval to commence.

A new tank farm area will be constructed on the northern side of the tanker truck loading station (see Figure 4.2). Refurbishment of the tanks and bunding for the tank farm will conform with Australian Standards AS1940-2004 and AS1962-2006. The tank farm will have remote fire suppression systems installed.

It is planned to be able to store up to 14 days oil production on-site to cater for any period where buyers have receival limitations such as during planned maintenance periods. Planned oil production per day and 14-day storage capacity is as follows:

Oil Type	**Daily Production tonnes**	**Planned 14-day Storage Capacity tonnes**
Plasticrude	43.63	610.83
Heavy Fraction Bitumen	7.87	110.18

The Stage 1 planned maximum tonnages of oil storage are well below the levels that would trigger any WH&S consideration for the Altona Advanced Recycling facility being designated as a “Major Hazard” facility.

Figure C12.1 Product tanks at the Altona Dow site that are available for refurbishing into Plasticrude Product tanks for the Advanced Recycling facility

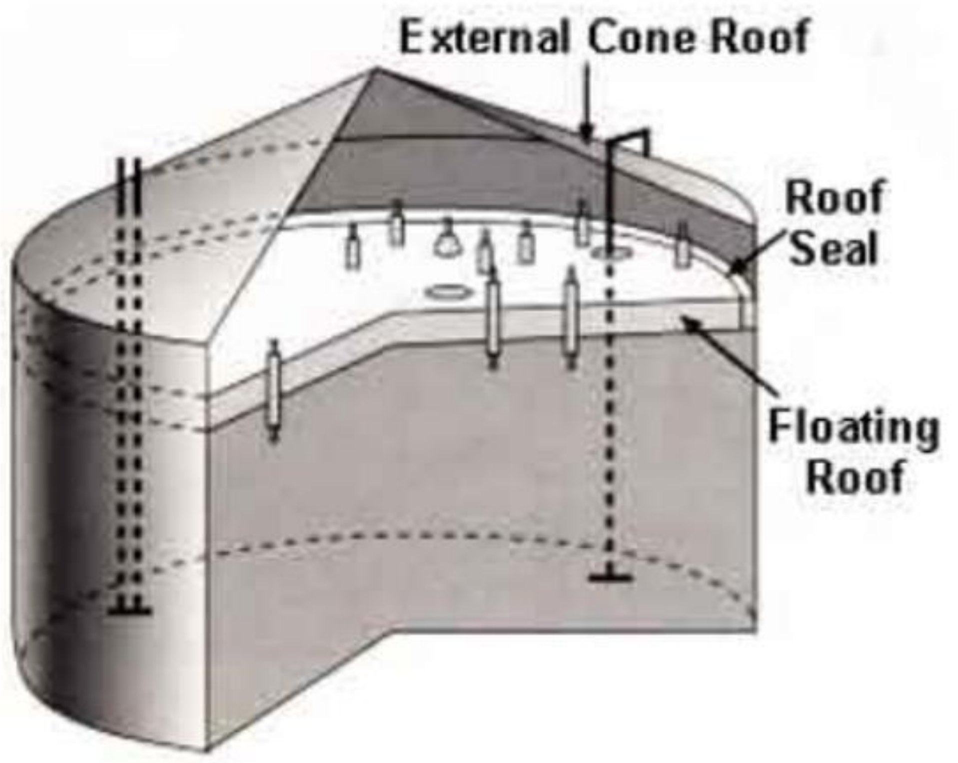


Figure C12.2 Typical design of a Product Tank with an internal floating roof.

C12.1 Pollutant air emissions from Product Oil tanks

The installation of internal floating rooves in the refurbished tanks at the Dow site will minimize pollutant air emissions from both the Plasticrude and Heavy Fraction Bitumen tanks. There are computer programs available that can model air emissions – such as TANKS from EPA-USA. It is necessary, however, to have the detailed design of the tank and the internal floating roof before any such computer modelling can be undertaken.

ARV has been working with Brockman Engineering, Geelong, on considering how best to refurbish the Product Oil tanks. Brockman Engineering are tank refurbishment specialists. We are awaiting Project Financial Approval before the Project Preliminary and Detailed Design stages can commence.

There are two manufacturers and suppliers of internal floating rooves, these being:

- Matrix Technologies, Mascot, NSW, and
- Australasian HMT Pty Ltd, Somersby, NSW.

Upon the commencement of the Project Preliminary and Detailed Design stages, ARV plan to have computer modelling of Product Tank pollutant air emissions so that the BATT design of the internal floating rooves can be installed into the refurbished Product Oil tanks.

The input details needed for computer modelling are specific to each tank such as:

- Tank size
- The product being stored in the tank
- The type of floating roof installed
- The seal type used for the floating roof

C13.0 Transportation of Product oils

Product Oil transportation to be carried out by standard oil tanker trucks.

The Altona Dow truck tanker loading station will be rebuilt to service the loading of tanker trucks that will transport Plasticrude and Heavy Fraction bitumen to customers.

Figure C13.1 Dow's tanker truck loading station – this facility will be rebuilt for loading out Plasticrude and Heavy Fraction oils.

In discussions with transportation companies:

1. For Plasticrude transportation it will be possible to load B-Double tanker trucks (55 tonnes) for transporting Plasticrude to customers. During Stage 1 Advanced Recycling operations with 305 tonnes per week of Plasticrude manufacture, 6 x truckloads per week will be needed for Plasticrude transportation.
2. For Heavy Fraction bitumen transportation, where weekly production is 55 tonnes, it is expected that 2 x truckloads per week of Heavy Fraction bitumen transportation will be needed.

Figure C13.2 Typical B-Double 55 tonne capacity tanker truck to be used for Plasticrude transportation

Figure C13.3 Typical tanker truck for transporting Heavy Fraction bitumen

C14.0 Management of site solid waste

Solid waste management has been covered in Chapter 12 of the previously submitted document “Development Licence Application Supporting Documentation Altona Advanced Recycling Facility Using Cat-HTR™ Technology” so will only be summarized as follows:

Solid waste to be placed in skip bins that will be emptied into landfill on a regular basis in quantities estimated in the table below. Solid waste will be collected on site as follows:

1. Garbage from site personnel - food scraps, food wrapping etc. Any wrappings that can be recycled will go into the appropriate recycling streams. Dedicated bins will be used for non-recyclable rubbish and the collected by waste management contractors on a regular basis and sent to landfill.
2. Industrial wrappings from parts deliveries etc. - wrappings that can be recycled will go into the appropriate recycling streams. Dedicated bins will be used for non-recyclable rubbish and collected by waste management contractors on a regular basis and sent to landfill.
3. The Plastics Preparation Process is where contaminants such as glass, metal, paper, PVC plastic, hard plastics and grit will be removed from the waste plastic feedstock stream. As these contaminants are removed at different points in the plastics preparation line, it will be possible for most contaminants (such as glass, paper, metals, hard plastics and PVC) to be collected and recycled. Non-recyclable contaminants such as grit will be sent to dedicated bins that will be collected by waste management contractors on a regular basis and sent to landfill.
4. Solid waste from the Water Treatment Plant - solid waste from the Cat-HTR wastewater will be removed from the water, dried and sent to dedicated bins that will be collected by waste management contractors on a regular basis and sent to landfill.

Type of waste	**Waste code**	**Descriptive title**	**Amount (per week)**	**Classification**	**Recovery / disposal code**
Waste from site personnel	W_3	Industrial Waste (Commercial and Industrial) – Waste from commercial and industrial sources that includes putrescible waste	~4.5m^3	Industrial waste (non-priority)	D22 – Landfill disposal R4 – Recycling/reclamation of metals and metal compounds R19 – Recycling/reclamation (Cardboard and plastics)
Solids rejected from the end-of-life plastic during feedstock preparation	Expected to consist predominantly of – Z100, 300, 310, 320, 400, 410, 420, 430, 500	Industrial waste (non-priority)	27 tonnes	Industrial waste (non-priority)	R4 – Recycling/reclamation of metals and metal compounds. D22 – Landfill disposal
Sludge waste from water treatment plant	L200-NH	Industrial wastewaters (excluding sewage) which meets the conditions in a permission in the Table in Schedule 1 of the Regulations	Volume unknown	Priority waste (non-reportable)	D5 – Landfill disposal of Category B waste
Cat-HTR™ process	There is no waste that requires disposal. All of the feedstock end-of-life plastic that is processed is converted into product either as a gas, as plasticrude or as the heavy bitumen fraction.				

C15.0 Management of site odour emissions

Site odour management measures will be included in the design of infrastructure and operations.

Odour from waste plastic feedstock is not expected to be a problem based on the following:

- iQRenew is now processing waste plastic at its facility at Tuggarah, NSW. The waste plastic is collected through the CurbCycle Project Central Coast NSW where soft plastics are bagged and placed in kerbside recycle bins. The waste plastic is removed from general recyclables at iQRenew's MRF then baled and transported to the Tuggarah facility for processing into waste-to-energy fuel. There is no evidence of odour emanating from the collected waste plastics.
- Plastics preparation will be in a shed which stifles any odour emissions.

Potential odours will be managed as follows:

Potential Odour Source	Management Measures
Stored waste plastic feedstock upon shipping containers being opened and waste plastic being unloaded and prepared for Cat-HTR processing	• Site location has a 1.3km buffer zone to the closest residential area • Shipping containers will be opened into an enclosed building.
Product oil storage	Product storage tanks will have internal floating ceilings that minimize any product oil odour from escaping the tanks – see Figure C13.2
Solid waste skips	• Solid waste skips will have lids on them – see Figure C15.1 which shows a typical skip design. • They will be emptied on a regular basis so that any odour associated with decaying matter is removed from site. • It is expected that solid waste skips will be located outside so that trucks emptying the bins will have access to them at all times.

Should any minor odour emissions occur despite the engineering design then the 1.3km buffer zone to residential areas will dilute the odour to the point where it will be difficult to detect.

Any complaints from residents or neighbouring businesses will be addressed by site management.

Figure C15.1 Typical skip to be used for storage of solid waste.

The detailed engineering design of the Project facility is evolving and yet to be undertaken. Based on processing trials that are being carried out at Licella NSW and elsewhere, it appears that odour emissions will not be an issue for the Stage 1 Project that will process 20ktpa of waste plastic feedstock. Trials underway have not had problems with feedstock odour.

However, for Stage 2 operations where feedstock throughput will be increased, if odour was considered to be an issue, then an option to control this would be to install a negative pressure system in the process shed and duct the airflow to the boilers where odours will be minimized through passing them through the high temperature boiler for rapid oxidation.

It is not envisaged that this will be necessary for Stage 1 operations

C16.0 Management of site noise emissions

Site noise management measures will be included in the design of infrastructure and operations.

This Item has been covered in Chapter 8 of the submission already issued to EPA Victoria "Development Licence Application Supporting Documentation - Altona Advanced Recycling Facility Using Cat-HTR™ Technology".

As stated in Chapter 8 of the previous submission:

The modelled results presented in Table 8.6 indicate that noise levels generated due to operation of the proposed facility would fall below the most stringent noise limits at all noise sensitive locations identified in the assessment and would be considered to have a low potential for human health impacts.

As the predicted noise levels are also below measured background levels, noise emissions from the proposed Altona Advanced Recycling facility are unlikely to be audible and attract adjustment for tonality or other noise characteristics. Therefore, no adjustments have been made to the predicted levels.

There are also multiple industrial activities that may contribute to measured noise level at some receivers, to the East, West and South of the facility, during night-time hours. However, as predicted noise levels from the facility are significantly below the project noise limits for night- time operations, an assessment of cumulative noise is not required under the Noise Protocol.

D. Utilizing BATT for Site Management Plans

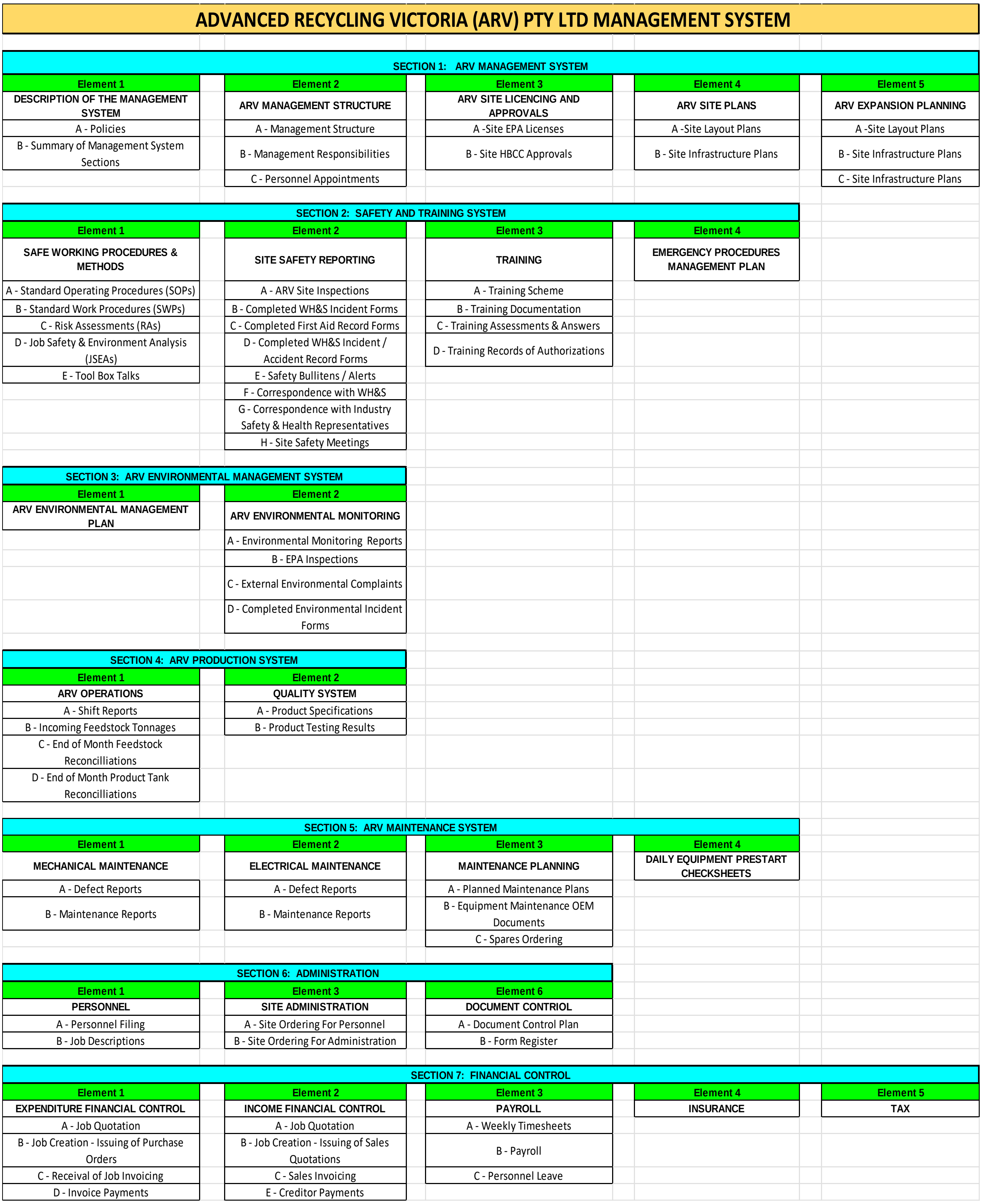
D1.0 Project Management System Overview

The Project Management System, as shown below, will ensure that:

- The risks that all project activities pose are identified
- The measures that are required to minimise Project risks are identified
- Project activities are managed in accordance with management systems
- Performance against management systems is audited at regular intervals
- All regulatory permits issued for the Project are complied with.

The management system will be reviewed at least once every four years or in response to significant changes to the activities, accidents or non-compliance.

Table D1.0 below shows the components of the Project Management System.



ADVANCED RECYCLING VICTORIA (ARV) PTY LTD MANAGEMENT SYSTEM

SECTION 1: ARV MANAGEMENT SYSTEM

Element 1	Element 2	Element 3	Element 4	Element 5
DESCRIPTION OF THE MANAGEMENT SYSTEM	**ARV MANAGEMENT STRUCTURE**	**ARV SITE LICENCING AND APPROVALS**	**ARV SITE PLANS**	**ARV EXPANSION PLANNING**
A - Policies	A - Management Structure	A -Site EPA Licenses	A -Site Layout Plans	A -Site Layout Plans
B - Summary of Management System Sections	B - Management Responsibilities	B - Site HBCC Approvals	B - Site Infrastructure Plans	B - Site Infrastructure Plans
	C - Personnel Appointments			C - Site Infrastructure Plans

SECTION 2: SAFETY AND TRAINING SYSTEM

Element 1	Element 2	Element 3	Element 4
SAFE WORKING PROCEDURES & METHODS	**SITE SAFETY REPORTING**	**TRAINING**	**EMERGENCY PROCEDURES MANAGEMENT PLAN**
A - Standard Operating Procedures (SOPs)	A - ARV Site Inspections	A - Training Scheme	
B - Standard Work Procedures (SWPs)	B - Completed WH&S Incident Forms	B - Training Documentation	
C - Risk Assessments (RAs)	C - Completed First Aid Record Forms	C - Training Assessments & Answers	
D - Job Safety & Environment Analysis (JSEAs)	D - Completed WH&S Incident / Accident Record Forms	D - Training Records of Authorizations	
E - Tool Box Talks	E - Safety Bullitens / Alerts		
	F - Correspondence with WH&S		
	G - Correspondence with Industry Safety & Health Representatives		
	H - Site Safety Meetings		

SECTION 3: ARV ENVIRONMENTAL MANAGEMENT SYSTEM

Element 1	Element 2
ARV ENVIRONMENTAL MANAGEMENT PLAN	**ARV ENVIRONMENTAL MONITORING**
	A - Environmental Monitoring Reports
	B - EPA Inspections
	C - External Environmental Complaints
	D - Completed Environmental Incident Forms

SECTION 4: ARV PRODUCTION SYSTEM

Element 1	Element 2
ARV OPERATIONS	**QUALITY SYSTEM**
A - Shift Reports	A - Product Specifications
B - Incoming Feedstock Tonnages	B - Product Testing Results
C - End of Month Feedstock Reconcilliations	
D - End of Month Product Tank Reconcilliations	

SECTION 5: ARV MAINTENANCE SYSTEM

Element 1	Element 2	Element 3	Element 4
MECHANICAL MAINTENANCE	**ELECTRICAL MAINTENANCE**	**MAINTENANCE PLANNING**	**DAILY EQUIPMENT PRESTART CHECKSHEETS**
A - Defect Reports	A - Defect Reports	A - Planned Maintenance Plans	
B - Maintenance Reports	B - Maintenance Reports	B - Equipment Maintenance OEM Documents	
		C - Spares Ordering	

SECTION 6: ADMINISTRATION

Element 1	Element 3	Element 6
PERSONNEL	**SITE ADMINISTRATION**	**DOCUMENT CONTRIOL**
A - Personnel Filing	A - Site Ordering For Personnel	A - Document Control Plan
B - Job Descriptions	B - Site Ordering For Administration	B - Form Register

SECTION 7: FINANCIAL CONTROL

Element 1	Element 2	Element 3	Element 4	Element 5
EXPENDITURE FINANCIAL CONTROL	**INCOME FINANCIAL CONTROL**	**PAYROLL**	**INSURANCE**	**TAX**
A - Job Quotation	A - Job Quotation	A - Weekly Timesheets		
B - Job Creation - Issuing of Purchase Orders	B - Job Creation - Issuing of Sales Quotations	B - Payroll		
C - Receival of Job Invoicing	C - Sales Invoicing	C - Personnel Leave		
D - Invoice Payments	E - Creditor Payments			

Table D1.0 Components of the Project Management System

D2.0 ARV Environmental Management Plan

The ARV Environmental Management Plan has not yet been written but will be finalised before operations commence.

Key Environmental Factors that will be addressed in the EMP are:

- Minimization and control of exhaust air emissions
- Management and recycling of wastewater
- Management of site erosion and sedimentation
- Minimization/elimination of soil contamination and management of soil contamination if it does occur
- Minimization/elimination of oil spills and management of oil spills if it does occur
- Hazardous chemicals management
- Solid waste management
- Dust management
- Noise management
- Vibration management
- Spoil management
- Management of the removal of vegetation
- Maximizing the use of green and renewable energy at site and in use during industrial processes.
- Monitoring of all site emissions on a continuous basis.
- Ongoing improvement schemes for reducing Project Green-House Gas emissions.

Environmental Objectives of the EMP are:

- No impact of soil erosion or disturbance from project activities
- Minimal impact on air quality
- No impact on local waterways (including soil erosion, chemical spillage and disturbance arising from the project activities)
- No noise complaints due to project activities
- Compliance with all environmental legislation and licencing requirements
- Excavated spoil, imported fill and contaminated soil to be disposed of or reused in accordance with legal requirements
- No spills or runoff of contaminants entering waterways (stormwater, surface runoff or groundwater) or contaminating land
- No sediment / contaminant laden water
- Measured ongoing improvement in the recycling and reuse of all materials entering the Project site
- No incorrect disposal of solid waste
- Measured ongoing improvement in the reduction of Project Green-House Gas emissions.

D3.0 Site Emergency Procedures Management Plan

The importance of the prevention of accidents including accidents that may have environmental consequences is recognised. Detailed engineering design will include emergency response infrastructure.

Site management preparations for accident and emergency situations will include:

- Risk assessments for all aspects of Advanced Recycling operations
- Engineering design phase consideration of risk, accidents and emergency situations
- Consideration before construction commences of risk, accidents and emergency situations
- Consideration before operations commences of risk, accidents and emergency situations
- Reviewing and updating Risk Registers on an annual basis.
- Training in emergency response and co-ordination of internal emergency response and external emergency response agencies

The Site Emergency Procedures Management Plan (SEPMP) will be implemented and maintained at the site to ensure the site staff are fully prepared for such incidents. The SEPMP will be reviewed every three years as a minimum and after any reportable incident on site. The document will be continually improved in these reviews to include best practice and minimise the risk of accidents occurring.

D3.1 Action to minimise the potential causes and consequences of accidents

Action will be taken at the site to minimise the potential causes and consequences of accidents. These actions will include:

1. Raw materials, products and wastes will be stored to prevent their escape into the environment
2. Vehicles will follow designated routes
3. Where appropriate, barriers will be constructed to prevent vehicles from damaging equipment
4. Containment will be provided to prevent the escape of potentially polluting materials
5. Tanks for the containment of products will be fitted with level measurements to prevent overfilling
6. CCTV will be installed to minimise the risk of unauthorised access and to monitor site activities in key areas
7. A log will be maintained of all incidents and near misses
8. Responsibilities for managing accidents will be clearly defined. Clear instructions on the management of accidents will be maintained
9. Appropriate equipment will be maintained to limit the consequences of an accident.

D3.2 Hazard identification

The following hazards have been identified for inclusion in site detailed engineering design and operational risk assessments:

1. Unauthorised access to site
2. Vehicle collision
3. Failure of site surfacing resulting in ground contamination

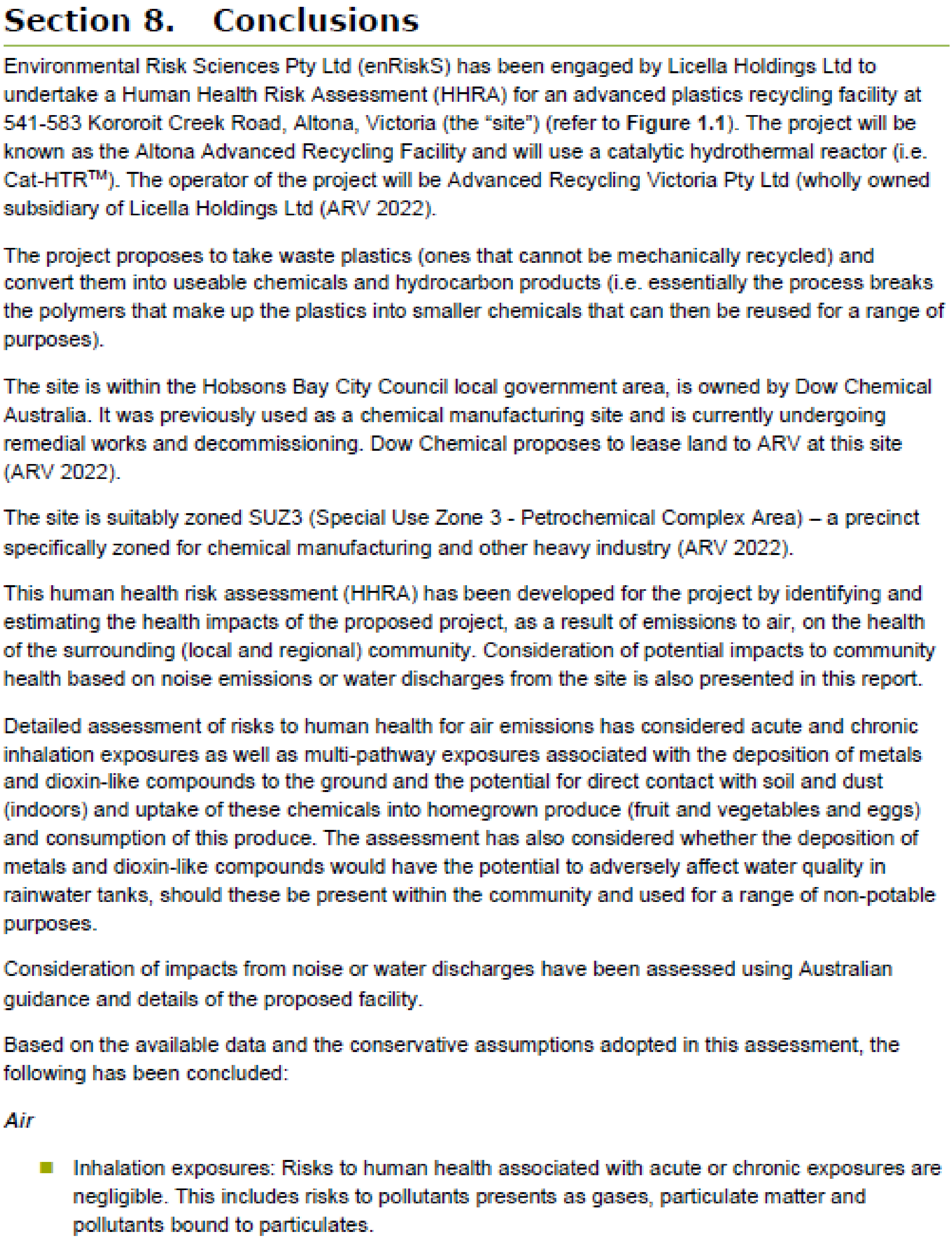
4. Fuel spills from vehicles
5. Spillage of waste materials during delivery to the hoppers
6. Spillage of liquid raw materials
7. Major fire
8. Minor fire
9. Security and vandalism
10. Asphyxiation and toxicity
11. Failure to contain fire water
12. Explosion
13. Extreme weather events and flooding
14. Failure of machinery
15. Failure of abatement technology
16. Boiler failure
17. Failure of equipment

E. Human Health Risk Assessment

As a means of considering the environmental impact from the proposed Stage 1 Advanced Recycling operations at Altona, ARV has engaged Environmental Risk Sciences Pty Ltd (enRiskS) to conduct a Human Health Risk Assessment (HHRA) on the project.

The HHRA document is presented in Appendix 9.

The Conclusions of the HHRA are that the Project will have negligible impact on the environment and on human health.



Section 8. Conclusions

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Licella Holdings Ltd to undertake a Human Health Risk Assessment (HHRA) for an advanced plastics recycling facility at 541-583 Kororoit Creek Road, Altona, Victoria (the "site") (refer to **Figure 1.1**). The project will be known as the Altona Advanced Recycling Facility and will use a catalytic hydrothermal reactor (i.e. Cat-HTR^{TM}). The operator of the project will be Advanced Recycling Victoria Pty Ltd (wholly owned subsidiary of Licella Holdings Ltd (ARV 2022).

The project proposes to take waste plastics (ones that cannot be mechanically recycled) and convert them into useable chemicals and hydrocarbon products (i.e. essentially the process breaks the polymers that make up the plastics into smaller chemicals that can then be reused for a range of purposes).

The site is within the Hobsons Bay City Council local government area, is owned by Dow Chemical Australia. It was previously used as a chemical manufacturing site and is currently undergoing remedial works and decommissioning. Dow Chemical proposes to lease land to ARV at this site (ARV 2022).

The site is suitably zoned SUZ3 (Special Use Zone 3 - Petrochemical Complex Area) – a precinct specifically zoned for chemical manufacturing and other heavy industry (ARV 2022).

This human health risk assessment (HHRA) has been developed for the project by identifying and estimating the health impacts of the proposed project, as a result of emissions to air, on the health of the surrounding (local and regional) community. Consideration of potential impacts to community health based on noise emissions or water discharges from the site is also presented in this report.

Detailed assessment of risks to human health for air emissions has considered acute and chronic inhalation exposures as well as multi-pathway exposures associated with the deposition of metals and dioxin-like compounds to the ground and the potential for direct contact with soil and dust (indoors) and uptake of these chemicals into homegrown produce (fruit and vegetables and eggs) and consumption of this produce. The assessment has also considered whether the deposition of metals and dioxin-like compounds would have the potential to adversely affect water quality in rainwater tanks, should these be present within the community and used for a range of non-potable purposes.

Consideration of impacts from noise or water discharges have been assessed using Australian guidance and details of the proposed facility.

Based on the available data and the conservative assumptions adopted in this assessment, the following has been concluded:

Air

- Inhalation exposures: Risks to human health associated with acute or chronic exposures are negligible. This includes risks to pollutants presents as gases, particulate matter and pollutants bound to particulates.

- Multiple pathway exposures: Risks to human health associated with chronic exposures to pollutants, bound to particulates, that may deposit to surfaces and be taken up into produce for home consumption relevant to surrounding areas where residential land use occurs are negligible.

Noise

- Based on the available information (i.e. noise from the site is not expected to be noticeable), the potential for noise from the site to result in adverse health impacts within the community is considered to be low/negligible.

Water

- The potential for adverse health impacts within the off-site community associated with use of water at the site is considered to be negligible.

APPENDIX 1

CSIRO REPORT 2021 ADVANCED RECYCLING TECHNOLOGIES TO ADDRESS AUSTRALIA’S PLASTIC WASTE

Herein contains the report ‘Advanced recycling technologies to address Australia’s plastic waste’ as provided by CSIRO in August 2021.

Australia’s National
Science Agency

Advanced recycling technologies to address Australia’s plastic waste

August 2021

Citation

King, S, Hutchinson, SA and Boxall, NJ (2021) Advanced recycling technologies to address Australia's plastic waste. CSIRO, Australia.

Copyright

© Commonwealth Scientific and Industrial Research Organisation 2021. To the extent permitted by law, all rights are reserved and no part of this publication covered by copyright may be reproduced or copied in any form or by any means except with the written permission of CSIRO.

Important disclaimer

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

CSIRO is committed to providing web accessible content wherever possible. If you are having difficulties with accessing this document please contact csiro.au/contact.

Acknowledgments

The authors would like to acknowledge the following people and organisations:

- Chemistry Australia (Samantha Read, Peter Bury, Nick Zovko), Qenos (David Francis) and LyondellBasell (Robert Moran) for their guidance as an industry stakeholder reference group for the report.
- Dr Christian Doblin, CSIRO, for his assistance with gasification technologies.
- Dr Deborah Lau and Dr Ashleigh Cousins, CSIRO for their review of the report.
- Zachary Perillo and Mike Andres for their review of state legislation applicable to plastic waste for pyrolysis.
- Dr Joely Taylor for her editorial contribution.
- Natalie Kikken, CSIRO, for her communications assistance.
- Susannah Quidilla and Amelia Menzies, CSIRO, for their design contributions.

Contents

Figures

Tables

Glossary

TERM	DESCRIPTION
ABS	Acrylonitrile butadiene styrene
Advanced recycling	Conversion to monomer or production of new raw materials by changing the chemical structure of a material or substance through cracking, gasification or depolymerisation, excluding energy recovery and incineration.
APCO	Australian Packaging Covenant Organisation
ARENA	Australian Renewable Energy Agency
ASA	Acrylonitrile styrene acrylate
Ash	The powdery residue left at the end of a decomposition process.
atm	Atmospheres (unit of pressure)
Carbon black	Any group of intensely black finely divided forms of amorphous carbon, usually obtained from the partial combustion of hydrocarbons.
Cat-HTR™	Licella's catalytic hydrothermal reactor technology that uses supercritical water to convert a variety of waste feedstocks into bio-crude.
Char	The remaining carbonaceous solid residue remaining from conversion of plastics.
Chemical recycling	See Advanced recycling
Chemolysis	The breakdown of a large molecule to smaller building blocks using chemicals.
Downcycling	Where recycled material is of lower quality than the original material.
Enzymolysis	The splitting or cleaving of a substance into smaller parts by action of an enzyme.
EPS	Expanded polystyrene
ERA	Environmentally relevant activity
Feedstock recycling	See Advanced recycling
FMCG	Fast moving consumer goods
Gasification	Waste materials are heated to very high temperatures (e.g. 1,000–1,500°C) with some oxygen or steam that breaks down the molecules into a syngas.
HBCD	Hexabromocyclododecane
HDPE	High-density polyethylene
Hydrocracking	The addition of hydrogen to hydrocarbon molecules to break them down into simpler molecules, often done with a catalyst and under pressure.
Hydrogenation	The chemical reaction between molecular hydrogen and another compound, usually in the presence of a catalyst.
Hydrothermal treatment	Reaction of compounds with water molecules at high temperatures (160–450°C) at a pressure that maintains water in the liquid state.
ISCC	International Sustainable Carbon Certification
LCA	Life cycle assessment
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
LPG	Liquified petroleum gas
Materials recycling facility (MRF)	A specialised plant that receives, separates, and prepares recyclable materials for marketing to end-user manufacturers.
Molecular recycling	Another name for feedstock recycling, returning polymers to small molecules.

TERM	DESCRIPTION
Monomers	A molecule that that can react with other monomer molecules to form a very large molecule, a polymer.
MSW	Municipal solid waste
PA	Nylon
PB	Polybutylene
PC	Polycarbonate
PE	Polyethylene
PET or PETE	Polyethylene terephthalate
Plastics-to-chemicals	Conversion of plastic material into useful chemicals.
Plastics-to-fuels	Conversion of plastic material into fuels for vehicles, boilers, generators, etc.
Plastics-to-plastics	Conversion of plastic material into new useful plastics.
PMMA	Poly(methyl methacrylate)
Polyolefins	Large molecules formed by the polymerisation of olefin (or alkene) monomer units consisting of carbon and hydrogen only. Polyethylene and polypropylene are polyolefins.
PP	Polypropylene
PRF	Plastic recovery facility
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl chloride
Pyrolysis	The treatment of materials with heat in the absence of oxygen, with or without catalysts. Usually conducted between 400 and 1,000°C.
RMF	Recycling Modernisation Fund
RPO	Recycled polymer oil
SAN	Styrene acrylonitrile
Solvolysis	A generic term for processes where a material reacts with a solvent to break into smaller components (e.g. hydrolysis, methanolysis, aminolysis, glycolysis).
Thermal cracking	The use of heat and pressure to break large molecules into smaller molecules.
Thermolysis	The use of heat to break down materials.
Thermoplastics	Materials that soften (become plastic) on heating and harden on cooling and are able to repeat this process.
Thermoset polymers	A polymer that irreversibly becomes rigid when heated.
Upcycling	The transformation of unwanted products into new materials perceived to be of greater value.
Virgin material	Material that has been sourced through primary resource extraction, often referred to as primary materials.
WEEE	Waste electrical and electronic equipment
WtE	Waste to energy – the generation of energy from the treatment of waste.

Executive summary

Australia intends to significantly improve waste recovery for plastics. One mechanism to achieve that is through increased recycling, including the use of advanced recycling technologies. New policies, such as the plastic waste export ban for mixed plastics (commenced 1 July 2021), 70% of plastic packaging recycled or composted by 2025 and the national action plan of 80% resource recovery rate from all waste streams by 2030 mean Australia must innovate to realise a circular economy for plastics. Despite international investment and application at commercial scale, advanced recycling for the recovery of waste plastic is not yet part of Australia's recycling strategy and lexicon, but it could be.

> “Advanced recycling is the conversion to monomer or production of new raw materials by changing the chemical structure of a material or substance through cracking, gasification or depolymerisation, excluding energy recovery and incineration”[1].

Advanced recycling is also referred to as chemical, molecular or feedstock recycling. These terms can sometimes be used interchangeably. Advanced recycling is complementary to mechanical recycling. It can assist with diverting mixed, flexible and contaminated waste plastics that are not able to be mechanically recycled economically and would otherwise go to landfill.
This report describes three major advanced recycling processes, purification, depolymerisation and conversion technologies, to produce intermediate products (light and heavy oil, gas, char). These products can be further processed into recycled polymers that are able to be manufactured into new products with recycled content, represented in Figure 1. A summary of these technologies is provided in Table 1 with the preferred polymers and summary of typical outputs or products.

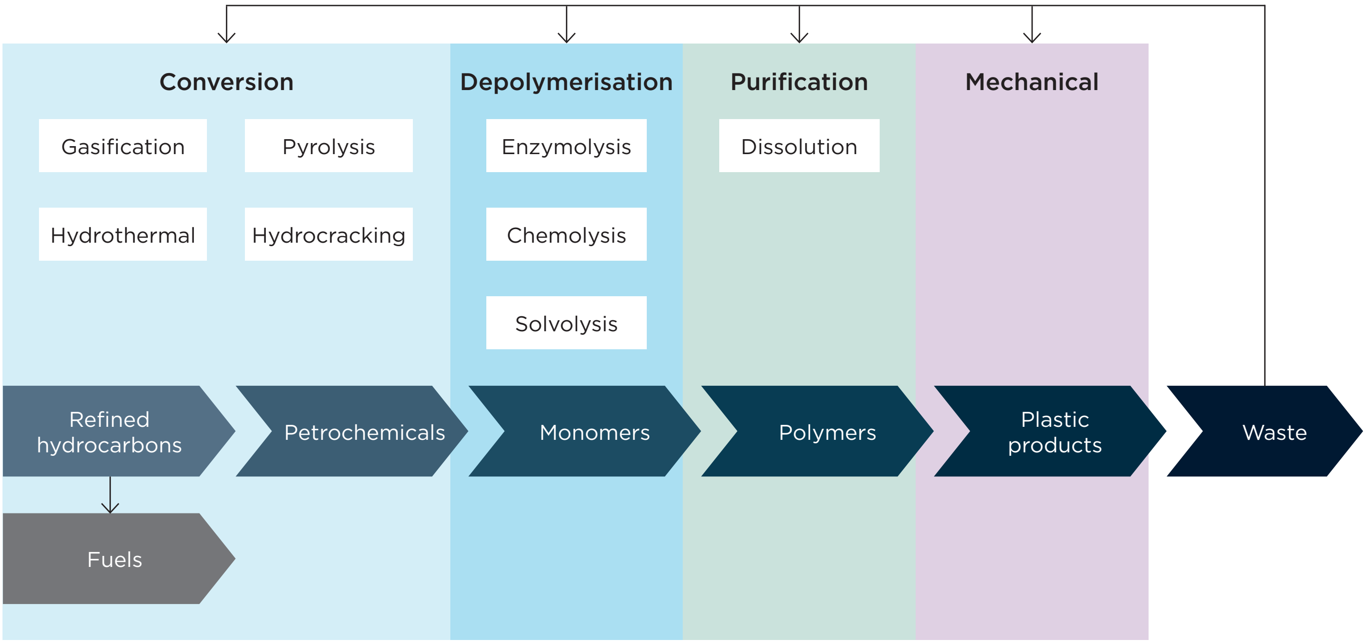


Figure 1: Summary of advanced recycling technologies and their products

Derived from Closed Loop Partners 2019

---

[1] https://www.iso.org/obp/ui/#iso:std:iso:15270:ed-2:v1:en

Plastics are a highly valuable feedstock for waste-to-energy plants due to their high calorific value but may instead be processed by advanced recycling technologies which specifically focus on waste plastics. Advanced recycling conversion technologies can convert plastic waste to oil (not including gasification where the typical output is syngas). This oil may be further processed and used as a fuel. This is depicted in Figure 2 as a 'plastic-to-fuel' pathway. However, advanced recycling also provides an opportunity to further process that oil with an outcome that is more beneficial for the waste hierarchy than the creation of fuel. The same plastic waste to oil pathway must be followed by any advanced recycling technology that might want to convert 'plastic-to-plastic', by cracking the oil (the process of breaking the chemical bonds of long chain hydrocarbons to smaller units) to produce a monomer (the building block of polymers) which can be further processed to a plastic. This is a desirable circular economy proposition as the plastic waste has been recycled, back to plastics.

In this report we consider major plastic polymer types, their generation as waste streams, polymer interactions within processes, and barriers to the application of technology for the treatment of plastic waste in Australia. International industry examples are used to illustrate the economic and environmental implications of plastic waste recycling by various technologies. Through direct industry engagement, we also report major factors influencing the adoption of advanced recycling in Australia.

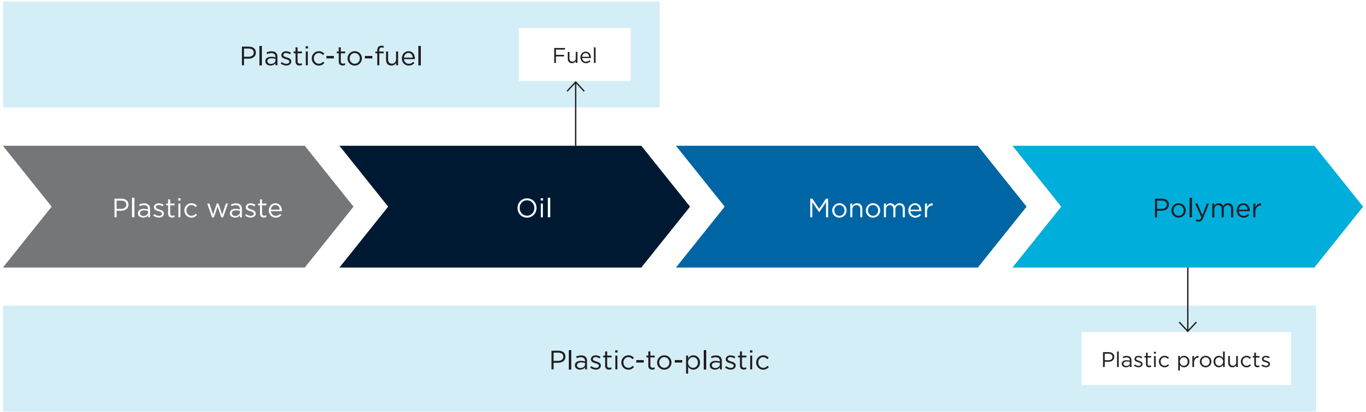


Figure 2: Plastic to fuel compared to plastic to plastic pathways for advanced recycling

Australia has all the critical elements necessary to launch a new industry of advanced recycling for plastics, which supports greater recovery, recycling and reuse of materials consistent with improved circularity and sustainable economic development. Three major report highlights are:

1 Advanced recycling will increase Australia's recovery of plastics

Advanced recycling is highly complementary to mechanical recycling as it provides a pathway for problematic wastes, such as mixed, flexible and contaminated plastic wastes that might otherwise go to landfill. Australia needs multiple options to improve recovery and recycling of waste plastics to meet national recovery (80% average recovery by 2030) and packaging (50% average recycled content, and 70% plastic packaging recycled by 2025) targets. Given Australia's current low rate of plastic recovery, it is unclear how these targets will be met with the current technology options. Advanced recycling technologies exist to repurpose plastics into valuable materials that might otherwise go to landfill.

2 Advanced recycling will generate new markets for products in Australia, including monomers, recycled polymers and fuels

There is increasing global and local market demand for recycled polymers. Domestic demand is sometimes being met by imported material. A new domestic advanced recycling industry has the potential to meet domestic demand and export high-value products to meet global demand. Advanced recycling produces food contact compliant recycled polymer, which has advantages compared to mechanical recycling. Independently verified mass balance certification provides the necessary chain of custody and traceability of recycled polymer.

3 Australia has the critical elements to adopt advanced recycling for plastic waste

Australia has major infrastructure (refinery, steam cracker) and polymer manufacturing skills and capability (plastics supply chain), which are essential for processing recycled hydrocarbon intermediate outputs that can be further manufactured into recycled plastics. Technologies at different scales are currently available in Australia. Collaboration across the supply chain is essential and has been demonstrated at pilot scale to work effectively.

Following industry engagement and assessment of themes through the PESTLE framework (political, economic, social, technological, legislative and environmental), the pathway for establishing an advanced recycling industry for plastics in Australia requires the following for success:

- A national discussion about advanced recycling to improve awareness of the range of technologies available, and to facilitate an understanding of where it sits in the waste hierarchy.
- An innovation approach to support pilots, trials with plastic wastes, collaboration across the supply chain and an innovation network to support scale up coordinated, for example, with a national centre.
- Harmonisation of government definitions, policy and approvals to support greater adoption of advanced recycling.
- Government support and engagement, which is essential for launching a new advanced recycling industry.
- Greater differentiation between advanced recycling of plastics and waste-to-energy technologies.
- Full collaboration across the entire supply chain, including waste managers, technology providers, polymer manufacturers, refinery operators, plastics manufacturers/recyclers and brand owners, to match demand with supply of recycled polymers.
- Techno-economic and life cycle assessment (LCA) studies to provide further evidence that technologies are commercially and environmentally sound.
- Adoption of globally recognised certification processes that exist to provide chain of custody verification and market confidence for recycled polymers and plastics that were processed through advanced recycling technologies.

Highlights

- The total Australian consumption of plastics in 2018–19 was just over 3.4 million tonnes with 2.54 million tonnes of plastic waste generated. Currently, Australia recovers 393,800 tonnes per year, which is 11.5% of consumption.
- From 1 July 2021 a total of 149,695 tonnes of mixed plastics is no longer able to be exported and is unlikely to be suitable for mechanical recycling without additional sorting. There is a risk this material will be stockpiled or sent to landfill.
- Advanced recycling can assist Australia to meet the national target of 80% resource recovery rate from all waste streams by 2030 and 70% of plastic packaging recycled or composted by 2025.
- Advanced recycling is complementary to mechanical recycling and accepts mixed, multi-layer, flexible and contaminated waste plastics that might otherwise go to landfill.
- Advanced recycling may be suitable for product steward schemes to address and recover plastic waste, such as almost 100,000 tonnes of agricultural plastics and over 800,000 tonnes of food plastic packaging. It is highly suited to the recovery of 300,000 tonnes of flexible plastic packaging.
- Advanced recycling is positioned above waste-to-energy on the waste hierarchy.
- Advanced recycling encourages pathways that are circular, rather than linear, by retaining material in the economy as part of a transition away from non-renewable and non-recyclable resources.
- Australia has unique technical expertise that would be suited to launching an advanced recycling industry for waste plastics, leveraging existing infrastructure (e.g. refineries and crackers) to recycle plastic wastes. Australia's polymer and plastics manufacturing supply chain is essential to realising benefits of advanced recycling and improved recycling rates of plastics.
- Advanced recycling technologies have a $120 billion annual addressable market in North America (Closed Loop Partners 2019).
- Global market demand for recycled plastics will continue to grow. Top global brands (representing 20% of all global packaging) average 6.2% recycled plastics in packaging where most have targets of 25% (and greater) to reach by 2025.
- Advanced recycling of mixed plastic waste by pyrolysis has a 50% lower climate change impact and energy use than energy recovery by incineration. Its carbon dioxide emissions are comparable to mechanical recycling (Jeswani et al. 2021).
- Technologies are available (four examples described in this report) and the Australian-invented Licella Cat-HTR™ technology converts 85% of plastic mass to hydrocarbon products.
- Advanced recycling produces food contact grade recycled plastics and can be certified with international standards using a mass balance approach.

Advanced recycling in Australia could utilise existing manufacturing infrastructure.
Image credit: Qenos

Table 1: Summary of advanced recycling technologies, polymer feedstocks and outputs

TECHNOLOGY	DESCRIPTION	PREFERRED POLYMERS	OUTPUTS
Purification	Purification technologies produce a polymer so are not generally considered advanced recycling technologies. However, because they use chemicals (solvents) as part of their process they are included for completeness.	3,5,6 – PVC, PP, PS	Polymers
Depolymerisation	Depolymerisation technologies convert plastics back to a monomer. These technologies are commonly applied to PET and may use an enzyme, chemical and/or solvent. It requires a clean stream of material such as plastic bottles (PET).	1,3,6 – PET, PVC PS, nylon and other polymers	Monomers
Conversion	**The following conversion technologies are named as such because they 'convert' plastics back to original chemical building blocks required to manufacture new plastics.**		
Gasification	Feedstock containing carbon is heated and reacted at high temperatures (>750°C) with a controlled amount of oxygen and/or steam to produce energy and a gas called syngas.	2,4,5,6 – HDPE, LDPE, PP, PS	Energy, syngas, ash
Pyrolysis	The thermal degradation of materials in the absence of oxygen. It may be conducted at low or high temperatures generally in the range 400–1,000°C. Pyrolysis may include a catalyst and additives such as hydrogen (known as hydrocracking or hydrogenation), which makes the conversion process more efficient and improves the quality of the oils produced.	2,4,5,6 – HDPE, LDPE, PP, PS	Heavy oil, naphtha (light oil), syngas (and/or other gases) and char
Hydrothermal	Use of high-pressure water as a reaction medium to crack polymer bonds and produce hydrocarbon products. Temperatures may be 250–500°C.	2,4,5,6 – HDPE, LDPE, PP, PS	Heavy oil, naphtha (light oil), syngas (and/or other gases) and char

Note: PVC = polyvinyl chloride; PP = polypropylene; PS = polystyrene; PET = polyethylene terephthalate; HDPE = high-density polyethylene; LDPE = low-density polyethylene

1 Introduction

Globally, there is a plastic waste crisis and the world is looking for innovative circular solutions to minimise plastic waste generation and increase recycling and reuse. The challenge to recover plastic waste is clear. It is estimated that by 2050, our oceans will contain more plastics (by weight) than fish (Ellen MacArthur Foundation 2016), and research has also shown that 95% of seabirds may have ingested plastic waste in their lifetimes (Hardesty et al. 2014). Global scenarios to 2050 show that 60% of plastics produced might be derived from reused or recycled plastics (Hundertmark et al. 2018), with an Australian scenario estimating that by 2030, 50% of plastics might be recycled, based on achieving an 80% average recovery rate (Schandl et al. 2021).

The recycling of plastics is critical to recovering material, adding value and reducing litter. Recycling is a major contributor to realising a circular economy for plastics (see Figure 3). However, there is more than one process for recycling plastics. Mechanical recycling pathways are suitable for well-sorted, single-polymer waste streams – particularly the higher value polymer streams of PET (polyethylene terephthalate) and HDPE (high-density polyethylene). Mechanical recycling produces a clean resin for reuse or an extruded product. Advanced recycling can accept multiple polymer types with a degree of contamination. Technologies convert plastics back into chemical building blocks that are then further processed to produce polymer resins. Advanced recycling can accept mixed, multilayer, flexible or contaminated plastics that mechanical recycling cannot. Further down the waste hierarchy is waste-to-energy where plastics are valued for their high calorific value, however, they are incinerated, which results in the plastics being lost from the economy for future reuse.

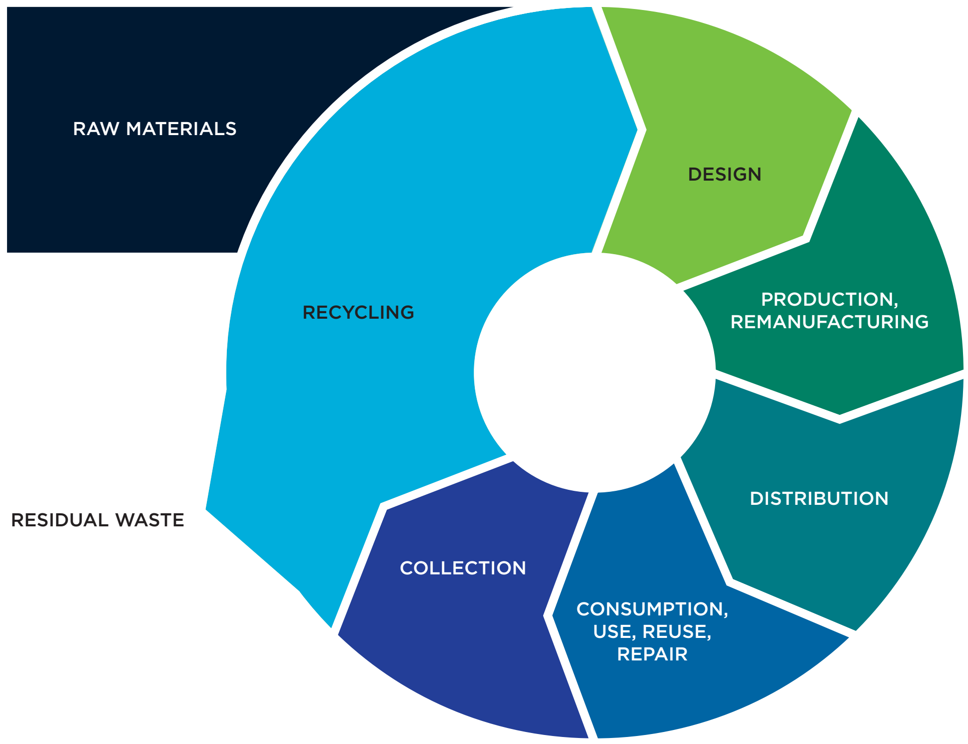


Figure 3: Circular economy

Adapted from image source: Australian Government 2019

Advanced recycling technologies have potential to assist in the recovery of plastics in Australia. It is estimated that feedstock technologies have a $120 billion annual addressable market in North America (Closed Loop Partners 2019). The benefits of advanced recycling are that it is complementary with mechanical recycling and overcomes some of the constraints of polymer degradation found in mechanical recycling. For example, thermo-oxidative degradation that occurs when plastics are melted down, which can make it difficult to continually produce a recycled plastic with the same physical properties as virgin plastics. Advanced recycling thus promotes circularity by improving the recovery and retention of plastic materials in the economy.

The lack of awareness of advanced recycling for plastics represents a risk to Australia in developing a circular economy in relation to plastics and achieving improved plastics recovery outcomes in support of the National Waste Policy Action Plan, National Plastics Plan, and the United Nations Sustainable Development Goals (particularly Goal 12 – Responsible Consumption and Production).

The purpose of this report is to investigate the applicability of advanced recycling to Australia to add value to end-of-life plastics that are not suitable for mechanical recycling pathways, as part of an integrated approach, consistent with the waste hierarchy. By doing so, we aim to address a knowledge gap for plastics recycling in Australia and identify key priorities that support innovation in the plastics manufacturing and recycling industries. This report aims to launch a national discussion on advanced recycling for plastics in Australia.

This report:

- Provides a credible, layperson's reference and guide to advanced recycling for plastics
- Aims to reduce confusion, and increase clarity, consistency and confidence around language and technologies
- Describes polymer types and plastic waste streams and their suitability for advanced recycling
- Describes the relevant factors for Australia in adopting advanced recycling.

Advanced recycling technologies will help address Australia's plastic waste challenge. Currently, each Australian generates an average of 101 kilograms of plastic waste per year, including 59 kilograms of single-use plastic waste (Pickin et al. 2020). An estimated 130,000 tonnes of plastic waste leaks into the Australian environment each year (WWF 2020). The decision by China and other South-East Asian countries to ban the importation of wastes, including plastics, is driving a need for Australia to develop domestic solutions for waste processing and recycling of these wastes, including increasing our waste processing capacity. Following these restrictions, Australia has announced plastic waste export bans, which commenced in July 2021 for mixed plastics and 2022 for unprocessed, single-polymer type plastics. Based on 2018–19 data Australia exported 149,695 tonnes of mixed plastics and 37,695 tonnes of single-polymer type plastics (COAG 2020). In addition, the national packaging targets aim for 100% of packaging (including plastics) to be reusable, recyclable or compostable by 2025, with a 50% average recycled content in packaging, and 70% of plastic packaging to be recycled or composted (APCO 2020).

The total Australian consumption of plastics in 2018–19 was just over 3.4 million tonnes. Of this, consumption can be divided into predominantly single-use applications (33%), long-life plastics (24%) and other/unidentified (34%). Australia's national waste policy action plan, target 3, sets a goal of an 80% average resource recovery rate from all waste streams by 2030 (Australian Government 2019). The Australian national waste report states 2.54 million tonnes of plastic waste was generated in 2018–19 (Pickin et al. 2020), which equates to 74% of consumption. Note that not all plastics consumed each year will reach end of life as some plastics contribute to products in long-lived applications such as buildings, electrical goods or vehicles. Currently, Australia recovers 393,800 tonnes per year, which is 11.5% of consumption.

To provide an estimate of Australia moving towards the national target of 80% average resource recovery for plastics based on available data, an additional 1.6 million tonnes of plastics will need to be recovered. Figure 4 shows the data for 2018–19 consumption and recovery compared to an estimated 80% of end-of-life plastics (just over 2 million tonnes). Note that this is an estimate, (not including any consumption increase) but demonstrates the scale of the plastic waste challenge. This requires significant infrastructure, commitment, and multiple options for processing plastics in Australia. There is a significant challenge for Australia to pivot from disposing of plastics, to collecting and processing waste plastics.

Compounding this challenge is that there is not a single type of 'plastic' and there are different polymers, each with different properties. Plastic products also contain additives and may comprise more than one polymer type. Moreover, there are two types of plastics, thermoplastics (such as PET, PE [polyethylene] and PP [polypropylene]) and thermoset plastics. Thermoplastics are suitable for mechanical recycling. The latter, thermoset plastics, are permanently crosslinked during manufacture and cannot be melted and reformed. Therefore thermoset plastics such as unsaturated polyester or epoxy resins are not suitable for mechanical recycling, other than being pulverised to a fine particle or powder (Hopewell, Dvorak & Kosior 2009).

A summary of different polymer types, their use and recyclability, is provided in Table 2.

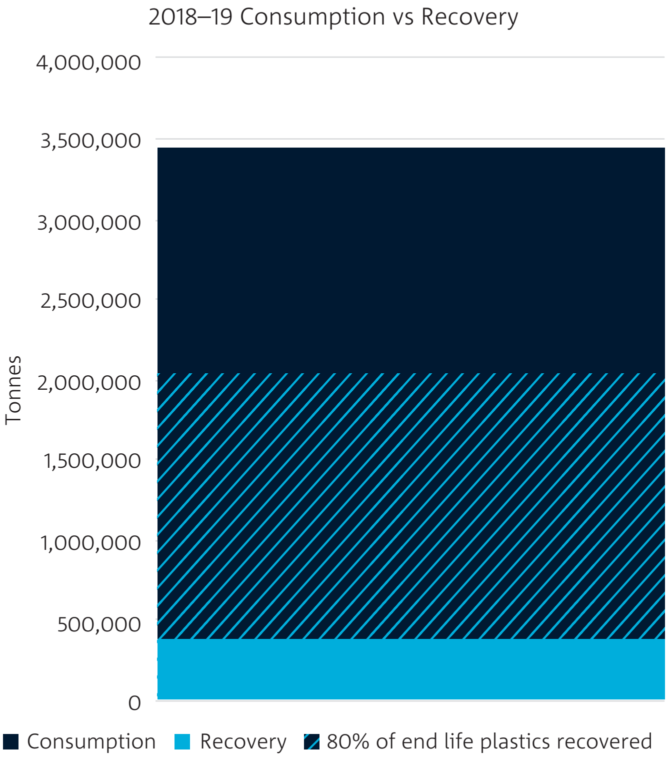


Figure 4: Comparison of current (2018–19) and estimates of future (2030) recovery demand of plastics, in line with national targets

Table 2: Polymer types, use, recovery and recyclability

CODE	NAME	USE	RECOVERY RATE 2018–19	RECYCLABILITY IN AUSTRALIA
1 **PET**	Polyethylene terephthalate (PET or PETE)	Consumer drink packaging, medicine bottles	21%	Packaging captured in container deposit schemes, existing recycling PET facilities. Good polymer for mechanical recycling pathways. An ideal polymer for depolymerisation.
2 **HDPE**	High-density polyethylene (HDPE)	Durable containers: detergent, bleach, shampoo, motor oil, milk bottles Cereal box liners, retail bags	19.7%	Municipal waste collection via MRF facilitates. Considered a good polymer for mechanical recycling pathways. When mechanical is not possible, best suited for conversion technologies.
3 **PVC**	Polyvinyl chloride (PVC)	Packaging: rigid bottles, blister packs Medical: bedding, shrink wrap, tubes, fluid bags Carpet backing, coated fabrics and flooring Construction: ducting, pipes	2%	Collection scheme for some medical plastics. Considered contamination in municipal plastics collections. Opportunities for greater collection in building and construction sector. Undesirable for conversion technologies. Best suited for purification technologies.
4 **LDPE**	Low-density polyethylene (LDPE)	Bags, film wrap, sealants, wire cable covering	17.3%	Consumer packaging wrap collected by REDcycle in Australian supermarkets. Clean post-industrial film suitable for mechanical recycling. Also suitable for conversion technologies.
5 **PP**	Polypropylene (PP)	Packaging containers, bottle caps, carpets, flexible packaging	8.9%	Low recycling rate in Australia. Suitable for either conversion or purification technologies.
6 **PS**	Polystyrene (PS) and Expanded polystyrene (EPS)	Packaging peanuts, Styrofoam, protective foam, insulation, yoghurt pots	11.5%	Growing focus to reduce PS in packaging to meet recovery targets. EPS packaging collected at transfer stations. There is some recycling into the built environment. The majority of what is collected is currently exported. Excellent candidate for purification technologies. Also good for conversion and depolymerisation technologies.
7 **Other**	A mixture of polymer types: ABS/SAN/ASA, PU, nylon, bioplastic and other aggregated or unknown polymer types	Multilayer barrier films, toothbrushes, some food containers, tyres, waste electrical and electronic equipment (WEEE), etc.	5%	Low recyclability, niche collection and recycling of different polymer types.

Recovery rate data source: O'Farrell 2019

Advanced recycling is suitable for face masks and other soft plastics.

The method for developing this report is based on a literature review of academic, peer-reviewed and grey literature (non-academic reports, e.g. government, not-for-profit, industry reports, working papers, etc.). Report authors also hosted a workshop with 36 industry participants to secure input to relevant factors for advanced recycling in Australia.

This report commences with an overview of plastics recycling pathways, and defines and describes the different advanced recycling technologies. The report then describes the suitability of polymers for different technologies and examples of plastic wastes and volumes (where possible) that are suitable for advanced recycling technologies. Finally, to evaluate the potential application of advanced recycling to the Australian context we present a range of factors (policy, economic, social, technology, legislation and environmental) for consideration. This report concludes with a summary of challenges and opportunities.

Advanced recycling technologies can leverage polymer manufacturing infrastructure.
Image credit: Qenos

2 What is advanced recycling?

Advanced recycling of plastic wastes is also referred to as feedstock, molecular or chemical recycling and encompasses a range of technologies that may involve chemical, thermal or biological processes to convert waste plastics into chemical building blocks. We apply the term 'advanced' to refer to a family of technologies that modify the chemical structure of waste plastics. Generally, advanced recycling converts waste polymers into their original monomers, oligomers, hydrocarbons, or other valuable chemicals, such as energy and fuels, which can be reused as raw materials for the production of new plastics.

A definition of advanced (feedstock) recycling from the ISO Standard (15270:2008) on 'Plastics guidelines for recovery' defines it as:

> Conversion to monomer or production of new raw materials by changing the chemical structure of a material or substance through cracking, gasification or depolymerisation, excluding energy recovery and incineration.[2]

Figure 5 shows the relevant stages of the plastics life cycle (indicated by the arrows at the base), the different types of recycling processes for plastics (e.g. conversion, depolymerisation, purification and mechanical), and technology examples for each recycling process. Lastly, it shows the recycling processes that are included in the advanced (feedstock) recycling standard definition, namely conversion and depolymerisation technologies.

The purification stage has the potential to be considered 'mechanical recycling' (Crippa et al. 2019) as the resulting product is a polymer. However, the primary method for purification uses chemicals (solvents), and as advanced and chemical recycling terms are often used interchangeably, purification is sometimes included as an advanced recycling approach. We have shown it as a separate technology in this report because the production of a polymer does not fit with the definition of an advanced recycling technology, as provided in Figure 5. However, we do describe purification technology as it is part of the broader family of technologies that sit beyond mechanical recycling.

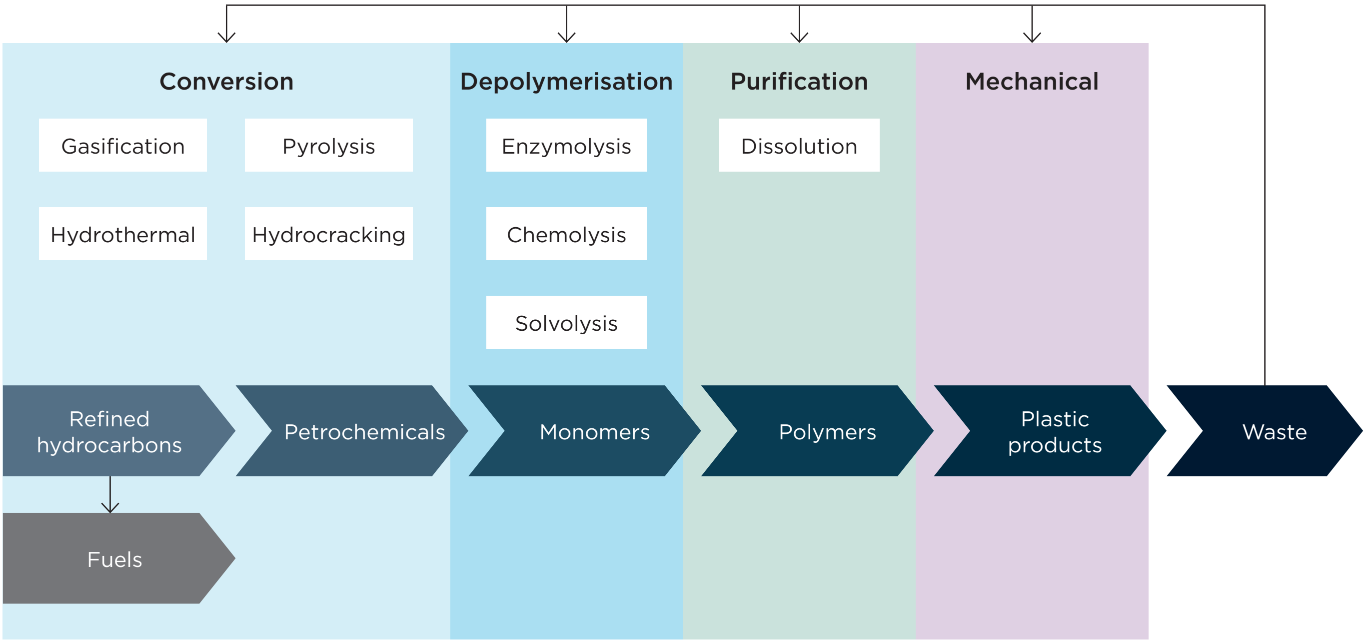


Figure 5: Summary of advanced recycling technologies and their products

Derived from Closed Loop Partners 2019

---

[2] https://www.iso.org/obp/ui/#iso:std:iso:15270:ed-2:v1:en

Another important consideration is the resulting products of these technologies. From conversion technologies, there are three main pathways – waste plastics-to-fuels, waste plastics-to-plastics and waste plastics-to-chemicals. Any technology that converts waste into fuel may be considered waste-to-energy technology (Parliament of Australia 2020). This is an important consideration as pyrolysis may produce a liquid oil and whether it is considered advanced recycling or waste-to-energy depends upon which market or supply chain those products become part of. Any kind of energy consumption is no longer part of a circular material loop and therefore is not considered part of a circular economy (Ellen MacArthur Foundation 2020a). To be considered advanced recycling, a conversion technology should integrate with existing infrastructure for the manufacture of chemicals to produce polymers. This topic is discussed further in Section 4.6.4 Plastics-to-fuels.

The structure of this section is to describe each of the recycling stages presented in Figure 5, commencing with mechanical recycling (which is not considered part of advanced recycling but included here for completeness and comparison).

2.1 Mechanical recycling

Mechanical recycling is a very well-established, mature technology. It is best suited to thermoplastic materials such as PET, HDPE, LDPE, LLDPE (linear low-density polyethylene), PP and PVC and is not generally suitable for thermoset polymers or laminates. Thermoplastics can be continually softened, melted, reshaped and recycled. Typically, waste thermoplastics are sorted by polymer type, chopped, washed, and melted into granulates before being extruded into new plastic products. Europe uses mechanical recycling to recycle approximately 5 million tonnes of waste plastic material per year (Qureshi et al. 2020). Mechanical recycling is most efficient when the waste is pre-sorted by plastics type, and process efficiency and product quality is reduced if mixed plastic wastes are introduced into processing. Polymer degradation also occurs during the recycling of thermoplastics due to the chemical and physical forces exerted during extrusion (Rahimi & Garciá 2017). Mechanical recycling often decreases the tensile strength and elongation at break of rPP[3], the tensile strength for rHDPE, elongation at break for rLLDPE, impact strength of rPP, and causes a multitude of issues for rPET (Schyns & Shaver 2021). Polyethylene has a high thermal stability, which allows it to undergo multiple melt-and-remould cycles in mechanical recycling processes. It has been found that LDPE can be extruded up to 100 times at 240°C, although performance is reduced after 40 extrusions, with significant changes in processability and mechanical properties observed (Rahimi & Garciá 2017). Locally, a trial has shown minimal deterioration in properties of HDPE for milk bottles when mechanically recycled 6 times and 10 times with pure HDPE incorporated at 50% and 70%, respectively (Davies et al. 2021).

Mechanical recycling does not remove all of the colourants or odours from waste plastics. There are mechanical recycling technologies to remove odours including filtration and vacuum extraction of odoriferous compounds during extrusion, washing with surfactants or addition of odour capturing materials, but these add an extra cost to the process (Schyns & Shaver 2021). Generally, the products of mechanical recycling do not meet the requirements for food contact compliant applications. Colours, odours and reduced physical properties ultimately lead to a downgraded product, sometimes referred to as 'downcycling'. Downcycling is mitigated by stringent sorting processes at the front end to ensure coloured or poor-quality plastic waste is removed prior to processing. Despite the limitations, mechanical recycling is an excellent way to recycle high-quality, clean, post-industrial waste and cleaned post-consumer waste to ensure that materials are retained in the market.

Mechanical recycling technologies are a key part of Australia realising a circular economy for plastics, with seven new or upgraded recycling facilities (mostly for rPET) with 145,000 tonnes a year of mechanical processing potential coming online in the next 1–3 years (Envisage Works 2020). One of these recent projects is the collaboration between Pact Group, Cleanaway, Asahi and the NSW Government in Albury, NSW to produce rPET and associated products from high-quality waste PET streams. When considering appropriate recycling technologies for mixed plastic waste, mechanical recycling and advanced recycling complement each other, whereby the polymer and product types more suited to mechanical recovery are avoided for use in advanced technologies.

---

[3] Note: r=recycled

2.2 Purification

Purification technologies take waste plastics and dissolve them in a suitable solvent, followed by a series of steps that remove additives and contaminants before solvent removal (Vollmer et al. 2020). The output is pure precipitated polymer pellets that are largely undegraded by the process and can be reformulated into products. Purification technologies have been used successfully for homogenous waste streams of PS, PE, PVC, PC (polycarbonate) and PP, and for more heterogeneous complex mixtures containing laminates or electric and electronic waste plastics. Technically this is not a chemical recycling process as generally no bonds are cleaved but it is a system that requires the use of solvent chemicals and a deep understanding of chemistry to be successful.

Purification processes use solvents to dissolve a plastic material, with immiscible solvents used to then extract the additives, leaving a purified polymer for recovery. The purification process includes pre-treatment, dissolution of the target polymer at elevated temperatures, filtration of undissolved solid materials, solvent extraction of impurities (such as dyes and flame retardants), reprecipitation and finally, solvent removal (drying or vacuum to recover the solvent). The recovered polymers are then extruded into pellets (Zhao, Lv & Ni 2018). An increasing number of purification-based recycling plants for the treatment of plastic waste are being commercially developed (Closed Loop Partners 2019).

PS is highly soluble in a range of solvents, and this flexibility makes it an excellent candidate for recycling by purification processes. There is an opportunity for PS collection stations to operate small-scale purification processes on-site to reduce the impact of storing collected EPS foam, which can consume a high volume of storage and transportation space. Purification processes for the recycling of PS also enable the removal of common contaminants, such as flame retardants and dyes from PS wastes, not only resulting in a purified rPS stream, but also reducing the impacts associated with improper treatment of these contaminants. Polystyvert Inc. in Canada recycles PS into clean rPS polymer pellets that can then be used to make new PS products (Polystyvet 2020). Dissolution has also been applied to recover PS from construction and demolition wastes using the CreaSolv® process developed by Fraunhofer (Germany). PolyStyreneLoop uses this technology in the Netherlands to recover PS and the banned flame-retardant hexabromocyclododecane (HBCD) (PolyStyreneLoop 2021).

Like PS, the use of purification methods to recycle PP waste has also been demonstrated commercially (Closed Loop Partners 2019). PP wastes are amenable to purification processes for recycling because a selective solvent has been identified that enables impurities to be extracted. PureCycle Technologies in the US uses supercritical butane to dissolve and purify post-consumer PP waste (PureCycle 2021). The technology was originally developed by The Procter & Gamble Company as part of their commitment to reduce the impact of their products on the environment. It is reported that the process produces rPP with the same properties as virgin material. PureCycle plans to be in production by late 2022 with a plant being constructed in Ohio, US, which will have a processing capacity of 48,000 tonnes a year. There are plans for the construction of larger plants in Europe (Acquisition 2020).

PET can be dissolved using a number of solvents and this has been used to recover it from packaging and mixed textile products. Worn Again Technologies uses purification technology to purify PET. Dyes are removed in the first stage, which is done by swelling the plastic, the plastic is then dissolved and filtered to remove any insoluble impurities (Sherwood 2020). While the PET does not acquire any damage to the polymer bonds during the process it does lose some crystallinity which lowers its toughness, stiffness and resistance to solvents (Sherwood 2020).

PVC waste streams have been purified by VinyLoop®, a Solvay (Belgium) technology (Sherwood 2020). PVC was selectively dissolved in an organic solvent then precipitated by steam-driven evaporation of the solvent, which itself was recycled. The process took PVC streams often contaminated with textiles and other materials and produced PVC that was said to be of the same quality as the original material. VinyLoop® was commercialised as a joint venture in 2002 and ran until 2018. The plant in Ferrara, Italy was established to recycle up to 10,000 tonnes of waste a year, primarily cable insulation. Unfortunately, the economics were not viable, largely because the plasticisers in the PVC were not removed in the process. Initially this was thought to be an advantage as the PVC could be used for the same products, but the plasticisers used were subsequently banned by the European Chemicals Agency (Plasteurope 2018).

Purification technology has been applied to separate films containing PE/PP/aluminium foil and recover PC from waste electrical and electronic equipment (Vollmer et al. 2020). APK uses their Newcycling® process in its commercial plant located in Germany to separate films and can process 8,000 million tonnes per year (Vollmer et al. 2020). Waste electrical and electronic equipment has a high proportion of PC that can be extracted using a mixture of acetonitrile and dichloromethane in high yield (>95%) with similar purity and quality to virgin PC (Weeden, Soepriatna & Wang 2015). This method uses 84% less energy and costs less than 30% of the cost of producing PC from petroleum (Vollmer et al. 2020).

Many polymers do not dissolve completely due to their high molecular weight and cross linking. Instead, they soften to allow the infiltration of solvent molecules to dissolve the impurities. In Australia, the organisation PVC Separation has developed a solvent process that can separate laminates and multilayer films but does not require full dissolution of the polymers (Vollmer et al. 2020). In the process a plastic laminate material is infiltrated but not dissolved by a low boiling point solvent. It is then heated rapidly to above the solvent boiling point and the action of the flash evaporation causes the layers to separate. Utilising a similar technology, Saperatec in Germany plans to have a plant (18,000 tonnes a year) operational by the end of 2021 that will separate PET, PE and aluminium foil in laminate materials (Vollmer et al. 2020; Saperatec 2020).

Some of the challenges for purification technologies include the identification of optimum solvents and conditions, the processes associated with safe use of hazardous solvents, and the difficulty in removing the solvent at the end of the process resulting in cost increases and lower quality material. The ideal solvents are environmentally benign, easily recovered and have a high dissolution capacity (Goldberg, Haig & McKinlay 2019). Disposing of the extracted contaminants also requires consideration.

Like mechanical recycling, the product of purification technologies are polymeric material and a small amount of degradation of properties (depending on the process) is often observed. While purification technologies often have limited input streams, they do offer a purer and less degraded product than mechanical recycling. This is because any contaminants are chemically removed. Purification technologies also offer the highest carbon dioxide savings of the various advanced recycling methods because no chemical bonds are broken (Vollmer et al. 2020).

2.3 Depolymerisation processes

Depolymerisation processes for recycling of plastic waste involve breaking down the polymer to constituent monomers or small groups of monomers. These chemicals can then be used to make the same plastic material again, making the manufacture of these products a circular process. Depolymerisation is achieved using chemical (chemolysis/solvolysis), thermal (thermolysis) or biological (enzymolysis) processes. It is most efficient for polycondensate polymers including PET, PA (nylon) and PU (polyurethane). Depolymerisation of polyolefins (PE and PP) is limited due to the presence of strong carbon–carbon bonds, making the application of depolymerisation processes for monomer recovery more energy intensive with a wide range of products for polyolefin polymers (Vollmer et al. 2020).

PET depolymerisation is the most widely used in the plastics recycling industry, and is achieved using a number of different methods (Table 3) (Closed Loop Partners 2019). The simplest method is glycolysis, which converts PET to bis 2-hydroxyethylphthalate and other specialised polyols that can be used to make other polymers (Ragaert, Delva & Van Geem 2017). Coloured PET can still be challenging as the monomers produced can be discoloured and require further clean-up (Rahimi & Garciá 2017). Loop™ Industries takes PET and uses catalytic thermolysis at low temperatures to return it to monomers that can be used to make new PET (Loop Industries 2021).

Enzymatic treatment (enzymolysis) of PET plastics and fibres can convert them back to their original monomers. Carbios (France) has recently announced that they are also able to convert polyester textile waste back to monomers and then into bottles using their scalable PETase technology (Carbios 2020). Textiles to bottles is not possible using mechanical recycling methods. CSIRO has also developed a PETase enzyme that can efficiently break down PET to its original monomers. Enzymolysis can be slow compared to chemical techniques and enzymes may be sensitive to conditions and impurities.

Depolymerisation is an interesting recycling option for PU as it cannot be mechanically recycled (Vollmer et al. 2020). PU has been successfully depolymerised to mixtures of polyols that can be repolymerised to good quality PU by mixing with virgin feedstocks (Sheel & Pant 2018). PU can be depolymerised by hydrolysis and glycolysis (Rane et al. 2015). There are a number of pilot scale plants for the depolymerisation of PU under construction in Germany (Lardiés 2020).

PS can be depolymerised using thermal catalytic methods in the presence of oxygen to produce the monomer styrene. PS can also be depolymerised using high-power microwave technology, and this is in early commercial development with Pyrowave, a Canadian-based enterprise (Pyrowave 2021). This process uses 15 times less energy than manufacturing styrene from virgin resources and offers high yields (95%), with a processing capacity of approximately 750 tonnes a year.

PC can be depolymerised by a number of different chemolysis methods to provide monomers that can be made back into PC or used in other production streams (Emami & Alavi Nikje 2019). Hydrolysis, glycolysis, methanolysis and aminolysis can all be used to depolymerise PC (Antonakou & Achilias 2013). Most of these methods lead back to bisphenol-A, which unfortunately has limited commercial value. It is usually converted to other compounds with greater value during the degradation process. The depolymerisation is complicated by the fact that PC often contains high concentrations of additives (Antonakou & Achilias 2013).

While depolymerisation of PVC is technically possible, the value of the products formed is low and it is not currently economically worthwhile when compared to the manufacture of virgin PVC (Rubio 2021). It can be achieved by thermal degradation in a two-step process, including a low temperature (250–320°C) dehydrochlorination reaction to remove chlorine from the material, followed by higher temperature processing to yield toluene and/or benzene (Yu et al. 2016).

One drawback of depolymerisation as a recycling process is that most methods require a relatively pure input stream of polymer to produce a high-quality product. Other issues include separating the chemical cleavage agent and by-products (an issue for both purity of products and recovery and reuse of reagents), achieving good contact area between the cleavage agent and the solid polymer and recovering dissolved catalysts (Vollmer et al. 2020). Depolymerisation processes will also have unreacted material and other solids that may contain hazardous or toxic residues that will require disposal (Goldberg, Haig & McKinlay 2019).

Table 3: Depolymerisation of common plastics

INPUT POLYMER	PROCESS	OUTPUT	OUTPUT USE
PET (textiles/bottles)	Enzymatic degradation	Terephthalic acid Ethylene glycol	New PET
PET	Hydrolysis	Terephthalic acid	New PET
PET/textiles	Chemical glycolysis	Bis 2-hydroxyethyl terephthalate Polyols	New PET Epoxy, PU, acrylic, etc.
PET	Methanolysis	Dimethyl terephthalate	New PET
PET	Aminolysis	Diamides of terephthalic acid	New chemicals
PS	Microwave degradation	Styrene	New PS
PVC	Thermal	Hydrogen chloride, benzene (<300°C) Toluene (>300°C)	Input chemical industry
PA	Thermal hydrolysis	Caprolactam	New PA
PA	Methanolysis	Caprolactam	New PA
PU	Glycolysis/hydrolysis	Polyols	New PU
PMMA	Thermal	Methyl methacrylate	New PMMA
PC	Alkaline hydrolysis	Bisphenol A	New PC

2.4 Conversion technologies

Conversion processes take waste materials and convert them into much smaller molecules that can be used to make new polymers, new chemicals or fuels. The technologies discussed here include gasification, pyrolysis and hydrothermal processes. The products are separated by boiling point ranges and are either used directly as fuels or processed further before use. This processing can involve refinery processes including distillation, olefins cracking and other petrochemical conversion to produce monomers and other small molecules for plastics, chemicals or fuels.

2.4.1 Gasification

Gasification is a process whereby a feedstock containing carbon is heated and reacted at high temperatures, typically greater than 750°C, with a controlled amount of oxygen and/or steam to produce energy and a gas called syngas. Syngas is rich in carbon monoxide and hydrogen and contains some short hydrocarbons. Small amounts of solid char and tars (often defined as hydrocarbons with a molecular weight greater than benzene) may also be produced. The syngas can be combusted to produce electricity (waste-to-energy) or used as a feedstock for the production of chemicals.

The technology for gasification is well established for processing coal, biomass and to a lesser extent municipal solid waste (MSW). Gasification is usually performed in fixed bed reactors, fluidised bed reactors or entrained flow reactors, which have been designed for specific requirements (e.g. feed material and scale of operation). Plasma gasification is another route for producing syngas. Plasmas generate very high temperatures, which result in high gas yields, very little tar formation and the elimination of toxic compounds.

The input gases (steam, air, oxygen and/or nitrogen) in gasification systems have a significant effect on the syngas produced. Air gasification is the simplest technology as the reaction is self-sustaining, with the energy required being offset by the energy released by reaction of the oxygen in the air and the organics in the feed. The syngas formed contains nitrogen, which makes it more amenable for power generation than chemical manufacture. Gasification with oxygen instead of air produces a higher calorific value syngas free of nitrogen. However, an air separation plant is required, which increases the cost of the process. Steam gasification of waste plastics also generates syngas without nitrogen and maximises the production of hydrogen. However, the process is endothermic, requiring an external heat source to heat the gasifier.

Waste plastics have different properties and are highly heterogenous compared with other feedstocks, which means they can't be processed in conventional gasifiers. The Texaco gasification process is the most well-known for gasification of plastic wastes. It is a two-step process where the plastic is first liquefied to a synthetic heavy oil followed by processing in an entrained gasifier (Ragaert et al. 2020). A major challenge with gasification of waste plastics compared with other feedstocks is the generation of a higher proportion of tars. The tars need to be removed before the syngas can be used. Tar removal can be achieved through additional thermal or catalytic breakdown of the hot tars, or cooling and separation of the condensed tars. All plastics can be processed by gasification. However, due to the chlorine content, PVC can only be processed if the gasifier is constructed of corrosion resistant materials and is fitted with a suitable scrubbing technology to remove the hydrogen chloride produced from the gas. Issues experienced when gasifying waste plastics are generally ameliorated by blending them with biomass or MSW. Co-gasification of waste plastic or refuse-derived fuel from MSW with biomass improves the process because of the synergistic effects of the two different feeds leading to reduction of the sticky ash/tar formed (Yang et al. 2021).

Gasification for processing waste plastics has been demonstrated at commercial scale. EBARA developed a commercial-scale process in 2003 that processes 70,000 tonnes a year of waste plastic at Showa Denko's site in Kawasaki (JGC Holdings Corporation 2020). The technology incorporates a pressurised twin internally circulating fluidised bed gasifier with oxygen and steam injection. The hydrogen and carbon dioxide produced through processing waste plastics is used to produce ammonia for fertiliser production and for products such as dry ice and carbonated drinks, respectively. Powerhouse Energy Group are constructing a waste plastics gasification facility in the UK to generate electricity and hydrogen using steam injection into a rotating drum gasifier (Powerhouse Energy Group 2021). The plant is proposed to have the capacity to process 12,600 tonnes a year of plastic waste. Enerkem has been operating an oxygen/steam fluidised bed gasifier in Edmonton, Canada since 2011 that processes 100,000 tonnes a year dried MSW and converts it into ethanol and methanol (Butler, Devlin & McDonnell 2011).

The gasification industry has seen many abandoned projects due to technical challenges and lack of government support (World Waste to Energy 2020). The main technical challenges for large-scale plastic waste gasification are the large energy requirements, managing the waste tar and ash formed in the process and maximising heat transfer through the reactor.

2.4.2 Pyrolysis

Pyrolysis is the thermal degradation of materials in the absence of oxygen, with or without catalysts. Pyrolysis is usually conducted between 400 and 1,000°C (Goldberg, Haig & McKinlay 2019). It is a mature technology that enables the processing of biomass or waste plastics. There are commercial plants already operating around the world, and industrial and pilot-scale plants are in development in many countries (Qureshi et al. 2020). The pyrolysis plants that are coming on stream currently range in size substantially depending on local need. There are many technologies that are modular and relatively small scale (0.5–10 tonnes a day), such as those developed by Blest, PlastOil, IQ Energy Australia and Plastic2Oil (Closed Loop Partners 2019; Qureshi et al. 2020). Larger systems are also operating with more under development that can process 10–500 tonnes a day. Some of the companies involved include Agilyx (US), which has more than 50 projects in development, and Oursun Resources (China), which has a number of facilities running and is an exporter of pyrolysis technology (Closed Loop Partners 2019).

Plastics pyrolysis involves the degradation of long polymer chains to form a mixture of smaller hydrocarbon molecules. The three major products from pyrolysis are oil, syngas (pyrolysis gas) and char. The oil is often collected in two fractions with different boiling point ranges, namely heavy oil (similar to diesel) and light oil, also known as naphtha (more like gasoline). The oil fraction produced can sometimes be used directly by a furnace, diesel engine, turbine or boiler without further treatment. These products can be combusted for heat production for the pyrolysis system itself.

An issue for the pyrolysis of mixed plastic wastes is the complexity of reactions that occur, especially where they lead to the formation of large complex molecules (Sharuddin et al. 2016). Distillation of the resultant oils will afford a number of fractions; however, sophisticated separation technologies are required to produce pure chemical feedstocks. The oils can be used as a feedstock for refinery industries or olefin (steam) crackers for further conversion and separation into chemicals or fuels displacing natural gas and crude oil as feedstock.

The process of pyrolysis is highly flexible as the operating conditions can be optimised to deal with different input materials and to alter the yield of the various outputs (Sharuddin et al. 2016). Temperature, reactor type, residence time, flow rate, catalyst and type of fluidising gas are all parameters that can be manipulated. What is critical, and perhaps most challenging, is matching the plastics input supply and polymer mixtures with operating conditions and desired outputs. Due to the technical flexibility of processing, pyrolysis can be used to recycle a range of waste plastics, including single-polymer plastic wastes, mixed plastic wastes, plastic wastes contaminated with harmful chemicals and additives, and those that can no longer be mechanically recycled. Elevated pressures lead to increased coke formation and heavy fractions of oil where catalysts are not used (Vollmer et al. 2020). Catalysts result in higher amounts of smaller hydrocarbons and lower liquid yields. One of the benefits of pyrolysis technologies for waste plastics is that they do not cause water contamination like mechanical recycling. By using pyrolysis to convert plastics that are not suitable for mechanical recycling into fuel or feedstocks for refineries there are savings in greenhouse gas emissions, water consumption and energy use compared to using fossilised sources of crude oil (Qureshi et al. 2020).

Though pyrolysis can be useful for recycling a range of mixed and contaminated plastic waste streams, the efficiency of processing, and purity and quality of end products is impacted by the presence of contaminants and purity of inputs for processing (Butler, Devlin & McDonnell 2011). Contaminants such as antioxidants and flame retardants in some plastics will also lead to traces of sulfur, chlorine, bromine, nitrogen and other elements that will impact the purity of the products formed. Thermally degraded materials that contain these elements are more likely to produce molecules that react with each other, reducing process efficiency and leading to the formation of large complex molecules (Butler, Devlin & McDonnell 2011). The resultant end products are usually lower quality and will require further refining using catalytic conversion and/or separation processes.

Pyrolysis is particularly useful for polyolefin recycling, as these plastics are not amenable to depolymerisation processing due to the unreactive nature of the polymer chains. Pyrolysis of polymers such as PE, PP, polybutylene (PB) and PS result in the formation of a range of basic hydrocarbon products that can be further processed into useful materials (Sharuddin et al. 2016). For polyolefins, there is some laboratory-scale research suggesting that pyrolysis processes could produce a feedstock very high in monomers and oligomers that could be used directly to synthesise more plastic material (Donaj et al. 2012). However, it is challenging to produce high yields of single monomer types due to the chemistry of the breakdown of the polymer chains, which is why most pyrolysis processes do not aim to produce these monomers as products (Vollmer et al. 2020).

While PVC plastics are useful for their fire-resistant properties and are found in many products such as cables, hoses and medical bags, they are particularly problematic for pyrolysis processes as they release hydrogen chloride gas, which is both hazardous to the environment and highly corrosive for equipment. The resulting pyrolysis liquid will also contain chlorinated materials, which prevents its use as a fuel or petrochemical feedstock (Ragaert et al. 2020). Pyrolysis can only be achieved once the PVC material goes through a dechlorination step, which adds additional cost to the process. Given the corrosive and toxic nature and low yields of the products, PVC is not considered a desirable polymer for pyrolysis, and only very low contamination levels (0.1–1%) of PVC can be tolerated in pyrolysis of mixed plastics before the outputs are impacted (Miskolczi, Bartha & Angyal 2009). Plasma pyrolysis is robust enough to process complex mixtures containing PVC and produce a syngas that is low in tar and has a high heating value (Solis & Silveira 2020). The technology is robust enough to process complex mixtures, including PVC. The high temperatures limit the formation of free chlorine gas from hydrogen chloride, thus reducing the formation of organochlorines and associated emissions.

As well as PVC, contamination of the plastic feedstock by PET also impacts pyrolysis due to the formation of organic acids, which are corrosive and possess high boiling/sublimation temperatures. The formation of organic acids can lead to equipment contamination and damage and the formation of low-quality oils with high viscosity, high acidity and low calorific values (Jia et al. 2020).

To produce outputs that are higher in quality, the pyrolysis system can include catalysts and/or hydrogen. The pyrolysis reactor system also has a large impact on the nature of the outputs and some common systems are discussed later.

Brightmark

Brightmark is a San Francisco, USA-based company founded in 2016, that develops, owns and operates waste to energy projects employing technology solutions including advanced plastic recycling (or plastic renewal). Brightmark is commissioning a plastics renewal facility in Ashley, Indiana, USA. It will divert 100,000 tonnes of plastic waste each year from landfills and incinerators, converting it into 18 million gallons of ultra-low sulfur diesel fuel and naphtha blend stocks and 6 million gallons of wax. Brightmark is also constructing a 400,000 tonnes per year facility in Macon, Georgia, USA.

Brightmark's plastic renewal facilities take co-mingled plastic waste in single stream, with the ability to renew all recyclable plastics classified as 1–7, including the difficult to recycle plastic types 3–7, especially the single use and multi-layer plastics that are commonly used in consumer packaging. Plastic waste is collected, prepped for conversion by shredding, removing metals, drying, and pelletising. Pellets are then extruded and fed into pyrolysis vessel(s) continuously, and once inside the vessel, the pelletised plastic material is then heated and vaporised in an oxygen starved environment. The vapor is captured, and cooled into a hydrocarbon liquid, which is refined into fuel products (ultra-low sulfur diesel) and paraffin wax. The naphtha and hydrocarbon liquid itself can serve as feedstock for virgin polymers.

PlastOil modular pyrolysis

PlastOil uses pyrolysis technology from Biofabrik (Germany) in their modular plastic processing WASTX system. The compact and fully automated system can convert up to one tonne of plastic per day. The system is designed to offer a decentralised option to plastic waste treatment and produce outputs that can be used locally. The oil produced can be used for combustion engines to generate energy or can potentially be fed into chemical production. The technology was developed in Germany and is currently being tested in locations around the world, including Melbourne.

The pyrolysis system converts plastics (HDPE, LDPE, PP and PS) into a high-quality oil that can be directly used in industry and the community. The system can tolerate small amounts of PET, paper and food contamination, but PVC must be removed. The WASTX Plastic technology modular system takes chopped dried plastic waste with a small amount of catalyst and compacts it using a tamping screw feed to compress the input material, remove air and preheat it. The temperature is then increased up to 500°C with nitrogen gas to break down the material into gas (12%), pyrolysis oil (85%) and carbon black (3%). The system can utilise the pyrolysis gas as a feed material for a generator that can provide up to 70% of the power required by the process.

In Australia, PlastOil is working with the University of Melbourne, RMIT and CSIRO in collaboration with Australian Paper Recovery to identify research needs that support scale up of this technology. Commercial arrangements are currently under discussion and will be unveiled in the coming months.

PlastOil's modular plastic recycling technology, the WASTX Plastic System.
Image credit: PlastOil

IQ Energy Australia

IQ Energy is developing a modular, scalable and containerised advanced recycling unit that will recycle dirty and mixed plastics back into a plastic-derived crude oil or gas that can be further refined into a variety of consumer or industrial products, including virgin plastics. The units are fully automated and containerised and this enables them to be decentralised and replicable so that they can be installed in a range of locations large or small, urban or regional, and regulated or less regulated waste management contexts (e.g. in some areas of South-East Asia).

The plant contains four modules: a thermal dryer, gasifer, thermolyser and pyrolyser. The modules come in two sizes that can be chosen depending on the volume of waste to be processed: 2,500 tonnes a year and 8,000 tonnes a year. The pyrolysis module can be used to convert all plastic types into oil and gas products. Modules can be added to increase the volume of waste that can be processed.

The technology can generate its own renewable energy by utilising the organic matter of feedstock to heat and power the pyrolysis process and consequently increase the yield of 'plastic molecules' available for recycling. The company has a focus on minimising its emissions to the environment. Problematic waste streams can be converted to useful materials, with air emissions such as nitrogen oxides, sulfur oxides and hydrogen chloride converted to salts and solids, which are captured and reused, and work is progressing on carbon dioxide capture. Manufacture of the first project for Canada is imminent with the intent of being operational by the end of 2021.

Catalytic cracking

Catalytic cracking in pyrolysis uses a suitable catalyst to lower the temperature and time required to complete the breakdown of the plastic polymer materials, which can make processing more economically viable (Panda, Singh & Mishra 2010). Catalysts can have many functions that will improve the stability and quality of the end products and process efficiency including hydrogenation of the alkenes, isomerisation of formation products, and removal of heteroatoms (e.g. oxygen, nitrogen and halogens). Catalysts can also reduce the degradation temperature of the polymers (Grause et al. 2011). The type of catalyst chosen will significantly influence the products formed during the process and can generate higher quality products with properties similar to diesel or petrol often with lower molecular weights compared with thermal pyrolysis (Sharuddin et al. 2016). These products are more acceptable to be used directly as fuels.

Catalytic pyrolysis of polyolefins (PE, PP) offers the best results during pyrolysis because the processes used are similar to those in the petrochemical industry. Catalysts are well developed as they are the same or similar to those used in the petrochemical refining sector (Butler, Devlin & McDonnell 2011).

The most common catalysts for pyrolysis are made from silica-alumina, zeolites, clays (montmorillonite, saponite), activated carbon, metal oxides and alkali and alkaline metal carbonates (Panda, Singh & Mishra 2010). Heterogenous catalysts are used most frequently for catalytic pyrolysis. Heterogenous catalysts are in a different phase to the reaction materials, usually in solid form, mixed with gas or liquid.

Poisoning of the catalyst is a significant problem for catalytic cracking. Carbonaceous deposits on heterogenous catalysts often require catalyst regeneration at high temperature (Butler, Devlin & McDonnell 2011). Inorganic materials, heteroatoms (nitrogen, oxygen) and halogens found in PET, nylon, PVC and other difficult polymers, can contaminate the catalyst leading to poor outcomes and high expense. If PET, nylon, PVC or other polymers are to be pyrolysed then the choice of catalyst is very important. PET needs a catalyst that acts to decarboxylate the ester group, releasing carbon dioxide and leaving hydrocarbon rich material (Panda, Singh & Mishra 2010).

Pyrolysis with inline catalytic reforming is often used to decompose unwanted products such as terephthalic acid from PET (Jia et al. 2020). The liquid or gaseous products from pyrolysis are passed over a catalyst bed and as such, the impurities in the plastic waste remain in the reactor, avoiding deactivation of the catalyst (Solis & Silveira 2020). This type of system generates high-quality hydrogen with lower costs than gasification (Lopez et al. 2017).

Hydrocracking

Hydrocracking (hydrogenation) is pyrolysis that uses hydrogen gas in the catalytic cracking process to produce high-quality hydrocarbons with very low levels of toxic by-products such as dioxins (Butler, Devlin & McDonnell 2011). It is usually a two-step process where the pyrolysis step produces an oil or gas that is then passed over a catalyst bed with hydrogen gas. Hydropyrolysis reactors use a fluidised bed reactor containing catalyst and hydrogen gas is fed into the same reactor (Vollmer et al. 2020).

Hydrocracking offers advantages where the output from pyrolysis is required to be a stable product that can be stored with low contamination. Hydrogen is added to the thermal degradation products of polyolefins, which are often unstable, to convert them to more saturated products, alkanes rather than alkenes (Butler, Devlin & McDonnell 2011). The addition of hydrogen reduces the amount of char produced in the pyrolysis system by reacting with the precursors of char formation (Vollmer et al. 2020). Hydrocracking deoxygenates the pyrolysis products so that the system can handle polyolefin material contaminated with some PET (oxygen containing). They also generate iso-paraffins, which are branched hydrocarbons that offer a higher quality fuel product more similar to what you would expect from a refinery fuel (Butler, Devlin & McDonnell 2011). Iso-paraffins are not suitable as input material for crackers that feed into HDPE or PP production as these polymers are straight chains. Disadvantages of hydrocracking are that it often happens at high pressures (70 atm) and can be expensive due to the cost of hydrogen and the equipment required. PVC contamination is a significant problem as its chlorinated by-products deactivate the catalysts used.

Pyrolysis reactor types

There are many different reactor types and these are summarised in Table 4, with an associated summary that compares reactor types and their operational features. Gasification technologies also use similar types of reactors to process waste plastic materials.

Extruders can be used as a pre-treatment that can feed into other reactors. Material passes through an externally heated screw/auger. This has the advantage of removing air and ensuring that the material is well heated and mixed.

Fixed bed reactors are the oldest type of pyrolyser. Reaction occurs in a steel vessel with a fixed bed of material where the products flow out as they heat up and expand and the char remains in the reactor.

Fluidised bed reactors offer excellent temperature control and have excellent heat and mass transfer and can be used with or without catalysts. A gas or liquid stream is used to fluidise the bed material which facilitates the heat and mass transfer and prevents the formation of hot spots. Catalysts can be added to the bed material or in a second reactor to react with the vapours produced. They use heat to vapourise the melt polymer feed while simultaneously cracking the hydrocarbons formed in a continuous system. Drawbacks include the added requirement of an inert fluidising gas, long residence times for mixing, lost bed materials and the necessity for catalyst to be topped up. In addition, scale up presents challenges, and it often provides low liquid yields due to over cracking (Panda, Singh & Mishra 2010).

Bubbling fluidised bed reactors have waste material fed into a bubbling bed of hot sand. The bed is fluidised using an inert gas to give intense mixing and ensure good temperature control and heat transfer.

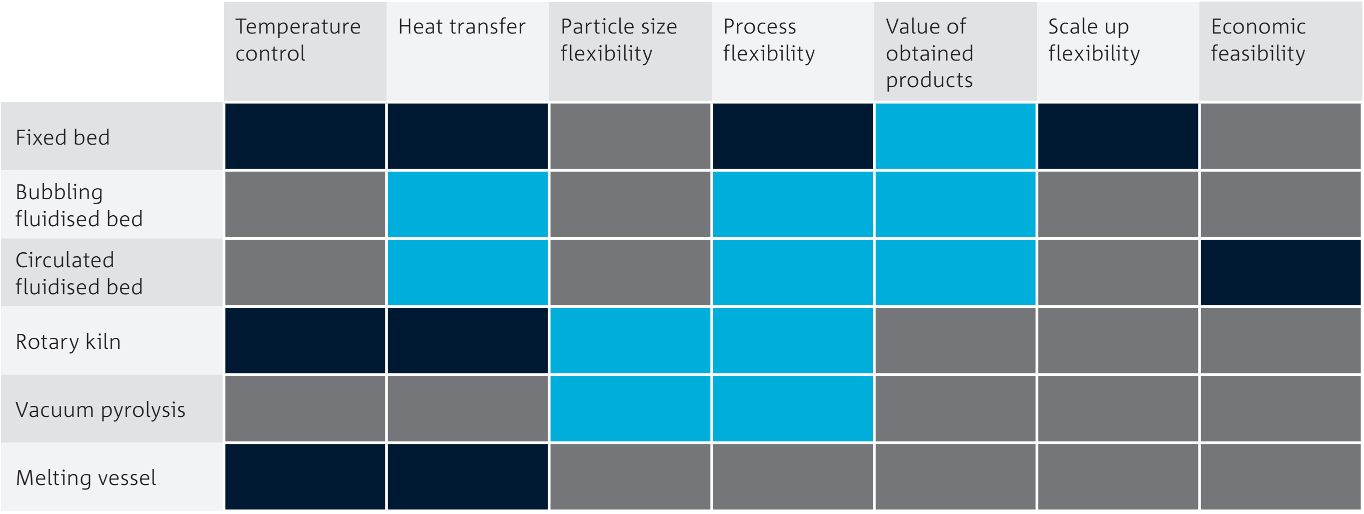
Circulated fluidised bed reactors work on the same principle as the bubbling fluidised bed, but the bed is highly expanded and solids continuously cycle around an external loop comprising a cyclone and loop seal. Temperature control is very good and solid products are easily removed.

Rotary kiln reactors have been used extensively to pyrolyse waste. The waste material is fed into a rotating vessel where ceramic or metal balls are used to mix the material to avoid char build-up. The heat is supplied via externally heated walls. Rapid heating and short residence time can be achieved. The scale is limited due to the difficulty in heat transfer as the diameter of the vessel increases.

Vacuum pyrolysis reactors pass waste material from top to bottom of the system on a series of heated plates that increase in temperature. Limitations of vacuum pyrolysis include regular fouling of the vacuum pump, challenges with heat transfer and low yields of liquids.

Melting vessels or stirred tank reactors are commonly used to produce chemicals but they have been used to pyrolyse plastic waste. They involve in situ heating by an oil or vapour and use of a catalyst. They suffer from poor heat transfer and require big infrastructure and frequent maintenance.

Table 4: Reactor comparison for pyrolysis of plastic waste



	Temperature control	Heat transfer	Particle size flexibility	Process flexibility	Value of obtained products	Scale up flexibility	Economic feasibility
Fixed bed	⬛	⬛	▩	⬛	🟦	⬛	▩
Bubbling fluidised bed	▩	🟦	▩	🟦	🟦	▩	▩
Circulated fluidised bed	▩	🟦	▩	🟦	🟦	▩	⬛
Rotary kiln	⬛	⬛	🟦	🟦	▩	▩	▩
Vacuum pyrolysis	▩	▩	🟦	🟦	▩	▩	▩
Melting vessel	⬛	⬛	▩	▩	▩	▩	▩

🟦 Good ▩ Satisfactory ⬛ Poor

Adapted from Qureshi et al. 2020

2.4.3 Hydrothermal processes

Hydrothermal processes are similar to pyrolysis technologies, but these processes operate with the addition of water and are more flexible regarding plastic feedstock compositions. Hydrothermal processes use hot compressed water as a reaction medium to convert complex organic compounds into smaller and simpler products (Qureshi et al. 2020). These conditions make the water a good solvent for dissolving organic compounds, although co-solvents and other materials such as biomass and catalysts are often added to improve the process. Most of the research into this process has centred on biomass biological inputs, but hydrothermal processing has been identified as a promising option for plastics recycling due to the ability to process mixed plastic wastes (Shen 2020). Contamination from glass, metal, grit and stones must be removed, but in contrast to other processes, the plastic wastes do not need to be dried before processing, which can improve process economics (Qureshi et al. 2020). Hydrothermal processing is suitable for complex mixed wastes and hard to recycle plastics, including contaminated PET, carbon fibre reinforced plastics, printed circuit boards, polycarbonate, styrene-butadiene, polylactic acid and nylon. It can also tolerate other organic materials such as paper and food wastes. Processing wastes in the presence of water also stops unwanted side reactions, leading to high yields of stable hydrocarbon liquids with low gas formation (Chen, Jin & Wang 2019). The water also dissolves unwanted side products such as hydrogen chloride and oxygen containing materials. However, the processes are quite energy intensive, and the main output is a complex synthetic oil that usually needs to be upgraded by standard refinery operations before it can feed into production of chemicals again.

Hydrothermal processing is particularly suitable for condensation polymers such as polyesters, polyethers, polycarbonates and polyamides that are also suitable for depolymerisation processes, due to their susceptibility to react with water under thermal and/or catalytic conditions (Pedersen, Thomas & Conti 2017). The recovery of monomers from polycarbonate and styrene-butadiene using hydrothermal processing, has been demonstrated at a laboratory scale (Pedersen, Thomas & Conti 2017). In addition, oil products that are very similar to naphtha and have excellent heating values (48–49 million joules per kilogram) have been recovered from PP using hydrothermal processing (Chen, Jin & Wang 2019).

Hydrothermal processing of PVC, particularly medical wastes, has been successful when a source of lignin is added. The lignin derived from materials such as woodchips prevents agglomeration of hydrochar and assists the dechlorination reaction (Shen et al. 2016). The end product of hydrothermal processing of PVC in the presence of lignin is predominantly hydrochar, with little chlorine contamination, and is therefore suitable for use as solid fuel.

The leading hydrothermal processing technology is the Licella Cat-HTR™ process (Licella Holdings, Australia), which has been demonstrated in pilot scale for processing mixed plastic wastes to recover a synthetic crude oil. This process is scaling up globally and will be adopted to process mixed plastic waste in the UK. Licella can add a distillation fractionation process to their recycled polymer oil (RPO), which will produce high-quality intermediate products (e.g. an ultra low-sulfur heavy oil and naphtha) and intermediate products with minimal contaminants (such as chlorine).

In summary, some of the key advantages of Licella technology are that it:

- has efficient heat transfer and operates at a comparatively low temperature, 450°C, which is associated with producing lower char than other processes
- accepts PET (which can clog pipes and contaminate products in pyrolysis processes)
- is tolerant of contamination (e.g. paper, cardboard) and is therefore good for processing multilayer plastics packaging
- can process thermoset plastics
- is tolerant of some chlorine (from PVC), which washes out with water as a salt.

Licella and CAT-HTR™ technology

Licella Holdings, an Australian-based company, has developed Cat-HTR™, a continuous flow catalytic hydrothermal liquefaction process. Licella uses supercritical water (high pressure and temperature) to break down a range of polymers into light hydrocarbon gases and a liquid product that resembles a high-quality, ultra-low sulfur synthetic 'Plasti-crude' that can be used to make new plastics, chemicals, fuels or road products in the same way as fossil crude. The process feedstock consists of mixed plastic waste including composite polymers, and multilayer, flexible and rigid plastics. The process is not impacted by the presence of contamination from non-plastic materials, such as paper and other organic matter.

Shredded plastic waste is heated and compressed, then combined with supercritical water and the temperature increased. In a separate reactor (the Cat-HTR™), the supercritical water acts to break down the bonds holding the polymers together to create useful short-chain, stable hydrocarbons. At the end of the process, during the depressurisation step, the Plasti-crude can be used as is and co-processed in existing refineries or separated into different outputs such as a naphtha fraction – for new plastics, fuels – diesel and fuel oil – and waxes and residue for use in chemical or road applications. These products can be stored and purchased for application in other industries. While the operating conditions of the technology can be modified to deliver varying output fractions, a general midpoint is a production of 85% liquid, 12% gas and 3% ash.

A number of different scale pilot plants in NSW have trialled and upscaled the technology over the past 13 years. In the UK the first licensee, ReNew ELP, in collaboration with Dow (polymer manufacturer), established the first commercial facility for this technology in Teesside, England. The facility is planned to process up to 80,000 tonnes of mixed end-of-life plastics.

Amcor, Coles, Nestlé and Licella are working with LyondellBasell and iQ Renew to assess the feasibility of a commercial-scale Cat-HTR™ plant in Victoria. It is planned that the plant will process a variety of end-of-life plastics and convert them to oil, which will be used to manufacture new soft packaging materials (ELP 2020).

2.4.4 Conversion technology outputs

The outputs (products) obtained from advanced recycling methods will depend on a number of factors, the most important being the method used, plastic inputs, process temperature, heating rate, catalyst use and other process additives (hydrogen, steam, water). Contamination of the input materials with PVC and plastics containing oxygen, nitrogen or other heteroatoms with affect the quality of all of the output materials.

Figure 6 shows some of the possible pathways for recycling mixed plastic waste by conversion processes. From left to right the diagram shows three different conversion technologies, each of which produce different outputs. These are termed ‘intermediate products’ as they generally all require further processing (shown in the next stage) before they become final products. The diagram uses purple arrows for products most likely to become fuels, and black arrows for intermediate products heading to a refinery pathway. There are multiple pathways and options, therefore this diagram is a simplification. For example, the syngas product arising from pyrolysis and hydrothermal processes may also include more hydrocarbon gases than is typical for syngas. Note also that syngas produced from gasification may also follow the same path as syngas from pyrolysis and hydrothermal technologies and go directly to a steam cracker to form monomers.

As shown in Figure 6, the main product from gasification of plastic wastes is syngas, and this can be recovered to make useful materials including hydrogen, methanol, ammonia, naptha (light oil) and waxes. It can also be combusted in a plastics-to-fuels pathway. The solid material produced from the processes, such as ash and char, may have useful applications but will most likely need to be upgraded before being a useful material.

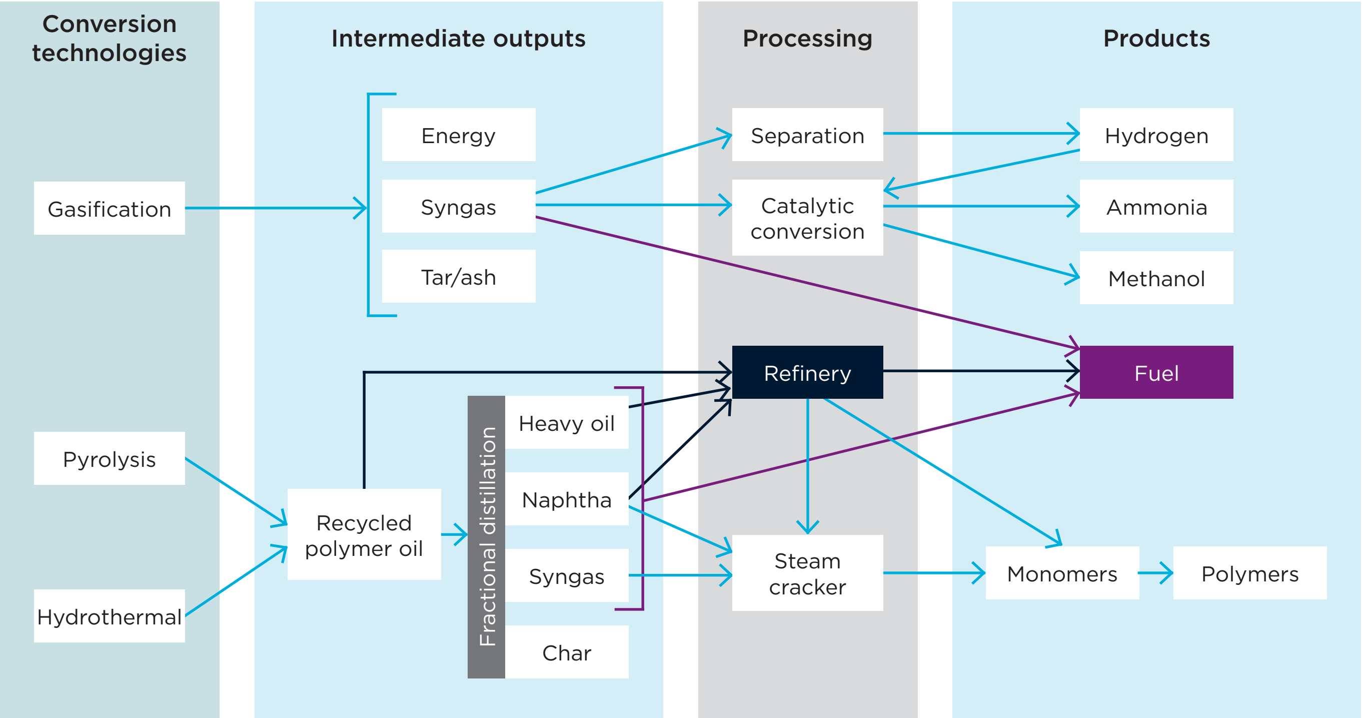


Figure 6: Outputs arising from conversion processes, showing additional processing options and downstream products

The products from pyrolysis and hydrothermal processing are similar, although their actual composition will vary greatly depending on operating conditions, reagents and input materials. The liquid hydrocarbon outputs generated by pyrolysis and hydrothermal conversion processes can be used as fuel, or as reagents to make new polymers. Refineries can incorporate crude naptha or heavy oil from advanced recycling with crude oil and process it to afford chemicals and fuels. Similarly, a steam cracker can take small molecular weight hydrocarbons and, using steam cracking technology, make monomers that can be used to manufacture new PE and PP, respectively. The steam cracker will work most efficiently with input materials that are high in straight chain hydrocarbons and less efficiently with high levels of aromatics and branched hydrocarbons.

Hydrothermal processing produces mainly solid and liquid materials, with more solid material produced at lower temperatures. Continuous hydrothermal processing produces a RPO (recycled polymer oil, sometimes also referred to as ‘plasti-crude’) that has a wide boiling range. This can be separated by fractional distillation into naphtha and oil fractions. The highest boiling fraction can be used in bitumen or processed by a refinery. The naptha is similar to a petrol fraction and has a number of possible pathways as shown in Figure 6.

Figure 7 gives an indication of the proportions of solid, liquid and gaseous products from gasification, high and low temperature pyrolysis, catalytic pyrolysis and hydrothermal processing of plastic wastes. Generally, low temperature pyrolysis without catalysts leads to formation of (comparatively) a large amount of solid char, a medium quantity of liquid products and a small amount of gaseous products. High temperature pyrolysis produces much less char, with a higher proportion of gases formed. When a catalyst is added to a pyrolysis system, catalytic pyrolysis, it significantly reduces the volume of char produced as there are fewer side reactions. The liquid product produced also increases as does the gaseous component due the more extensive breakdown of the materials. The hydrocarbons formed are more uniform in composition. In comparison, hydrothermal processing of plastic waste material produces low levels of gaseous products and solid char with excellent yields of stable RPO (liquid) produced.

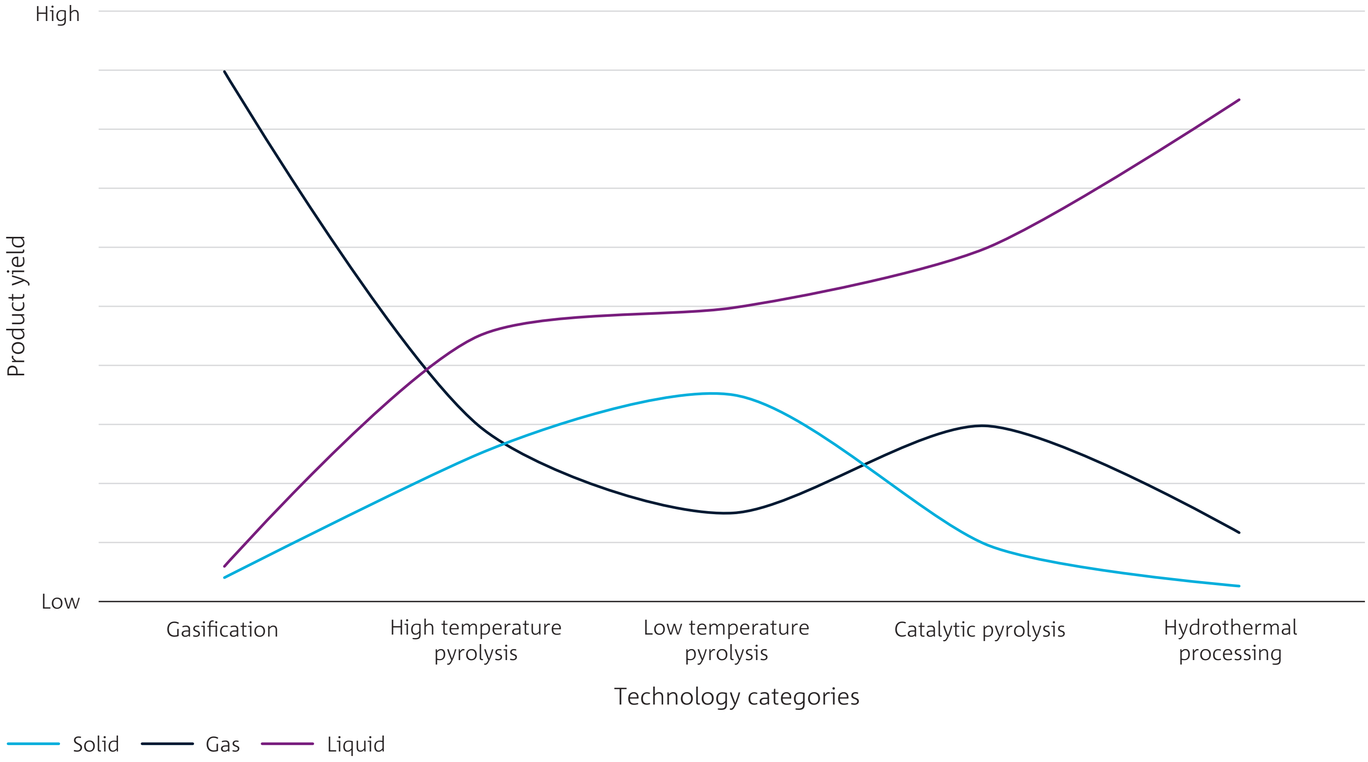


Figure 7: State and indicative yield from various advanced recycling methods

Advanced recycling technologies could generate new opportunities for Australia's manufacturing industry.
Image credit: Qenos

Syngas

Syngas (synthetic gas) is the gas produced from pyrolysis and gasification of carbonaceous material (natural gas, coal, biomass, organic wastes, plastic material). It is a mix of hydrogen, carbon monoxide, carbon dioxide and some short hydrocarbons (Goldberg, Haig & McKinlay 2019). Generally, the higher the temperature of the process the higher the proportion of gases produced. Gasification produces syngas as the major product. The syngas from pyrolysis will contain more light hydrocarbons than gasification and is usually a significantly smaller proportion of the outputs. Catalytic pyrolysis with reforming in its last stage can produce excellent quality syngas too (Solis & Silveira 2020).

Syngas is an important resource for the production of hydrogen, ammonia, methanol and synthetic fuels. Syngas is difficult to sell into the natural gas market as most companies will not want to risk degrading the quality of their product and as such needs further refining (TyreStewardship Australia, Sustainability Victoria & Department of the Environment and Science 2018). Syngas can be burned to provide heat energy to the pyrolysis system or to generate electricity in a gas turbine combined system (Erdogan 2020). The hydrocarbon portion of the syngas can also potentially feed into an olefins steam cracker to lead straight back to PE production. Eastman uses the resulting carbon monoxide and hydrogen from gasification of combined mixed plastics and coal to make acetyl-based products such as cellulose acetate (Tullo 2020).

Hydrogen

Hydrogen gas is produced predominantly from gasification of plastic wastes, although pyrolysis systems can be tailored to produce higher quantities. The hydrogen is separated from syngas using a selective membrane or pressure swing adsorption (Marcantonio et al. 2019). Hydrogen is an excellent energy carrier and its energy can be released as heat through combustion or as electricity using fuel cells. It is used in refining processes to hydrogenate hydrocarbons and increase the energy density of fuels or to produce specific chemicals. It is also used to make ammonia for fertiliser.

Methanol

Syngas from waste plastic gasification can be used to produce methanol. Syngas, hydrogen and carbon dioxide are reacted in a fixed bed tubular reactor at high temperature and pressure using a catalyst to produce methanol (Giuliano, Freda & Catizzone 2020). Methanol is a critical feedstock for the manufacture of other chemical products including formaldehyde, acetic acid and plastics, with approximately 100 million tonnes (~US$32 billion) produced globally each year (International Renewable Energy Agency & Methanol Institute 2021). The methanol-to-olefins process is used extensively to produce PE, particularly in China. Methanol is used directly as fuel for vehicles and boilers, and blended with gasoline. It is a convenient product to transport as it is a liquid and it is able to use infrastructure that other fuels use. It is currently largely produced from fossil fuels, and demand for it has increased substantially since the mid-2000s. The most of the world's methanol comes from syngas produced from the steam reforming of natural gas.

Char

Char is the solid residue left after the pyrolysis or hydrothermal processing of materials that are high in carbon. Char from plastic pyrolysis is often low or negative in value and will generally need to be further treated to form useful products. The quantity and quality of the char from plastic waste will depend on the input materials, and the process variables such as temperature, residence time, heating rate, reactor type and catalyst (Saptoadi, Rohmat & Sutoyo 2016). When heating rates are high, the liquid yield is higher, and the char yield decreases. The quantity of char produced during pyrolysis and gasification is generally low (1–3%) but can be as high as 20% if there are heat transfer challenges with the system (Miandad et al. 2016; Wyss et al. 2021). The char produced in hydrothermal processing is more variable. When polyolefins are the main input to hydrothermal processes, the solid yield is low.

The char will contain some carbon and complex hydrocarbons due to reactions between products and ash. When volatile hydrocarbons have a longer residence time in the reactor and they can repolymerise to form high molecular weight char. Often inorganic fillers are added to polymers to improve the moldability and stability of plastics, particularly in more rigid and complex materials. These inorganic materials will remain and become part of the recovered char/ash. If input materials are contaminated with dirt (likely from agricultural plastics), metals from foils and dyes, or other additives, these contaminants will also be present in the char.

Depending on the quality, the char can be briquetted and used for heating or to adsorb heavy metals and toxic gases in water or air filtration systems. Char can also be used as an additive to asphalt or as a colourant for plastic materials including tyres. A recent publication has shown that flash joule heating of pyrolysis ash from waste PP can produce excellent yields of high-quality turbostratic graphene in the laboratory (Wyss et al. 2021). When added, the turbostratic graphene improved the performance of cement and polymers.

If pyrolysis is efficient and the plastic input is low in contaminants, carbon black will be the main component of the char recovered. Carbon black has a value of approximately $900–$1,000 per tonne (Randell, Baker & O'Farrell 2020). Carbon black is mainly carbon in para-crystalline form that has a high surface area to volume ratio. It is widely used as a pigment in tyres, where it acts to increase thermal and abrasion resistance to extend their life. Carbon black is also used in other non-tyre rubber goods including as an additive to PP where it acts as an ultraviolet stabiliser.

Heavy and light oils, and waxes

The oil from the advanced recycling of plastic waste is often collected in two different boiling point ranges, with a heavy oil fraction (hydrocarbons with greater than 12 carbon atoms; comparable to diesel) recovered between 150 and 380°C and a lighter oil or naphtha (hydrocarbons with 4–12 carbon atoms; more comparable to gasoline or naphtha) recovered between 35 and 200°C (Vollmer et al. 2020). Heavy oil varies in composition depending on the process, conditions used and input material. It is often comparable in properties to a conventional diesel and can be used as an energy source for boilers and furnaces.

The oil from pyrolysis may contain chlorine, moisture, organic acids, sulfur and solid residues. Further purification will be necessary to produce a high-grade fuel if these are present. Where contamination is minor it can be blended with diesel fuel. The analysis of various blends from different pyrolysis oils has consistently shown positive results, with lower carbon dioxide emissions from the blends than diesel alone (Erdogan 2020). However, there was a general increase in nitrogen oxide and carbon monoxide emission with increasing plastic oil in blends.

Naphtha (light oil) is similar in properties and composition to petroleum fuel. Recovered naptha is often blended with crude oil and processed in a refinery or used directly as a fuel. Where the naptha has a higher proportion of smaller straight chain hydrocarbons it would be a useful input for an olefins steam cracking system. Octane numbers for the light oil fraction are generally lower than for conventional gasoline because of the large amounts of straight chain paraffins present. It is more beneficial to have branched paraffins and aromatics for combustion in vehicles (Ragaert, Delva & Van Geem 2017).

Waxes form a large part of the products of PE and PP recycled by low temperature thermal pyrolysis without a catalyst present (Arabiourrutia et al. 2012). They are also a product of hydrothermal processing. The waxes are typically high molecular weight hydrocarbons with boiling points in the range of 343 and 525°C, and these can be used to produce lubricants and coatings. To return it as a feedstock for plastic materials, waxes can be catalytically reformed and separated in the same manner as crude oil or fed back into the process to break them down into smaller molecules.

Undesirable by-products

A clear understanding of feedstock materials is required to monitor and mitigate environmental and human health risk from advanced recycling. All advanced recycling plants will have to consider how to capture gas and liquid emissions as both are potentially harmful to human health and the environment (TyreStewardship Australia, Sustainability Victoria & Department of the Environment and Science 2018). Some of the gases may be produced in the conversion process or when combusting the gases for energy include sulfur dioxide, nitrogen oxides, hydrogen sulfide, ammonia, dioxins and furans, hydrocarbon gases, carbon dioxide, carbon monoxide, formaldehyde and hydrogen cyanide as well as particulate matter (TyreStewardship Australia, Sustainability Victoria & Department of Environment and Science 2018).

Dioxins and other toxic heteroatom containing by-products (e.g. containing oxygen, nitrogen, sulfur) can be removed from oil products by hydrocracking after the pyrolysis step. If PVC is included in the recycling process, a pre-treatment step to remove the hydrochloric acid will be required and systems to manage the resultant acidic gas, including scrubbing with a basic chemical solution, will need to be installed. Although the hydrochloric acid captured by the scrubbing system can be recovered, it will be contaminated by some light hydrocarbons and is unlikely to be able to be reused. Scrubbing systems to remove hydrogen sulphide may also need to be considered.

Often systems are designed to use the gas produced in pyrolysis to power a generator to provide heat energy for the process, which will reduce gas emissions. If not consumed in the process, to control air pollution, a thermal oxidiser (after burner) can be used to decompose gaseous air pollutants through chemical oxidation. Gasification and pyrolysis produce less direct air emissions and residues than incineration (Demetrious & Crossin 2019).

The char can be contaminated with inorganic materials, ash, aluminium from foil and possibly heavy metals from dyes and glues used in plastic products (Goldberg, Haig & McKinlay 2019). To mitigate the contamination the system can preferentially use plastic materials that are rich in soft plastics and transparent polyolefins that are low in these materials. Float sink techniques can be used to separate char and ash but the char may need to be disposed of in landfill.

If the naptha or heavy oil are to be used as fuels there are limits for certain contaminants. The regulations are far more restrictive for gasoline than for diesel. Polyaromatic hydrocarbons are a common side product from pyrolysis reactions. These are required to be less than 8% of diesel fuel in Europe, and while usually lower proportions are formed during pyrolysis this will need to be monitored (Gala et al. 2020). There are also limits on moisture and benzene (<1%) and the acidic components that may come from PET.

2.5 Waste-to-energy

Incineration and thermal technologies that produce energy as their primary product are common in Europe. Annually, waste-to-energy plants in Europe contribute 39 terawatt hours and 90 terawatt hours of electricity and heat, respectively, and are estimated to prevent about 50 million tonnes of carbon dioxide emissions that would otherwise be generated by fossil fuel production (Levaggi et al. 2020).

Waste-to-energy is considered a recovery process, and as such falls second to last on the waste hierarchy (recover) before disposal (landfill). Waste-to-energy technologies are not considered as truly circular, given that they follow a linear path, resulting in the downgrading and/or permanent loss of materials from the economy. However, it is argued that in creating energy and fuel by-products, waste-to-energy may contribute to circularity through production of new materials. There are substantial environmental and economic burdens, with waste-to-energy processes producing significant environmental emissions and chemical wastes. Waste-to-energy processes are energy intensive, with high capital and operating costs. Incineration of plastic materials generates substantially less energy then the energy conserved by recycling (Rahimi & Garciá 2017).

Waste-to-energy processes accept gross MSW (municipal solid waste) diverted from landfill, of which plastic waste can be a subset component. The presence of plastic waste in the input feed of waste-to-energy processes can be useful, due to their high calorific value, which allows the processes to operate with a stable calorific intake and maintain process efficiency. However, these processes are generally unable to process single waste streams. As such they are a solution for highly mixed and low-quality waste streams that cannot otherwise be upgraded or recycled, and for wastes that are not suitable for mechanical or advanced recycling.

In late 2020, it was reported that the Australian Renewable Energy Agency (ARENA) invested $98 million in 25 waste-to-energy projects across Australia (Parliament of Australia 2020). Australia's first large-scale thermal waste-to-energy plant is under construction in Kwinana, WA (Avertas Energy), with completion due late 2021. The facility is proposed to divert 25% of Perth's post-recycling waste from landfill and to generate 36 million watts of baseload electricity for the grid (ARENA 2020a). A second thermal waste-to-energy plant has been approved in WA (Acciona and Hitachi Zosen Inova), which will increase the WA waste-to-energy capacity further, diverting another 300,000 tonnes of MSW from landfill, and generating 29 million watts of power (ARENA 2020b, 2020a). There are other projects in the pipeline for other states such as QLD (ARENA 2020a).

Though waste-to-energy processes have a role to play in the recovery of energy, fuels and other value adding by-products, it is largely accepted by the Australian federal and state governments that waste-to-energy processes should complement other material recovery and recycling processes, with the goal of more broadly improving waste management outcomes in Australia (Parliament of Australia 2020). As such, WA, Victoria, NSW, SA and QLD all have policies and position statements addressing the use and targets associated with waste treatment by waste-to-energy processes, and there are moves to harmonise these policies across jurisdictions. In 2020, the Victorian Government announced that it would cap waste-to-energy for 1 million tonnes of MSW per year to 2040, with significant investment made for innovations in waste management that complement energy recovery processes (DELWP 2020).

Gasification technologies can be used to produce useful products that can be converted into new chemical products or used as waste-to-energy processes. Gasification technologies can be used to process waste plastics exclusively, or are more commonly applied to MSW (containing waste plastic) as waste-to-energy technology. Seven Thermoselect gasification plants have been operating in Japan since the mid-2000s processing unsorted MSW at throughputs of up to 100,000 tonnes a year (Yamada, Shimizu & Miyoshi 2004). Many gasification systems worldwide are now moving towards the production of useful products, including hydrogen, rather than just energy generation.

3 Plastic waste supply for advanced recycling

Advanced recycling technologies require a plastic waste supply. The quality of outputs depends on the polymer type or plastic waste being processed, along with technology type and operating conditions. Advanced recycling in Australia requires a clear understanding of the production, consumption and generation of plastic wastes, and the suitability of these wastes for the conversion processes of pyrolysis and depolymerisation.

This section commences with a description of the types of polymers available and their suitability for different technology options. It next describes the segments of the plastic waste market (e.g. mixed plastics, soft/flexible plastics) that may be more suitable for advanced recycling. Advanced recycling is ideal for plastics that do not already have a mechanical recycling pathway. In this sense, it is highly complementary, and not competitive, with mechanical recycling. Plastics that are difficult to mechanically recycle include plastics degraded by environmental conditions, thermoset plastics and plastics with high levels of additives. Also, mixed plastics, laminate materials, and dirty or contaminated plastics are difficult to mechanically recycle. In general, plastics degrade over time and by exposure to heat, light and chemicals. Plastics also contain fillers, such as calcium carbonate, silica, carbon black or metal oxides (for colour). These minerals are insoluble and create issues for mechanical recycling.

3.1 PET (Polyethylene terephthalate)

PET is one of the most widely used plastics for packaging due to its intrinsic properties, colourlessness, heat and cold stability, and durability. PET is a condensation polymer that contains oxygen. It is widely used in packaging foods and beverages, especially soft drinks and juices. PET is also used in clothing, films and moulded parts for automotive and electronic applications. To produce a high-quality mechanically recycled output the plastic needs to be sorted by colour and graded. Often PET bottles are recycled into lower grade thermoforms or fibre (downcycling) because it is challenging to maintain the physical properties and avoid discolouration in mechanical recycling.

PET has existing mechanical recycling pathways in Australia and clean collection systems such as container deposit schemes. The value for clean PET bales has ranged from \$400 a tonne (2019) to \$230 a tonne (2020) on the local and export market. This compares to a value of virgin PET resin of around \$1,400 a tonne (Envisage Works 2020).

PET can be a problematic feedstock for pyrolysis as it decomposes to phthalic acids, which deteriorate the quality of the oil produced and can lead to clogging of the pipes in the system (Qureshi et al. 2020). PET pyrolysis oil contains benzoic acid, which results in lower calorific value of the oil (30 million joules per kilogram), making it a less desirable polymer type (Sharuddin et al. 2016). The use of catalysts and hydrocracking can improve the quality of the products obtained from PET, but it would be best if the system was designed around PET waste material. The products formed would be largely gaseous in a successful pyrolysis system for PET due to the conditions needed to minimise the deleterious products (Sharuddin et al. 2016).

Hydrothermal processing would be an excellent option for conversion of PET to hydrocarbon products, particularly with mixed waste systems. In a typical hydrothermal system, the water acts as a hydrogen donor and increases the amount of hydrogen in the product while also reducing the oxygen content. The oxygen in PET is able to be reduced in hydrothermal systems (Seshasayee & Savage 2020).

The most desirable chemical recycling option for PET is depolymerisation as it requires less energy and returns PET to its monomers. This can be achieved with biological degradation using PETase technology to depolymerise the PET back to monomers for manufacture back into PET. PET is readily converted back into its monomers or similar building blocks for other chemicals by chemical depolymerisation reactions (Closed Loop Partners 2019). The most advanced depolymerisation recycling processes have been developed for PET because the market is predominantly in food packaging, which has stringent quality requirements (Goldberg, Haig & McKinlay 2019). A number of commercial plants currently use these technologies to provide feedstocks for the production of new PET.

3.2 HDPE (High-density polyethylene)

HDPE forms a large part of municipal plastic wastes. It has high strength and is used widely in detergent bottles, oil containers, toys and many more products. HDPE is a polyolefin with long straight chains with very little branching and is well suited to conversion technologies. The price for washed and flaked HDPE has fluctuated from $400 to $650 a tonne. The price for virgin resin is around $1,400 a tonne, as at October 2020 (Envisage Works 2020). Mechanical recycling pathways are possible for PE products, which generally involve downcycling to materials that are not food contact compliant (laundry detergent bottles, pipes, benches, etc.). In Europe, technology has been developed to take waste rigid HDPE (milk bottles) and mechanically recycle it into new food contact compliant materials with two plants currently supplying the dairy industry in the UK (Goldberg, Haig & McKinlay 2019). Currently the best way to make recycled material from HDPE food contact compliant (US Food and Drug Administration approved) is via advanced recycling.

The pyrolysis of HDPE has been studied extensively and it produces excellent oils when pyrolysed at reasonably high temperatures (550°C). Catalysts are preferred in the pyrolysis as they lower the temperature required and produce liquid materials that are easy to handle. As the temperature increases above 550°C then the proportion of gaseous products increases steadily. Fuels obtained from pyrolysis of HDPE tend have good calorific values (42.9 million joules per kilogram) comparable to gasoline (43–46 million joules per kilogram) and are generally suitable to be used without much upgrading (Kumar & Singh 2011). HDPE is also well suited to gasification as it produces relatively clean gaseous products with low tar production. Hydrothermal processing will also effectively convert waste HDPE into oils.

3.3 PVC (Polyvinyl chloride)

PVC is widely used in the construction industry as it is inexpensive, rigid and durable with high environmental resistance. However, due to the chloride in its polymeric structure, recycling at high temperature results in the release of free hydrogen chloride gas, which is corrosive to plant and contaminates the end products (Rahimi & Garciá 2017). In addition, PVC often contains plasticisers, fillers and dyes, which make it a difficult waste to recycle due to technical limitations (contamination) and environmental restrictions (emissions). In 2018–19, PVC formed 11% of plastic consumed in Australia (O’Farrell 2019). The extensive use of PVC in the community causes issues with the contamination of plastic streams that are co-collected for recycling, especially if the recycling process is based on thermal conversion. For these processes, the tolerance to PVC contamination is very low (0.1–1%) (Miskolczi, Bartha & Angyal 2009). Even PET mechanical recycling tolerates less than 50 parts per million PVC as the acids formed during extrusion cause the rPET to be brittle and yellowish (ASG 2021).

There is a need for conversion technologies to pre-sort their mixed plastic input to ensure there are very low levels of PVC. Waste reprocessors are concerned that PVC packaging is a continuing issue in recycling streams as it causes problems in both rigid and flexible packaging recycling (O’Farrell 2019). PVC packaging has been banned in Canada, Spain, South Korea and the Czech Republic, with other countries limiting its use (Center for Health 2021). Australia will phase out PVC packaging labels by December 2022 (Pickin et al. 2020). It is well known that chlorinated compounds, including PVC, are harmful and undesired in recycling systems, as they cause corrosion and poison catalysts. A pyrolysis study conducted with PE, PP and PS with 0–3.0% PVC examined the effects of increasing concentration of PVC (Miskolczi, Bartha & Angyal 2009). They found that chlorine was found in all products and levels increased with the amount of PVC pyrolysed.

Given the challenges with thermal processing of waste PVC, mechanical recycling is a good option. However, due to the high level of additives and contaminants care should be taken to sort it and process it with only like materials, so as not to contaminate secondary products. In addition, purification can be used to recycle PVC as it is soluble in certain solvents, although it is technically challenging to separate out the plasticising agents and this makes reuse difficult. VinyLoop®, a PVC waste recycling purification plant in Italy, used butanol as a solvent and steam as an anti-solvent to recycle PVC from flexible cables to produce rPVC that would be suitable for the same use (Plasteurope 2018).

3.4 LDPE (Low-density polyethylene)

Like HDPE, LDPE is made from ethylene but with more branched molecules, which reduces the density of the plastic. In comparison, LLDPE is a substantially linear polymer that has frequent short branches. LDPE and LLDPE are used in rigid containers including bottles, containers and lids and as flexible materials such as films, plastic wrap, pouches, bags and cable covering. Australia uses around 400,000 tonnes a year of LDPE and LLDPE plastics and around 17% of this is recovered (O'Farrell 2019).

LDPE/LLDPE are suitable for mechanical recycling and the material can be processed many times without noticeable loss in properties (Rahimi & Garciá 2017). However, it is often used in laminate materials, where it is difficult to separate from other materials via mechanical recycling. Solvent-based purification technologies are available for LDPE/LLDPE (Vollmer et al. 2020). LDPE behaves in much the same way as HDPE when it is treated using advanced recycling methods, affording high-quality hydrocarbon liquids (see Section 3.2).

3.5 PP (Polypropylene)

Polypropylene (PP) is a versatile polymer, with a high melting point and high durability, and is resistant to acids and bases. It is used in robust products from car bumpers, rigid food packaging, polymer bank notes and face masks. Australian consumption of PP is around 500,000 tonnes a year, of which around 45,000 tonnes a year is recovered for recycling here or internationally (O'Farrell 2019). Municipal PP will often end up in mixed plastic bales when sorted in Australian materials recycling facilities (MRFs).

PP is suitable for mechanical recycling as it is a thermoplastic polymer. It is often coloured and has additives incorporated to enhance its properties like other plastics, which makes thorough separation important before recycling.

As with other polyolefins, PP is readily converted to hydrocarbon materials by conversion technologies, although it often contains more fillers and as such more ash will result when it is pyrolysed or gasified (Sharuddin et al. 2016). Purification is an excellent option for PP to remove dyes and additives and return excellent raw material using supercritical butane (PureCycle 2021).

3.6 PS (Polystyrene)

While PS and EPS (expanded polystyrene) are used less in Australia than other plastic materials, their use is increasing. In 2018–19, 77,000 tonnes a year of PS was consumed in Australia with a very low recovery rate of 11.6% (O'Farrell 2019), and there are not current markets for recycling of rigid polystyrene (APCO 2020).

EPS is lightweight, durable and an insulator and used extensively for protecting fragile items in transport and for extending the shelf life of fruit, vegetables and seafood. The collection of expanded polystyrene is challenging as it is not collected in kerbside bins due to its likelihood to break up into many pieces. Its large volume means that it takes up considerable space and while it can be collected at transfer stations it often ends up in landfill. While there are challenges with collection of polystyrene it is possible to use a variety of advanced recycling methods to recycle it.

PS and EPS are excellent candidates for purification technologies in all its forms due to their high solubility in a range of solvents. An excellent solvent for PS is cymene, a natural terpene-based solvent, which has been successfully used to dissolve PS. In Canada, collection stations immerse expanded polystyrene straight into cymene to dissolve it on site, substantially concentrating its volume and making transport significantly easier (Polystyvet 2020).

PS offers greater flexibility than other polyolefins in its conversion as it can be pyrolysed in controlled conditions to produce monomers (Crippa et al. 2019a). PS degrades at the lowest temperature of all plastics, and when a pure stream of PS is pyrolysed the monomers toluene, ethylbenzene and styrene are produced (Muhammad, Onwudili & Williams 2015). It is suitable for pyrolysis with other plastics and will increase the proportion of aromatic hydrocarbons in the recovered oils, increasing their suitability as fuels.

3.7 Mixed municipal plastics

After kerbside collection, municipal waste is sorted and separated out into materials including paper, steel, aluminium, cardboard, glass and plastic at a MRF. The plastic waste stream is then further sorted to recover PET and HDPE and a residual fraction, which is known as mixed municipal plastics. The mixed municipal plastic waste fraction usually contains code 3–7 plastics (Table 2), with residual quantities of PET and HDPE (Envisage Works 2020). Mixed municipal plastic waste that was recovered at MRFs was baled and exported overseas for treatment.

In 2018–19, Australia exported almost 150,000 tonnes of mixed plastics, which comprised 80% of the value of all waste plastics exports ($43 million) (DEE 2019). However, the China National Sword Policy, and the newly established Australian ban on the export of mixed plastic waste (commenced 1 July 2021) is driving a shift for Australia to recycle and recover our own wastes. Concurrently, the establishment of the Recycling Modernisation Fund (RMF) has the goal of developing new recycling infrastructure to increase local recycling and waste treatment capacity (Table 5). The RMF funding is provided to state and territory governments, who are primarily responsible for managing the collection and disposal of waste in Australia.

The National Waste and Recycling Industry Council reports that there is a 80,000–90,000 tonne shortfall in Australia's ability to locally process mixed plastic waste that is now diverted from export pathways (Read 2021). Despite there being established recycling pathways for some plastic waste streams via mechanical recycling in Australia, baled mixed plastic wastes are not always suitable for mechanical recycling due to the presence of polymer mixtures and other contamination. While mixed waste exports decreased by around 50% in 2019–20, advanced recycling can offer a pathway for the recovery of value from mixed plastic waste and contribute to achieving resource recovery targets set by the Australian Government.

Table 5: Exported mixed plastics compared to RMF infrastructure investment

JURISDICTION	MIXED PLASTICS EXPORTS 2018–19 (TONNES)	RMF PROJECTS PROCESSING CAPACITY (AS AT 31 MARCH 2021) (TONNES)
NSW	68,878	16,000 (Suez) + grant process underway
Victoria	58,500	20,000 (Cleanaway)
WA	11,897	35,000 (3 projects)
QLD	8,131	Nil
SA	2,041	Grant process underway
ACT	1,771	1,800 (MRF upgrade)
Tasmania	170	Grant process underway
NT	20	Nil
Total	**149,695**	**61,800**

Source: COAG 2020 and Read 2021

Mixed plastic wastes are more complicated to process by advanced recycling methods than pure streams of plastics. For efficient processing by advanced recycling it is likely that mixed plastic wastes would need sorting and cleaning to remove contaminants such as organics, PVC, textiles or residual metals. The addition of pre-sorting processes will increase the costs of production of raw materials and appropriate techno-economic assessments would be required to quantify the viability of processing mixed plastic wastes via advanced recycling. Mixed wastes cannot be processed using depolymerisation or purification technologies due to their different compositions and solubilities.

For recycling plastic mixtures, it is important to consider the plastic inputs into the advanced recycling system as each plastic has optimum degradation temperatures and conditions (Grause et al. 2011). There are complex interactions between products formed and this is increased when more complex mixtures are used as inputs. The most suitable technologies for mixed plastic waste are gasification, catalytic pyrolysis and hydrothermal processing (Solis & Silveira 2020). For all technology used for recycling of mixed plastic wastes, a clear understanding of the composition of the input materials is required to ensure process optimisation and efficiency, and to determine the quality of end products.

Gasification is generally less sensitive to PVC and PET contamination that may occur in mixed plastic waste inputs. However, the tar generated by processing mixed plastic wastes would be more complex, and pathways for recovery and reuse of these residuals may be more complicated (Ragaert, Delva & Van Geem 2017). As with the processing of pure plastic waste streams, the formation products are mainly gaseous (hydrogen gas, carbon dioxide and small hydrocarbons), and these can be separated by conventional technologies developed for existing gasification technologies.

In contrast to gasification, pyrolysis of mixed plastic wastes is more challenging. When working with mixtures, it is necessary to operate at temperatures higher than that of the highest melting plastic, which is more energy intensive when compared to processing single stream wastes. Although, higher liquid material recovery is achieved when using higher temperatures; this can lead to side reactions that may increase the char produced (Ragaert, Delva & Van Geem 2017; Solis & Silveira 2020). Pyrolysis systems for mixed plastic waste work best with combinations of polyolefins (PE, PP) and PS and generally tolerate only low levels of contamination from PVC, PET and other oxygen and nitrogen containing polymers. The input material also needs to be dry before it can be processed, which adds an energy cost. The addition of a catalyst during the process or as a separate cracking step can help the system to produce useful materials. A hydrocracking system where hydrogen is added can also manage oxygen and nitrogen containing plastic contamination (e.g. nylon, PET).

Hydrothermal processing does not require a drying step and can deal with low levels of contamination from PVC, rigid plastics, laminates and organic material. As such, it is the most flexible and tolerant technology for accepting mixed plastic wastes. When processing mixed plastic wastes, hydrothermal processing produces stable liquid hydrocarbons that can be stored and transported. Hydrothermal processing can also process MSW in conjunction with plastic waste.

3.8 Plastic packaging

Plastic packaging offers one of the best targets for advanced recycling, once pure polymer streams more suited to mechanical recycling have been removed. This is partly due to the national targets for recovery, particularly 70% recycled or composted by 2025, and that packaging currently has the greatest recovery rates compared to other application areas (O'Farrell 2019). Table 6 shows the 2018–19 plastic packaging consumption and recovery data (O'Farrell 2019). Based on the national target of achieving an average of 70% of packaging recycled by 2025, this shows an estimated increase of 474,240 tonnes of plastic packaging for Australia's recycling system (assuming all packaging is single use). A very small proportion might be met by organic recycling (composting) and some of this increase can be met by mechanical recycling. The implementation of new container deposit schemes in Victoria and Tasmania are important for securing pure polymer streams for those states. However, not all of the increased recovery will be suitable for mechanical recycling. This is where advanced recycling to a purified polymer, monomer or basic chemicals may be preferable.

Table 6: Tonnes of plastic packaging including consumption and recovery in 2018–19 and recycling targets to 2025

	PLASTICS RECYCLING DATA 2018–19		NATIONAL TARGET
Plastic packaging	Consumption	Recovery	By 2025 (70%)
Consumer	895,500	228,600	626,850
Commercial and industrial	183,800	52,600	128,590
Total	**1,079,300**	**281,200 (26%)**	**755,440 (70%)**
Increased recovery to 2025			474,240

3.9 Soft/flexible plastics

The term 'soft plastics', also known as flexible plastics, generally refers to plastics that can be scrunched into a ball and includes a range of polymer types, such as LDPE, LLDPE, HDPE and PP (APCO 2019). Soft plastics often contain multilayer, laminated materials, which make mechanical recycling challenging. The amount of soft plastics consumed and waste generated in Australia is difficult to calculate, but is estimated to be approximately 300,000 tonnes per year (APCO 2019). Soft plastics are used extensively and in many industry sectors, and have a number of collection systems in place in Australia (Table 7).

Soft plastics are frequently added to municipal recycling bins and cause problems with contamination at MRFs. The soft plastics mimic paper and become tangled in the equipment. The presence of soft plastics often means that large proportions of collected kerbside recycling end up being dumped in landfill.

Table 7 provides a summary of soft plastics consumed by industry sector, including polymer types available and current collection systems.

Current mechanical recycling of soft plastics in Australia typically involves the production of material and products for civil infrastructure (e.g. railway sleepers, highway sound barriers, bollards and park seating), road base and outdoor furniture. These reuse markets have the ability to grow but will not cope with the increased collection of soft plastic wastes, and as a result, other resource recovery processes need to be considered. Advanced recycling is the only option for recycling these plastics for reuse, and it generates output materials that are food contact compliant.

Recently, the consortium of Licella, Coles, Nestlé, LyondellBasell, VIVA Energy Australia, Taghleef Industries, REDcycle, iQ Renew and Amcor demonstrated the use of waste soft plastics to make a new candy bar wrapper (AM News 2021). They are currently conducting a feasibility study on the construction of a plant in Victoria that would be capable of producing 17,000 tonnes of soft plastic each year (Powell 2021). The use of feedstock could help brand owners source local content recycled packaging to meet the national packaging targets, which requires the industry to use 50% recycled content in packaging by 2025.

Table 7: Types of soft plastics by industry sector and collection systems

INDUSTRY SECTOR	PRODUCT DESCRIPTION	POLYMER TYPES	COLLECTION SYSTEM(S)
Municipal/ household	Mixed film packaging including retail bags, produce bags, consumer bags – pouches and film. Moderate contamination from glass, hard plastics, aluminium cans and residual food waste.	LDPE, HDPE, mixed other, PVC, PET, PP	Council trials of 'bag in a bag' collection of soft plastics; Melbourne and Central Coast councils have reported low contamination rates from trials. REDcycle drop-off points at retailers (grocery stores).
Commercial	Mixed film including shrink wrap, courier packs, food packaging and retail bags. Low contamination from hard plastics, paper.	LLDPE, HDPE, mixed other	Individual arrangements with contractors.
Industrial	Packaging offcuts, redundant packaging, plastic bags, bulk bags. High contamination with product residue, cardboard, gloves, general waste.	LDPE, PP, HDPE, mixed other	Collection and processing (e.g. Plastic Forests).
Agricultural	Bale wrap, grain bags, mulch film, baling twine. Can be highly contaminated with soil and residues.	LLDPE, LDPE, mixed other (e.g. woven PP, PVC)	Dairy Australia has a product stewardship grant to develop a regional and possibly national collection of silage wrap. The Plasback scheme operates in NZ (used to be in AUS). Plastic Forests accepts some agricultural wastes. Some councils have drop-off services (cost or free).

Adapted from: APCO 2019

3.10 Tyres

Australia produced 56 million waste tyres (465,000 tonnes) in 2018–19 (TyreStewardship Australia, Sustainability Victoria & Department of Environment and Science 2018; Randell, Baker & O'Farrell 2020). As there are no tyre manufacturers in Australia, there are no current product stewardship or take back schemes in place for tyres, and waste tyres are usually sent to landfill (licensed and unlicensed), stockpiled or illegally dumped (Schandl et al. 2021). There are a number of markets for products produced through the mechanical recycling of waste tyres including road surfacing, playground surfacing and explosives. However, these reuse activities do not deal with the total volume of waste tyres produced, and additional recycling processes are required to promote the recovery of resources from these materials.

Tyres are predominantly composed of steel wire, synthetic rubber (styrene-butadiene), natural rubber, carbon black, silica, nylon and polyester (Randell, Baker & O'Farrell 2020). Tyres are good candidate input materials for pyrolysis and gasification (Schandl et al. 2021) because they break down at relatively low temperatures and produce usable outputs. Although gasification and co-gasification of tyres with biomass have been extensively studied, there are few commercial-scale tyre gasification plants globally (Oboirien & North 2017).

When recycled by pyrolysis the tyres are first shredded and the metals are recovered. Typically, pyrolysis of tyres produces char (30%), steel (15%), oil (45%) and syngas (10%). The char is refined into carbon black. The oil can be used as a fuel for furnaces and the like but would need to be upgraded for use in vehicles. The syngas is best used as fuel for electricity generation on site.

There are a few tyre pyrolysis plants in operation in Australia and most are pilot or demonstration scale (TyreStewardship Australia, Sustainability Victoria & Department of Environment and Science 2018). The only plant that processes significant quantities of tyres is located in Queensland, Pearl Global, and processes 16,000 tonnes a year. BASF (Germany) uses its ChemCycling™ technology to co-pyrolyse end-of-life tyres with plastic waste to provide a naphtha feedstock for their steam cracker, the products of which they use to make a number of polymers (Sphera Solutions 2020).

Another pathway for recycling of waste tyres is devulcanisation, which converts them back to a material with similar properties to those of virgin rubber. Devulcanisation breaks the carbon–sulfur bonds that cross link the polymer, but it is not yet an economical process (Shulman 2019).

The challenges for pyrolysis in Australia include the high cost of plant, distributed input material, lack of consolidated markets to support economies of scale, limited successful plants to base the process on, distance from supply and end-markets, and a lack of extended producer responsibility. Plants have been successful in Europe where extended producer responsibility has underpinned the business case for construction of commercially viable plants and they have stable supplies and end-markets for the outputs (TyreStewardship Australia, Sustainability Victoria & Department of Environment and Science 2018).

3.11 Marine or plastic litter collections

There is potential for using marine debris or plastic litter collected from regionally isolated areas in advanced recycling technologies. The high cost of transportation of recyclable plastics often makes it uneconomic for remote communities to transport their waste or collect marine plastic debris, which leads to incineration or landfill options. Volumes and composition will vary significantly across locations. The important factors for successful advanced recycling technology for marine plastics or litter is robustness to contamination, modularity, ease of operation and ability to produce materials that can be used locally. The primary output is likely to be fuel for generators or boilers.

This waste stream will be composed of a wide range of plastics that will be degraded due to environmental factors including light and heat and will be unsuitable for mechanical recycling. While pyrolysis would be an option for these waste plastics, one of the main problems for processing would be separation of contamination from soil, salt, unsuitable plastics (PVC and PET), paper, glass and wood. Gasification processes operate at high temperatures, typically over 700°C, and are usually relatively large pieces of equipment that operate continuously. Gasification is not likely to be a suitable advanced recycling process for remote use. Hydrothermal processing is the least sensitive to contamination and would most likely offer the best solution in remote locations.

3.12 Thermoset plastics

Thermoset plastics are materials that have been irreversibly crosslinked to form a permanent solid material during their manufacture. Thermoset plastics are scratch resistant, and do not melt, deform or lose shape when heated or in extreme cold. Due to these excellent properties thermoset plastics form a large proportion of engineering and automotive plastics. Some examples of thermoset plastics and their uses include epoxy resins (carbon fibre reinforced products), silicone (adhesive, cooking utensils), phenolic resins (Bakelite), polybenzoxazine (coatings for circuit boards), vinyl esters (car parts) and polyurethanes (moulded furniture). Their properties are often enhanced by the addition of inorganic materials and fillers such as carbon or glass fibre and calcium carbonate. As thermosets are often used for engineering and electronic applications, they often contain flame retardants and toxic additives (Qureshi et al. 2020). Thermoset polymers are generally just contaminants in kerbside recycling bins as most of the products are in use for many years.

Thermosets cannot be recycled for the same purpose using mechanical recycling and can only be used as powdered or fibrous fillers (Devasahayam, Bhaskar Raju & Mustansar Hussain 2019). Thermal processes offer the best opportunity to recycle these polymers. Gasification, pyrolysis and hydrothermal processing are all applicable. However, pyrolysis and gasification systems need to use specific catalysts to effectively break down the polymers due to the high level of oxygen, nitrogen and other contaminants in thermoset polymers. As hydrothermal processing uses water to break down the polymers it is well suited to break down thermosets but may require the addition of basic chemicals (e.g. calcium carbonate) to assist. The presence of flame retardants and other fillers leads to the formation of toxic and halogenated by-products during thermal processing. Hydrothermal processing is able to remove chlorine and bromine in the water fraction. Thermosets lead to formation of more char than thermoplastic materials when thermally processed as they contain more fillers and have a higher proportion of oxygen or nitrogen. Whichever advanced recycling process is chosen, the best results will be obtained when thermosets form a small proportion of the total waste processed.

3.13 Summary

Based on the information presented in this section, Table 8 presents polymer types that are most suited to each advanced recycling option. Some polymer types appear more than once.

Table 8: Summary of preferred options for advanced recycling by polymer

PURIFICATION	DEPOLYMERISATION	CONVERSION
3 5 6	1 3 6	2 4 5 6

The following tables summarise suitability of polymers for each technology type (Table 9), and for waste plastics (Table 10).

Table 9: Summary on suitability of each polymer type for mechanical and advanced recycling technologies

POLYMER	MECHANICAL	PURIFICATION	DEPOLYMERISATION	CONVERSION
PET	Highly suitable when sorted.		Highly effective and commercially available.	Pyrolysis oil has organic acids – poor-quality oils and clogging of equipment. Hydrothermal processing works well.
HDPE	A good option but often results in downcycling.			Catalytic pyrolysis excellent option. Hydrothermal processing works well.
PVC	Possible but different materials may contain undesirable additives. Need to sort materials to ensure similar additives before processing.	Purification possible but may not be cost effective.	Hydrogen chloride produced when heated, which contaminates all processes.	
LDPE/LLDPE	Possible for clean material.			Catalytic pyrolysis excellent option. Hydrothermal processing works well.
PP	Suitable, but not generally separated and often included in mixed plastics.	Purification possible, pilot scale ventures coming on line internationally.		Pyrolysis and gasification good options. Hydrothermal processing works well. High levels of additives create more char/ash.
PS	Collection is challenging for EPS.	Purification excellent and pilot scale ventures running internationally. No styrene manufacturing in Australia.	Depolymerisation possible.	Pyrolysis and gasification work well.

Table 10: Summary on suitability of each plastic waste for mechanical and conversion technologies

PLASTIC	MECHANICAL	CONVERSION
Mixed municipal plastics	Undesirable	Gasification works best with PE, PP and PS. Can tolerate small amounts of PVC and PET. Pyrolysis works best with PE, PP and PS, no PVC or PET. Hydrothermal processing gives good products from complex wastes including laminates, thermosets, PET and nylon, and tolerates contamination from cellulosics.
Soft/flexible plastics (mixture of LDPE/LLDPE/ HDPE/PP – multilayer, laminate)	Mechanical downcycling to furniture, etc.	Suitable for all conversion technologies. (Purification is also possible.)
Tyres	Mechanical recycling a good option.	Pyrolysis is a good option with examples of technology operating in Australia.
Marine litter (highly degraded and contaminated wastes)	Undesirable	Pyrolysis possible fuel for generators. Hydrothermal processing possible.
Thermoset plastics (cannot be melted and reformed)	Mechanical grinding for use as fillers in composites	Conversion technologies best option. Pyrolysis challenged by oxygen, nitrogen and other contamination. Hydrothermal can cope with thermosets mixed with other waste.


TE
RECYCLE
NO CUPS
C BAGS

4 Factors influencing adoption of advanced recycling technology in Australia

This report describes technologies that have the potential to support Australia's waste management and plastics recovery goals but do not yet exist at scale. Therefore, when launching a new industry, it is useful to take a systems-based perspective of how Australia might adopt these new technologies. The following section summarises the relevant factors into six areas: political, economic, social, technological, legislative and environmental. Known as a PESTLE framework, it provides a broad perspective of the conditions that are relevant to a new technology and how it relates to the Australian context. The following section was developed based on peer-reviewed data and grey literature (media articles, company reports) and complemented by an Australian industry consultation workshop. Therefore, the factors described here provide an industry perspective of the key issues. A list of organisations that were consulted is provided at the end of this report.

4.1 Political

The policies of federal, state and territory governments have a large role in either enabling or discouraging industry investment into advanced recycling technologies. Local governments are also relevant as they are at the front line of balancing economic developments that benefit households and industry in local communities and regions. One of the most important points that was raised by industry was the number of difficulties encountered for industry (and consumers) when government policy is not harmonised. Australia's adoption of advanced recycling technologies would benefit from a national approach that seeks consistency across jurisdictions, while catering for regional differences.

4.1.1 Current Australian policy context

Australia has a strong commitment to improving the collection and domestic processing and use of waste plastics. This is evidenced by the recently released National Plastics Plan, and the 2019 National Waste Policy Action Plan, and is supported by national packaging targets established by the Australian Packaging Covenant Organisation (APCO) (Australian Government 2021; Ritchie 2019; APCO 2020). Australia has exported mixed plastic wastes to China and South-East Asia for many years. A portion of this waste has leaked into the environment and oceans due to poor storage where it is stockpiled, poor-quality material, lack of environmental controls and lack of trading options (Retamal et al. 2020). The Australian Government signalled an end to plastic waste exports and these will be implemented in 2021 for mixed plastics, and 2022 for unprocessed, single-type plastics. Each of these packages of domestic policy are consistent with the UN Sustainable Development Goals, in particular SDG 12 – Responsible Consumption and Production. The Australian Government, along with state and territory governments, has invested millions of dollars in supporting waste and resource recovery infrastructure. Various states and territories are introducing single-use plastic bans. It is important that advanced recycling is recognised in Australia's policy landscape due to the important role it can play in recycling plastics that are unsuitable for mechanical recycling and might otherwise be disposed of and lost to our economy.

4.1.2 Product stewardship schemes

The Australian Government has established a National Product Stewardship Investment Fund which recently funded over $10 million worth of projects, of which just over $5 million are plastics-related projects. In 2021, a Product Stewardship Centre of Excellence was launched to support best-practice product stewardship schemes in Australia.[4]

---

[4] www.stewardshipexcellence.com.au

Three of the national product stewardship projects funded by the federal government target soft/flexible plastics in Australia. Two of these address agricultural plastics and one targets food packaging (see Table 11). According to the project descriptions, they target almost 920,000 tonnes per year of plastics that are currently not being collected (DAWE 2021). These plastics are likely to be suitable for advanced recycling due to having some degree of contamination (soil or food), possibly multiple layers and mixed plastics. Farm plastics, unless non-contaminated, are likely to be good candidates for advanced recycling. Regarding food packaging, these plastics may be appropriate for mechanical recycling if they able to be sorted to a single polymer type and importantly, have a domestic market. Alternatively, material currently going to landfill may be suitable for pyrolysis, gasification or hydrothermal technologies. As these product stewardship projects are ongoing, it would be useful for these schemes to include consideration of advanced recycling technologies in addition to mechanical. Trials of plastic waste material may be required to ascertain their suitability for different technologies and what outputs different plastic waste combinations might deliver.

Table 11: Three product stewardship projects that are potential candidates for advanced recycling processes

PROJECT TITLE	AVAILABLE PLASTIC WASTE	GRANT AMOUNT
Recycling farm plastics	8,000 tonnes/year waste farm plastics, silage wrap	$965,400
Recycling non-packaging agri-plastics	90,000 tonnes/year	$893, 866
Recovering food packaging	1 million tonnes/year plastic packaging waste (820,000 tonnes/year going to landfill)	$985,866

Source: Department of Agriculture Water and Environment 2021

4.1.3 Innovation policy and governance

New technologies can offer significant benefits but mechanisms to support their adoption and launch a new industry requires a combination of industry and innovation policy. The European Commission report ‘A circular economy for plastics’ presents a framework for the governance of sustainable transitions through a socio-technical landscape (Crippa et al. 2019).

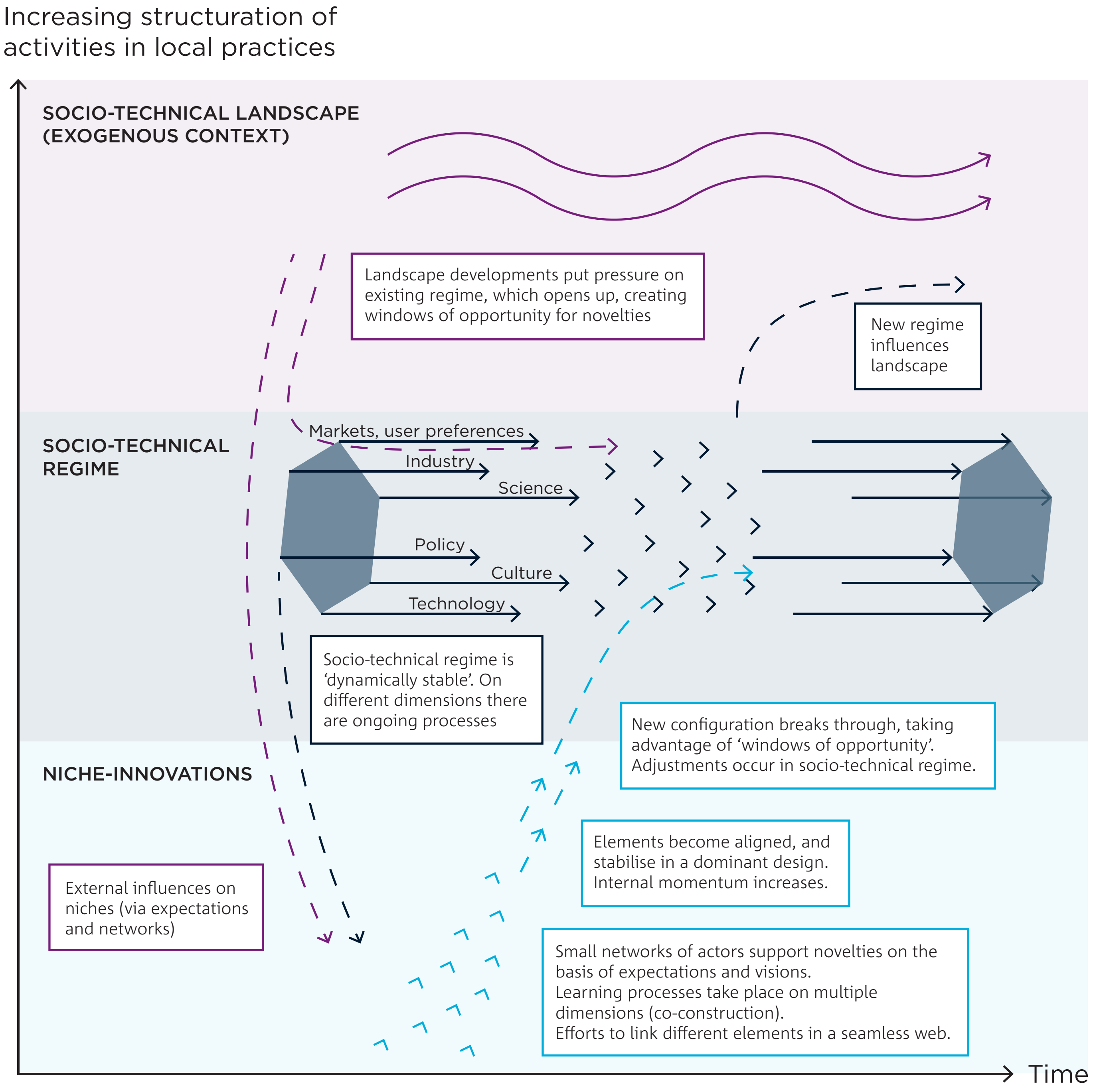
Figure 8 shows the transition over time of an innovation from niche to mainstream using three analytical levels. The niche innovation is the location of experimental or novel innovation. Innovations must break through to the socio-technical regime where established rules, such as industry practices, market preferences, policy and cultural norms are a stable influence. The landscape level represents external societal factors such as public demand for greater recycling. The regime influences an innovation and, should an innovation break through, is influenced by the emerging niche. The arrows in Figure 8 show the relationships and forces applied to each level (niche, regime and landscape) over time, as a niche innovation emerges (Geels 2011).

Niche innovations underpin long-term transitions and are similar to pilots, demonstrations, or experimental innovations. The concept of niche innovation applies to advanced recycling technologies as they are novel (different from the prevailing technology), complex (require multiple stakeholders) and can support a transition to circular economy. Niche innovations depend on three elements to emerge – a shared vision, innovation network and shared learnings.

An example of generating momentum for niche innovation is from Germany where the Fraunhofer Institute launched a national network for chemical recycling and the circular economy.[5] A similar approach adopted in Australia would provide the three essential key elements required by niche innovations to create long term change. A national network facilitates a shared vision for scaling up and implementing advanced recycling for plastics. A network approach is important as the success of advanced recycling depends upon integration and collaborations across the entire supply chain. Lastly, it is important that progress of different technologies is shared amongst the industry and innovation system. Sharing lessons learned will highlight key success factors and ensure mistakes are not repeated, which accelerates the adoption of new technologies. A national network combining industry and stakeholders from the innovation system will facilitate adoption of these technologies in a timelier fashion compared to a piecemeal approach. In Germany it was proposed that reference sites be implemented for the trial and scale up of technology, which would be useful in removing barriers to engaging in technology. These would be supported by funding, subsidies and regulatory frameworks (Lee, Tschoepe & Voss 2021).

---

[5] www.enfrecycling.com/directory/plastic-mrf/Australia



Landscape developments put pressure on existing regime, which opens up, creating windows of opportunity for novelties

New regime influences landscape

Socio-technical regime is 'dynamically stable'. On different dimensions there are ongoing processes

New configuration breaks through, taking advantage of 'windows of opportunity'. Adjustments occur in socio-technical regime.

Elements become aligned, and stabilise in a dominant design. Internal momentum increases.

External influences on niches (via expectations and networks)

Small networks of actors support novelties on the basis of expectations and visions.
Learning processes take place on multiple dimensions (co-construction).
Efforts to link different elements in a seamless web.

Figure 8: Multi-level perspective of socio-technical transitions

Adapted from source: Geels 2011

4.2 Economic

From an industry perspective, economic factors are the leading factor influencing advanced technology adoption in Australia. Landfill gate fees are important in determining if advanced recycling is cost competitive. Transport costs and distance of plastic wastes to processing are important. The scale of plant, additional sorting, cost of virgin material compared to recovered material, and the price of oil and energy costs – these all affect the economic viability of advanced technologies. For example, gasification facilities must offset capital costs with product revenues and tipping fees. The amount of fuels, chemicals or energy produced per tonne is affected by the management of the heat produced by the gasification process and whether it is captured or used at the facility to provide heat or energy to the system (Gershman & Bratton 2013).

The potential and size of market, noting again that these technologies complement rather than compete with mechanical recycling, is large. The North American market is estimated as a $120 billion opportunity (Closed Loop Partners 2019). However, many technologies are at an early stage. The early stage of development was noted by Closed Loop Partners who researched 60 global technology providers, and found many at lab scale but with the ability, or plans to scale up in the next 2 years (Closed Loop Partners 2019). There are several pilot plants operating in Europe, with some that have scaled up to an industrial scale (Recycling Technologies 2021).

Competition with waste incineration plants has contributed to gasification plants closing down in Germany (Lee, Tschoepe & Voss 2021) and Australian industry has raised competition with waste-to-energy plants as an emerging issue. Germany was a pioneer in the industrial-scale implementation of advanced technologies with advanced recycling centres in Berrenrath and Sekundärrohstoff-Verwertungs-zentrum Schwarze Pumpe (SVZ Schwarze Pumpe). Both plants were using gasification technologies to convert different types and mixtures of carbonaceous waste (e.g. unsorted MSW, plastic waste, tar and oil residues, waste wood, sewage sludges) mixed with coal into syngas and then producing methanol (~300 tonnes a day). Both plants were closed, the last in 2007, due to a range of factors including high operating costs, expenses maintaining the complex plant, low methanol prices and competition with waste incineration plants (Lee, Tschoepe & Voss 2021).

Clearly, market conditions have changed since 2007 and there are many examples of projects commencing around the world. However, in order to be competitive, recycled polymer will need to address economic drivers as they will typically have a higher price than virgin material (Goldberg, Haig & McKinlay 2019). An additional factor to consider is transport costs. It may be more efficient to process plastic waste into liquid intermediate products, rather than transport plastic waste. This is particularly relevant for regionally distributed cities and towns and where modular conversion technologies may be well suited.

4.2.1 Economic viability of advanced recycling technologies

Advanced recycling needs to compete with the low price of petrochemical feedstock. It has been said that this factor alone makes advanced recycling uneconomic without significant subsidies (Hopewell, Dvorak & Kosior 2009). However, despite the early stage of many technology solutions, there is evidence that advanced technologies can be profitable. An economic analysis of PP waste from New York, processed using pyrolysis (with a catalyst) and gasification was found to be profitable with a net present value of USD$149 million and USD$96 million, respectively. The key factors influencing economic performance were the discount rate applied, the price of waste PP and plant life (Bora, Wang & You 2020). Depolymerisation technologies have the potential for profitability as they avoid capital investments for petrochemical infrastructure and plants that manufacture PET. It has been estimated that a PET chemolysis facility requires 15,000 tonnes per year in order to be economically viable (George & Kurian 2014). By comparison pyrolysis, where outputs become cracker feedstocks, is estimated to be profitable down to $50 a barrel and as a technology, is generally more resilient to lower oil prices (Hundertmark et al. 2018). Another factor for consideration is the willingness of the public to pay a premium for recycled content.

However, these technologies are not without risks and there are examples of companies that have ceased operation. For example, VinyLoop®, a PVC waste recycling purification plant in Italy that used butanol as a solvent and steam as an anti-solvent, was shut down after more than 15 years of operation because the process was not effective enough to remove additives, such as plasticisers (Plasteurope 2018).

While PS is an excellent candidate for depolymerisation technologies there are no styrene producers in Australia therefore there is no connection with product outputs and a domestic manufacturing sector. PS is also an excellent polymer for pyrolysis systems as it breaks down at low temperatures and will provide aromatic compounds, which are particularly valuable if the output is to be a fuel (Erdogan 2020).

Each of the advanced recycling processes have an energy cost. Pyrolysis and gasification use high temperatures to break the chemical bonds and are energy intensive (Goldberg, Haig & McKinlay 2019). Depolymerisation and dissolution are also often carried out at temperatures over 80°C. Although many processes will use part of the outputs (oil or gas) to provide the heat energy required, there may still be an additional energy requirement and this needs to be factored into implementation.

4.2.2 Technology business models

A key economic challenge is maintaining security of supply and a consistent feedstock (Qureshi et al. 2020). This can be overcome by developing supply relationships with waste managers and additional pre-sorting of plastics. In fact, the business models for these technologies are likely to involve waste managers.

Large-scale commercial plants are likely to be sized at 30,000–200,000 tonnes a year. It is sensible to also offer recycling as a service where the plant receives waste, generates outputs and offers them for sale to the chemical sector (Recycling Technologies 2021). A second business model is likely to exist for small, modular units with capacity for processing 1,000–10,000 tonnes a year. Companies with plant that support distributed models of waste processing are more likely to offer the technology for sale. These modular units are suitable for regional or remote waste management. They may also be combined in series. They will require operation by suitably qualified waste handlers. While the technology provider secures revenue directly from the sale of technology, the operator of the unit will need to develop contracts with the chemical sector for the sale of product outputs (Recycling Technologies 2021). The business model for the collection of waste is also a key factor for consideration. This is where product stewardship schemes can provide a steady stream of plastic waste.

4.2.3 Licella Cat-HTR™ in Victoria

A feasibility study is looking at a potential site in Victoria for an advanced recycling facility using the Cat-HTR™ hydrothermal processing technology developed by Licella (Section 2.4.3) in a bid to tackle the growing issue of plastic waste (Licella Holdings 2021). The study is a collaboration between technology provider Licella, recycler iQ Renew, Coles, polymer manufacturer LyondellBasell and Nestlé to determine the technical, economic and environmental benefit of a Victorian advanced recycling industry. The study will build on the demonstration of making the Kit-Kat wrapper from soft plastics unveiled in 2021 (AM News 2021). The consortium acknowledges that without the input and cooperation from the whole value chain it won't be possible to implement the changes required bring about the industry.

4.2.4 Industry collaboration

For advanced recycling to be economically viable, there is a need for supply chain collaboration between manufactures, waste managers, advanced recycling technology owners and operators (Figure 9). In particular, there is a need for collaborative supply chain partnerships to be established with refinery or chemical manufacturing companies, as pursuing a plastics-to-plastics pathway depends on access to existing infrastructure to process the oil or gas outputs from advanced technologies. An example of the circular plastics-to-plastics supply chain stakeholders is provided below.

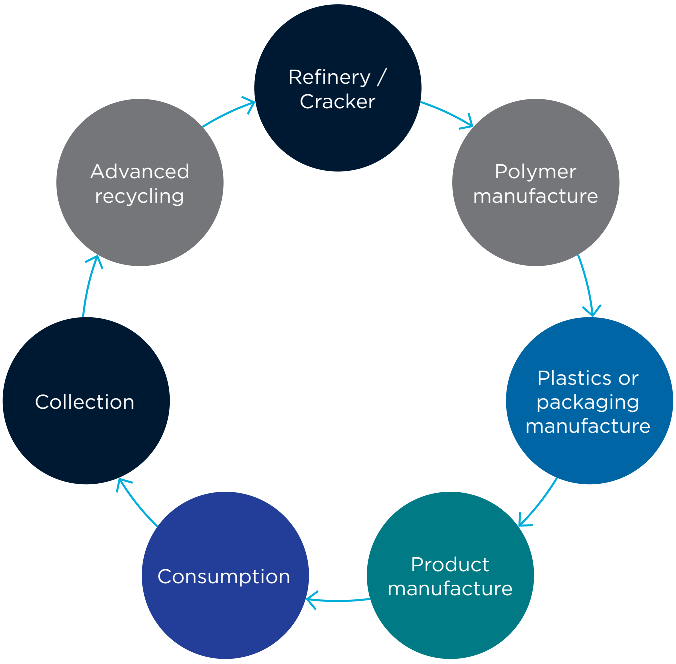


Figure 9: Circular industrial supply chain for advanced recycling of waste plastics back into plastic

Global brands are beginning to invest in advanced recycling technologies to ensure access to the limited supply of recycled plastics (Phipps 2019). These brands include Adidas, Unilever, P&G, Danone and Interface, which have all signed offtake agreements with a number of chemical recycling start-ups to support their growth. Plastics manufacturers Indorama and SABIC have also made strategic investments in Plastic Energy, Loop Industries and Ioniqa, and chemicals companies including BASF, Eastman Chemicals and LyondellBasell have integrated chemical recycling technologies in their own manufacturing and supply chains (Phipps 2019).

4.2.5 Advanced manufacturing export/import opportunities

The Ellen MacArthur Foundation Global Commitment unites businesses behind a common vision for a circular economy for plastics. The 2020 report includes more than 250 businesses and major multinational brand owners, representing 20% of all global packaging. These companies have on average 6.2% recycled content in plastic packaging. This constitutes a 22% increase year on year (Ellen MacArthur Foundation 2020b). Many major brands have targets to substantially increase their recycled content. A summary of the status of the top 10 fast moving consumer goods (FMCG) companies compared to 2025 targets is shown (Table 12). Four companies are not signatories to the Global Commitment, therefore data is not reported. These data show that while excellent progress has been made, there will be market demand for recycled plastics for global and domestic companies to meet their 2025 goals for recycled content in plastics packaging. This provides Australia with the potential to leverage existing infrastructure (refinery and crackers) to develop certified recycled chemicals (from waste plastics) for export. This means advanced recycling technologies could play a role in developing new, advanced manufacturing export opportunities.

Australia's major polymer manufacturing infrastructure may play a regional role by importing waste plastics processed by advanced recycling technologies from Asia-Pacific countries, such as New Zealand, for processing.

Table 12: Progress towards recycled plastic content for top 10 FMCG brands

		RECYCLED CONTENT IN PLASTICS (% BY WEIGHT)		TOTAL VOLUME OF PLASTIC PACKAGING (MILLION TONNES PER YEAR)
Top 10 FMCG Companies		Current (2019)	2025 target	
1	Nestlé	2	30	1,524,000
2	Procter & Gamble	n/a		
3	PepsiCo	4	25	2,300,000
4	AB InBev	n/a		
5	Unilever	5	25	700,000
6	JBS	n/a		
7	Tyson Foods	n/a		
8	The Coca-Cola Company	9.7	25	2,981,421
9	Mars, Incorporated	0	30	191,217
10	L'Oreal	6.9	50	137,280

Source: Ellen MacArthur Foundation 2020b

4.3 Social

The social dimension includes community education and awareness, stakeholder engagement, industry capability and securing social licence to operate. Industry feedback highlighted the importance of household education for the separation of plastics to reduce contamination and the need for increased community and government engagement on the role and environmental impact of advanced technologies. Industry also noted the importance of chemical engineering skills to be retained and developed in the manufacturing sector. The role of independent, trusted advisers such as CSIRO were noted by industry as having an important role in developing and communicating evidence-based information.

4.3.1 Community education on the value of plastics and recycling options

Australians consider plastics a serious environmental problem and there is data to show that plastic packaging is losing its social licence to operate (Dilkes-Hoffman et al. 2019). However, this is contrary to evidence that shows plastics to be preferable to paper and that plastics extend the life of food products, which prevents food waste. A recent study showed that plastics were considered the least favourable of food packaging options by Danish consumers, although they were actually the most environmentally preferred solution based on a life cycle assessment (LCA) (Boesen, Bey & Niero 2019). In addition to consumer education on the positive benefits of plastics packaging there is a need for increased consumer education on labelling that indicates the recyclability of products and harmonised municipal recycling messaging for households (Schandl et al. 2021).

The public has several misconceptions about plastic recycling. There is a view that all plastics are able to be recycled if they have the recycling code triangle on them. This is being addressed by the Australasian Recycling Label to be implemented for approximately 80% of supermarket items by 2023 (Australian Government 2021). Many people mistakenly believe that mechanical recycling is endlessly possible and an option for all plastic waste and as such do not understand how advanced recycling complements the recycling system. There are also misconceptions about the difficulties, cost and importance of separation of mixed plastic waste, resulting in high levels of contamination in MRFs.

4.3.2 Industry engagement

In a survey run in Germany, industry participants from diverse sectors (chemical, energy, non-government organisations, science) confirmed that their main concerns with advanced recycling were environmental impacts and uncertainty about the LCA impacts associated with chemical production (Lee, Tschoepe & Voss 2021). The main challenges identified to the implementation of technology in Germany were the high investment costs, high energy requirements and uncertainty around availability of waste as an input (Lee, Tschoepe & Voss 2021). The overall findings from the participant study in Germany were that there was a lack of quantitative data to evaluate the (positive and negative) benefits of advanced recycling. There is a need for evaluation studies and research and development to support establishment of reference sites. Supportive regulation to assist advanced recycling technology to compete against well-established waste-to-energy technologies will also be necessary.

4.3.3 Community acceptance and awareness (social licence to operate)

Social licence to operate is based on trust and can be withdrawn at any time. To build trust in advanced recycling with any group, the community must understand the perceived impacts and benefits, the governance, and have knowledge of the process, and this is achieved through strong relationships (Sustainability Victoria 2021).

There is confusion around the terminology for advanced recycling; it is also known as chemical, feedstock or molecular recycling. Also, there is a lack of clarity on inputs and targeted product outputs from advanced recycling (Lee, Tschoepe & Voss 2021). The public has very little understanding of advanced recycling. Most Australians understand the waste-to-energy incineration models and are concerned about loss of useful plastic material and greenhouse gas emissions from incineration. Advanced recycling needs a similar level of understanding amongst the community.

Lack of social licence was observed when two pyrolysis plants were recently proposed in Australia. Despite facilities like the proposed pyrolysis plant by Foyson Resources in NSW showing that they would take plastics that were not suitable for mechanical recycling, community groups such as the Total Environment Centre were concerned that recyclable plastic was to be burned as fuel (Vince 2015). Foyson Resources had communicated that their products were going to meet Australian standards, their plant would produce little noise and their emissions were a natural gas that they planned to use for energy and a non-hazardous ash waste. The NSW Environment Protection Authority rejected the proposal stipulating that it did not meet NSW's energy-from-waste policy (Burgess 2018). Likewise, a plant planned for Hume in the ACT that proposed to turn PE, PP and PS non-recyclable plastics into petrol, diesel and LPG via pyrolysis was stopped as a health panel decided that there was not enough evidence to prove the facility could be safe as it was a new technology (Burgess 2018). The community was concerned about emissions despite detailed information supplied by the company about the level of expected particulate and gaseous emissions. Foyson Resources detailed that its process would remove ash, and would deal with hydrocarbon contaminants, impurities and waste gas for heating by burning off gas at a high temperature to destroy noxious compounds. These recent examples show there is much to do to secure a social licence to operate for advanced recycling technologies. This can be achieved through the provision of credible, evidence-based information to government and community stakeholders.

4.4 Technology

This technology section includes factors that are necessary for plant scale up and implementation, such as access to existing cracker or refinery infrastructure. There is a need to understand the differences between technologies, the combinations of plastic waste inputs, operating processes and conditions, and the quality and yield of outputs.

4.4.1 Connection to existing refinery and polymer manufacturing infrastructure

The economics of some large-scale advanced recycling technologies is contingent on connecting with existing refinery or polymer cracking infrastructure to further separate molecules, so they are suitable for chemical processing. Australia currently has two polymer manufacturers, Qenos (PE) and LyondellBasell (PP). Without the presence of these manufacturers', conversion-based technologies Australia would only have a plastics-to-fuels pathway. Maintaining critical polymer manufacture infrastructure is essential to the viability of advanced recycling in Australia. As described further below, the State of Victoria holds critical pieces of infrastructure: a refinery, steam cracker and polymer manufacturing capability. It is in an ideal position to capitalise on these assets.

Around 20 years ago (2001), Australia had eight operating refineries that met almost all domestic fuel demand. Today, Australian refineries compete against larger and more efficient refineries in the Asia region. Australia currently has two refineries, one in Geelong (Viva Energy Australia) and one in Lytton, Queensland (Ampol). BP Australia announced in October 2020 that the Kwinana refinery would close and be converted to a fuel import terminal. ExxonMobil announced in February 2021 that their Altona refinery would close (ABC News 2021). The impact of the Altona closure is that Qenos will close and mothball one of its two ethylene-producing steam crackers, which will result in a 15% reduction in the production of PE and a reported loss of around 150 jobs (Macdonald-Smith 2021). The Qenos cracking facility takes ethane gas or liquid petroleum gas and produces ethylene to make HDPE and propylene that is supplied to LyondellBasell to make PP.

When high-quality ethane is fed to the steam cracker a high yield (80%) of ethylene and propylene is produced that can be used to make PE and PP products. The yield of ethylene and propylene from naphtha is lower (40% to 50%) depending on the quality of the feed and the configuration of the cracker. Methane and hydrogen (15%) are also produced and may be consumed as fuel in the process. The cracker can work well with small (two to five carbon) straight chain hydrocarbons to produce ethylene and propylene. One of the two Altona crackers previously processed much heavier oils, a capability that could be reinstated if it was economical.

Generally, the gases and naphtha produced from plastics pyrolysis and gasification contain a higher proportion of olefinic, isomeric and aromatic hydrocarbons. Such materials are well suited to a refinery processes and fuel applications. Without further treatment they provide low yields of ethylene if used directly as an input to a steam cracker. Steam crackers such as the Qenos Altona plant require a purified polyolefin input stream, free of oxygen, nitrogen and chlorine as these elements cause corrosion problems and can poison the various catalysts. Post-treatment processes have been developed to hydrogenate and purify the products of a suitably designed pyrolysis process, enabling the creation of a high-quality cracker feed. Any oxygen, nitrogen and chlorine contaminants can also be troublesome for the zeolite catalysts employed in a refinery fluidised catalytic cracker; however, the dilution into the much larger refinery fuel stream may make this workable.

While both refinery and polymer steam cracker paths can be used to process recycled polymer oil, steam crackers have the potential to produce ethylene and propylene that can be used to make new plastic materials whereas refineries will convert the majority of the product into fuel (gasoline and diesel).

A further risk identified by industry was, if Australia does not include advanced recycling alongside mechanical recovery to meet recycled content targets, then packaging capability may go offshore to achieve those targets. If packaging capability is lost to Australia, then the product manufacturing capability, technology and jobs will also be lost, resulting in Australia importing packaged finished goods.

4.4.2 Production of food contact compliant plastics

Most of the polymer manufactured in Australia meets food contact compliant plastics standards. Achieving a food contact compliant standard is a major consideration for recycled polymers. There is infrastructure to mechanically recycle PET suitable for food contact. PET has a high melting point so clean post-consumer PET from food applications is sterilised during the extrusion process. The plastic products produced meet US Food and Drug Administration guidelines. A big advantage of advanced recycling is that outputs can be fed back into the plastic production system for food contact compliant plastics, as they are the same as the raw materials. Thus, polymers other than PET can be recycled back into food contact grade plastics.

4.4.3 Technology scale up and research

One challenge for the collection of technologies that fit into the category of advanced recycling is that they are yet to be implemented at commercial scale for plastics recovery (Rahimi & Garciá 2017). There are, however, many that are on the verge of scale up in coming years and large-scale pyrolysis facilities might range from 30,000 to 100,000 tonnes per year with small-scale, modular units with up to 3,000 tonnes per year (Hundertmark et al. 2018). In the past, pyrolysis plants have faced market challenges; however, there are a range of technology providers emerging with modular technologies that are well suited to a distributed collection and recycling system (Crippa et al. 2019). It is estimated that the efficiency of pyrolysis is 71% but will increase with future development (Jeswani et al. 2021). Another relevant economic factor is that the heating energy required for pyrolysis is between 5% and 20% of the calorific value of the inputs, although ongoing improvements and catalytic cracking are improving outputs and reducing energy demand (Crippa et al. 2019).

An example of international investment is Plastic Energy, which is a Spanish company that has a commercial plastic waste conversion process using pyrolysis with two plants running in Spain (Sparrow 2020). They partnered with SABIC, a Saudi petrochemical company, to start the engineering and construction of a new advanced recycling system that will be in Geleen, the Netherlands, announced January 2021 (Plastic Energy 2021). They have also announced a collaboration with ExxonMobil to construct a plant in France capable of processing 25,000 tonnes a year and with Nestlé to create a recycling facility in the UK. The process uses predominately HDPE and LDPE, PS and PP that can no longer be mechanically recycled. Each tonne of plastic waste produces 850 litres of TACOIL (Sparrow 2020).

The polymer types of PET, PE, PP, PPMA (acrylic) and PS comprise 70% of global production. Currently there is little evidence that dissolution and depolymerisation technologies are economically viable at current market conditions. This is mainly due to the price competition with virgin materials. These technologies require greater research investment at lab and pilot scale to improve yield and energy efficiency (Crippa et al. 2019).

Research institutes have an important role in collaborating with industry for lab to pilot scale up. In addition, they have an important role in researching and providing evidence-based information to community and government stakeholders. The role of CSIRO in this regard was highlighted by industry participants during an advanced recycling workshop. Research institutes are part of the innovation system (as described in Section 4.1.3) and can assist in connecting industry supply chains under a vision of growing the advanced recycling network and shared learnings. Critical chemical and engineering research expertise can also be applied to the challenge of managing mixed polymer waste inputs to deliver ideal output yields.

4.4.4 Plastic waste supply – collection and sorting infrastructure

The quality of input material and sorting steps have a significant contribution to the final yield of advanced technologies (Jeswani et al. 2021). Industry participants provided very strong feedback that a major challenge for advanced recycling are issues with waste contamination (e.g. with PVC or non-plastics materials). New collection schemes for flexibles and greater aggregation of plastic wastes are needed to achieve high volumes of plastics suitable for advanced recycling. Current plastic separation technologies are not sufficient to produce high-quality (low contamination) inputs for advanced recycling. Australia needs investment in plastic recovery facilities (PRF) such as the example in Laverton, Victoria, by Cleanaway that operates alongside a materials recycling facility (MRF). There is a lack of readily available information at national or state and territory level about the processing capacities of plastics. This information is essential for policy and investment planning, particularly as facilities vary in their capability – tonnes per year, single vs multiple polymer types, municipal and/or commercial waste streams. However, there is a directory for Australian facilities available[5] (although it lacks information on tonnes processed per year and an easy to view measure of the polymer types accepted). The national plastics recycling survey has data on the number of waste processing facilities in each state by polymer type (O'Farrell 2019). Lastly, there is some data available on industry upgrade plans (Read 2021; Envisage Works 2020). Combining these data into a state or national perspective would provide a clear vision of gaps.

4.5 Legislation (and standards)

Implementation of legislation can be an enabler or barrier for supporting increased production of recycled plastics. The same legislation can be viewed by different stakeholders, positively or negatively. Given a general lack of awareness of advanced recycling technologies, some regulators consider them in the same category as waste-to-energy. Consideration should be given to technologies that exclusively process plastics for the purpose of deriving intermediate products, rather than electricity generation. The topic of standards and certification is highly relevant to advanced recycling technologies and is also reviewed in this section. It is useful to start by briefly mentioning recent legislation examples from the UK and US.

4.5.1 UK plastics tax

The UK will implement a plastics tax of £200 per tonne of packaging that does not reach a threshold of 30% recycled plastic. This tax commences from 1 April 2022 and it is intended to provide economic incentives for companies to include recycled content in packaging and to generate demand for recycled material and improve collection and diversion rates away from landfill and incineration (UK Government 2021). As Australia is integrated into global markets this tax will have a flow-on impact to some Australian companies.

4.5.2 US proposed *Break Free from Plastic Pollution Act 2021*

In March 2021, the US Congress evaluated the *Break Free from Plastic Pollution Act 2021*. This proposed act could place a three-year, temporary pause on permitting new or expanded plastics facilities and chemical/advanced recycling is no longer considered ‘recycling’. Any pause in permits for these facilities (which includes all types of technologies discuss in this report) is so that regulations that prevent air and water pollution can be updated. The primary concern is to limit impacts on community health arising from the operation of plastics production facilities (Staub 2021).

4.5.3 Legislative factors for advanced recycling plants

A major constraint for the development of advanced recycling industrial processes is the large number of differences in policy and regulation across Australia. These make it challenging for companies to operate in the national market as they must meet the requirements for every state. Existing policies and guidelines have limited application to emerging technologies. Specifically, the eligibility of plastic as an input for pyrolysis is not clearly defined in legislature. It is best determined using the states’ energy-from-waste policies and guidelines, as shown in Table 13.

The Queensland Energy from Waste Policy 2020 differentiates between waste to energy and waste to fuel. It places fuel recovery as one position higher than energy in the waste hierarchy. This is shown in Figure 10.

The regulatory pressures have driven Australian developments overseas. In NSW, Licella’s joint venture with iQ Renew has been restricted by the NSW Environment Protection Authority, reportedly because of its energy-from-waste policy, and Licella has now set up a ReNew ELP venture in the UK (Hannam 2019; ELP 2020). Likewise, Foyson Resources was planning a plastics-to-fuel plant in Hume, ACT. As it was a new technology it was determined by a health panel that there was too much risk. Foyson Resources has merged with Integrated Green Energy Solutions in the Netherlands and will be shipping their facility to Amsterdam. Renewology announced plans for a facility in Victoria in 2017 but reportedly did not receive government support and finance (Khadem 2017).

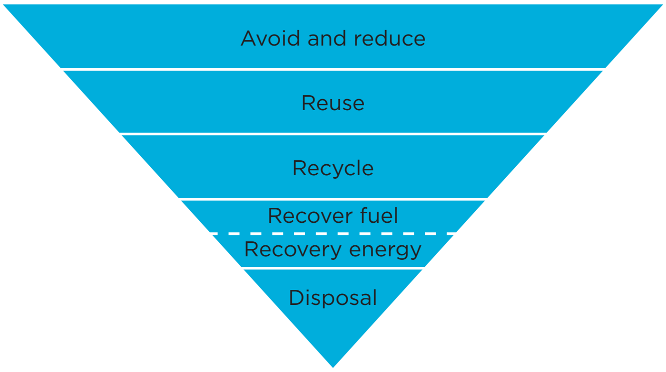


Figure 10: Queensland waste hierarchy considering energy from waste

Table 13: National and state-based energy from waste policy and guidelines that may affect advanced recycling for plastics operations

STATE	KEY POLICY	REQUIREMENTS
National	Parliament of Australia, inquiry into Australia's waste and recycling industries – 'From Rubbish to Resources: Building a Circular Economy' (2020)	Waste to energy refers to a range of technologies that convert waste to electricity, heat and fuel.
National	National Plastics Plan (2021)	The Australian government supports new technologies focused on reducing plastic waste and improving recycling. This includes chemical recycling.
VIC	Recycling Victoria – a New Economy (2020) Environmental Protection Act (1970)	Limit of 1 million tonnes/year until 2040. Plastic not specifically listed as an eligible feedstock, and is considered residual waste, which may be eligible for thermal treatment if it is assessed as the best alternative to landfill.
NSW	NSW Energy from Waste Policy Statement (2020)	Gasification and pyrolysis considered thermal treatment however energy from waste policy excludes thermal treatment where a transport fuel is produced. Does not recognise plastic as an eligible waste to use as input for thermal treatment. Does accept tyres for use in cement kiln.
QLD	Energy from Waste Policy (2020) *Planning Act 2016* Environmental Protection Regulation (2008) *Environmental Protection Act 1994*	Plastic not specifically mentioned other than, energy produced from fossil-derived plastics does not count as renewable energy. An environment relevant activity (ERA) approval is required, with ERA 61: *Thermal waste reprocessing and treatment* the most relevant for pyrolysis, with consideration to: • risk level – plastic is likely classed as Category 2 (moderate risk) • scale of operations.
WA	Waste to Energy Position Statement (2013) *Planning and Development Act 2005* Section 16e of the Environmental Protection Act 1986	Development approval is required under the *Planning and Development Act 2005.* Must be sited in industrial and appropriately distanced from sensitive land. Consistency with waste hierarchy: residual waste otherwise landfilled.

Mechanical recycling, as pictured, is a common process to recycle plastics, particularly for plastics used for food packaging. Advanced recycling complements existing mechanical technologies in Australia

4.5.4 Mass balance method for plastics-to-plastics

For technologies that process waste plastics into chemicals there is no way to distinguish recycled chemical feedstocks from non-renewable feedstocks. It is impossible to track chemicals from recycled feedstocks once they enter existing infrastructure where they are mixed in a continuous process, at a molecular level. Chemical plants are often linked directly together through logistical systems such as pipelines or transport linkages. This interconnectedness supports the use of a by-product from one system being used in another downstream process.

The Ellen MacArthur Foundation published a report on a 'mass balance' approach, which is a chain of custody method, to account for recycling of plastics back into chemicals when it is implemented at scale, and in conjunction with existing infrastructure. A chain of custody method is also applied to global resources such as timber, palm oil and cotton. A mass balance approach applies a bookkeeping method for ensuring that any certified recycled output does not exceed the input, minus any production or conversion losses. For example, pyrolysis and gasification processes are likely to achieve about 30–40% conversion to polymer (Goldberg, Haig & McKinlay 2019). The bookkeeping method requires a defined reconciliation period (Ellen MacArthur Foundation 2020a).

4.5.5 International certification

Using the mass balance approach, it is possible to achieve certification for recycled polymers processed through advanced recycling technologies. There are two options: International Sustainable Carbon Certification (ISCC) and REDcert2. Certification is important as claims of recycled plastics content should be verifiable. Certification processes track chain of custody through the supply chain, with some customers requiring certification. A certification process may also offer the potential to secure carbon credits.

Certification is increasingly important as it is possible for some manufacturers to mix virgin and post-consumer recycled plastic and market the product as 100% recycled. Given major multinational brand owners are committing to increased recycled content in packaging, the demand for recycled polymer will increase. The price of recycled PET has been US$1,000 a tonne compared to virgin PET at US$600 a tonne (Hicks 2020). For these reasons, certification of recycled polymer is important so that claims are verifiable and transparent.

4.6 Environmental

Environmental factors are a key element in securing social licence to operate alongside demonstrating technology meets environmental regulations. While recycling is often mentioned as a key part of ensuring plastics continue in a circular economy, the role of advanced recycling is often neglected. It is assumed that mechanical recycling is the only option, however it is not suitable for some plastics. Both mechanical and advanced recycling retain plastics materials in the economy. Advanced recycling technologies are part of a transition to a reduced dependency on non-renewable resources. This section addresses environmental concerns and impacts of these technologies.

4.6.1 Emissions from advanced technologies

Advanced recycling technologies all have some degree of emissions. In addition, dissolution and depolymerisation will have undissolved potentially hazardous material that will require disposal (Goldberg, Haig & McKinlay 2019). The solvents used in depolymerisation and purification technologies will need to be recovered and purified to keep emissions and costs low. Pyrolysis and gasification produce char (or ash) that may contain some useful material but will need some level of disposal of material contaminated with hazardous residues. Pyrolysis and gasification also generate toxic vapours that will need to be treated before emission to the atmosphere.

4.6.2 Life cycle assessment

The environmental impact of advanced recycling is an important consideration. A reliable life cycle assessment (LCA) provides transparency for the environmental and social impacts of processes. A LCA should be clear about its scope (what it includes or excludes), any comparison scenarios and impact measurements. As noted earlier, many advanced technologies are in an early stage of development. As they scale up to commercial levels, it is important that environmental impacts are monitored, so industry, government and the community have confidence that advanced recycling pathways are indeed a sustainable alternative to other treatment or disposal methods (Ellen MacArthur Foundation 2020a; Crippa et al. 2019).

There are a few studies on advanced recycling of plastics that have been completed using LCA methods. An academic study found that advanced recycling of mixed plastic waste by pyrolysis has a 50% lower climate change impact and energy use then energy recovery by incineration (Jeswani et al. 2021). There is also a significantly lower climate change impact comparing mixed plastic waste recycled from pyrolysis compared to plastics made from virgin resources (Jeswani et al. 2021). Another peer reviewed study found pyrolysis and gasification of PP plastic waste had lower greenhouse gas emissions than landfill or incineration alternatives (Bora et al 2020). ReNew ELP have reported that an independent LCA showed a 70% greenhouse gas emission saving compared to the production of hydrocarbons from fossil sources (ELP 2020). Using the Licella, Cat-HTR™ technology ReNew ELP convert over 85% of the plastic mass to hydrocarbon product that can be used to make new plastic or other hydrocarbon products.

A LCA was commissioned by BASF on their ChemCycling™ process, a pyrolysis-based advanced recycling system where the products are used to make new plastic products. This found that pyrolysis of mixed plastic waste emits 50% less carbon dioxide than incineration. Also that advanced recycling was comparable to mechanical recycling for carbon dioxide emissions (Sphera 2020).

Overall results showed that pyrolysis was preferred to incineration for mixed plastic waste. LDPE produced from pyrolysis oil (using the mass balance method described earlier) has significant climate change benefits compared to production from fossil-based naphtha but fewer benefits for the impact factors of acidification, eutrophication and photochemical ozone formation. An energy mix comprised of greater renewables was even more favourable to pyrolysis compared to incineration technologies for climate change values. This is relevant to developed countries such as Australia. However, for acidification and eutrophication impact categories, pyrolysis was not as preferable to incineration (Krüger 2020).

A recent Australian LCA, applied to the Victorian geographic context, found mixed plastics were best managed in landfill rather than incineration or gasification (the primary output is syngas) based on environmental impacts including acidification, climate change, photochemical oxidation and eutrophication potentials (Demetrious & Crossin 2019). This finding is significant as it does not accord with waste hierarchy conventions where energy is one step above (preferred to) disposal.

Overall, these data show that based on environmental life cycle assessments available in the public domain, advanced recycling has some advantages compared to alternatives for processing plastic waste. Any emissions from advanced recycling technologies need to be managed to reduce impact in other areas. However, there is a recognised need for LCA data relevant to the Australian context. Credible LCA studies will support government and community stakeholders with their concerns over environmental impacts of these technologies.

4.6.3 Non-government organisations and environmental group concerns

Some environmentalists suggest the plastics industry is disingenuous about its promotion of advanced recycling and attempting to placate criticism so it can go on increasing plastic production. To them, advanced recycling is a classic greenwashing scheme. Environmentalists maintain that advanced recycling consumes a lot of energy (Tullo 2020).

Advanced recycling in the US has been criticised by two environmental groups, Greenpeace and Global Alliance for Incinerator Alternatives. Two chief criticisms from both organisations are that many projects are not commercially viable and plastics-to-fuels should not be considered recycling (Greenpeace 2020; Patel et al. 2020). Given the early stage of the many technologies grouped under 'advanced' recycling, the first point is consistent with the early stage of development of many advanced technologies for plastics. The early stage of development was noted by Closed Loop Partners, who researched over 60 global technology providers and found many at lab scale but with the ability, or plans, to scale up in the next two years (Closed Loop Partners 2019).

The second criticism explores an important consideration regarding the end products developed from advanced technologies. Ideally, the goal is to upcycle plastics using advanced technologies into the chemical building blocks for manufacturing of new monomers and polymers. Sending products to a one-way use, such as diesel, results in products having a one-way, linear path, and this is inconsistent with the goals of a circular economy. This is addressed in the following section.

4.6.4 Plastics-to-fuels

One of the main outputs of conversion technologies, including pyrolysis, is a heavy oil fraction, which is a type of crude diesel. One viable market for that product is to sell that output as a fuel. This commits the pyrolysis output into a plastics-to-fuels path, which is undesirable if the goal is to transition to a circular economy. This market preference for fuel has been referred to as a 'linear lock-in' (Crippa et al. 2019). This issue is complex, however. Emerging pyrolysis technologies are small scale and there may be difficulties in selling their small volume outputs to the petrochemical industry, which operates on vastly different scales. There may be economic or market limitations for these small-scale operators to accessing refinery infrastructure or chemical industry supply chain partners (Lee, Tschoepe & Voss 2021).

However, there is a trade-off to be considered regarding the issue of plastics-to-fuels in Australia. If technologies that convert waste plastics-to-fuels are penalised to the extent that they are unable to operate, the alternative pathway for those materials might be landfill or a waste-to-energy plant. This limits potential future flexibility of options for outputs from advanced recycling infrastructure for use as a fuel or as a petrochemical feedstock. Of course, a domestic plastics-to-plastics pathway is only possible if Australia has refinery or polymer manufacturing infrastructure. A similar non-linear argument may be levelled against gasification technologies that produce ammonia for production of fertiliser and, of course, waste-to-energy technology. Therefore, it is important to note that conversion technologies may result in plastics-to-plastics or plastics-to-fuels products, or a combination of both. While plastics-to-fuels might be considered non-circular, whether this is an issue depends on the perspective of if that is considered a worse option than Australia's current paradigm of sending plastics to landfill. According to the waste hierarchy, waste-to-energy is preferred to disposal.

4.7 Summary

The industry perspective on each of these PESTLE areas is summarised in the following sections. More generally, industry reported that advanced recycling was not well understood, and it was important to clarify the different technologies. There should be greater recognition that multiple technologies are needed, and advanced recycling has an important role to play in Australia's greater recovery of plastic waste. Australia has the solutions, technology and very capable scientists and engineers.

Politically there is an opportunity for advanced recycling to be recognised as supporting Australia's waste policy action plan and plastics recovery targets to 2030. Advanced recycling is part of an advanced manufacturing sector and government support is likely to be necessary for launching a new advanced recycling industry.
The economic factors are essential for commercially viable technology. Australia has smaller, modular technologies available and the potential for larger scale technologies. There was recognition by industry that economic benefits must flow across the supply chain and collaboration was essential. Recycling of plastics does cost more than virgin polymer, so incentives are needed alongside consumer recognition that recycled polymer is a premium product. Industry understands the only way these technologies can operate is by securing a social licence to operate. This requires increased community engagement with evidence-based facts about the environmental impact of these technologies. Household education is essential to improve collection and reduce contamination of plastic wastes.

For the technology factors, industry saw a need to differentiate advanced technologies from waste-to-energy plants. There is emerging competition for plastic waste from waste-to-energy technologies. Advanced recycling results in food contact grade plastics that can't be achieved through mechanical recycling. There is a need for investment in innovative technologies to ensure Australia does not lag behind Europe and North America.

Legislation was combined with the important topic of standards. Mass balance certification is available for product processed by a refinery or steam cracker. Certification provides consumer and market confidence that any recycled polymer can be verified. Some industry members attending the consultation suggested a tax on virgin resin and others, an excise exemption for polymer-derived recycled fuels as mechanisms to improve adoption of advanced recycling. The harmonisation of definitions and approaches to advanced recycling of plastics would reduce confusion. Life cycle assessment was viewed by industry as important for providing evidence-based information on environmental impact. Comparisons to mechanical, waste-to-energy and landfill would be beneficial. The lack of LCA studies relevant to the Australian context is an information gap. The role of other third parties was viewed as important to provide credibility to any definitive information about advanced recycling.

Summary of industry feedback on PESTLE factors for establishing an advanced recycling industry for plastics in Australia

Political

Lack of awareness and understanding of technology leads to industry challenges with policy development and approvals.

Recognition that advanced recycling supports Australian national plastics recovery targets and processes plastics unsuitable for mechanical recycling.

Government support and engagement is essential for launching a new industry.

Manufacturing could benefit from a more progressive image and approach from policymakers. It must be valued to survive and provide economic development benefits to Australia.

Recognition that advanced recycling is different to waste-to-energy (may even compete with) and material processed should be counted in recycling rates.

Industry needs a consistent policy approach across jurisdictions.

Economic

Economic benefits must flow across the entire value chain for advanced recycling to be successful and greater collaboration across the supply chain is needed.

There is emerging competition with waste-to-energy for plastic waste.

Plastics circularity may cost more for consumers and the business case is contingent on securing a premium for recycled polymers over virgin.

Economic viability should be supported by extended producer responsibility schemes, incentives and policy changes.

Mass balance certification can provide carbon offsets for plastics oil and this is a financial incentive for refinery/cracking processing.

Advanced recycling needs risk takers, scale and security of upstream supply and downstream processing.

Market demand can be improved by government commitment to purchase recycled content.

Social

Need greater commitment by government stakeholders (e.g. councils) for household education to reduce littering, improve sorting and reduce contamination.

Secure social licence to operate with increased community engagement about the role of advanced recycling in reducing plastic waste.

Address community concerns with evidence-based facts about the environmental impact.

There is a role for trusted advisers such as CSIRO to explain this complex topic and undertake evidence-based research.

Increase adoption and awareness of recycled content labels.

It is essential to maintain and develop industry expertise in chemistry and chemical engineering.

Technology

Improved waste collection, separation and aggregation will be needed to achieve required volumes of input materials.

Contamination and inconsistency of plastic waste supply puts the technology at risk.

Greater investment is needed or Australia will get left behind by investments in Europe and North America.

Existing polymer manufacturing and refinery infrastructure is essential to creating circular outputs from waste plastics.

Technology options (small and large scale) are available now in Australia.

Need to understand the difference between technologies (e.g. pyrolysis, gasification, hydrothermal) and how they are different from waste-to-energy plants.

Need recognition that advanced recycling produces food contact grade plastics.

It is important to understand yields and outputs based on different technologies and plastics inputs.

Legislation

Industry needs a consistent approach across jurisdictions (states, territory, and local government areas).

Traceability and certification ensure material claimed as recycled is credible and verifiable.

Mass balance certification should be advocated by government and industry.

Definitions of advanced recycling are important.

ISCC Plus certification is emerging as a leading standard and could be adopted in Australia.

Tax virgin resin to incentivise use of recycled material.

Mandate levels of post-consumer recycled content.

Introduce container deposit scheme collection for waste plastics.

Recognise advanced recycling as part of Australian plastics recycling.

Environmental

Life cycle assessments (LCAs) are an essential evidence-based approach to quantify the environmental impact of advanced recycling compared with mechanical recycling, waste-to-energy, and landfill.

CSIRO and other third parties are important to combat scepticism in the community about plastics.

Lack of harmonisation across environment protection authorities is a major barrier for industry.

Advanced recycling can prevent post-consumer soft plastics from going to landfill.

There is a need for technology with low emissions.

Need greater clarity on plastics-to-fuels (energy) vs plastics-to-plastics (chemicals) and how these are treated compared to waste-to-energy.

5 Conclusion

Plastic waste is a critical issue for waste management and resource recovery in Australia. Recycling of end-of-life and mixed plastic waste will be needed to help meet resource recovery targets set by the Australian Government. Mixed plastic wastes are typically complex, consisting of numerous polymer types at varying composition. The complexity and variability of feedstocks makes these wastes unsuitable for established plastics recycling pathways in Australia. Traditionally, these plastic wastes have been exported for processing. From 1 July 2021 a total of 149,695 tonnes of mixed plastics is no longer able to be exported and is unlikely to be suitable for mechanical recycling. Without additional onshore sorting and processing, there is a risk this material will be stockpiled or sent to landfill.

Plastics that are not suitable for mechanical recycling are able to be processed with advanced recycling (also known as chemical or feedstock recycling) technologies. The recovery of intermediate output such as oils and gases that can be converted to recycled polymers represent a significant economic opportunity. Advanced recycling of plastic wastes will create new markets within the Australian economy, and potentially for export, that support circularity and sustainability in the production and consumption of materials.

This report describes the opportunity of advanced recycling for improving recycling of plastic wastes produced in Australia and identifies opportunities for new markets for recovered products. We described the main types of technology (purification, depolymerisation and conversion) and identified secondary products and market pathways for these products. We described the interaction of polymers with advanced recycling technologies and potential plastic waste streams that might be suitable for processing with these technologies. Through direct engagement, the industry perspective of gaps, barriers and enablers for establishing an advanced recycling industry in Australia is captured and presented with the PESTLE framework.

The key findings of this report are:

- Advanced recycling can assist Australia to meet the national target of recovering an average of 80% plastics by 2030.
- Advanced recycling is suitable for mixed, multi-layer, flexible and contaminated waste plastics that cannot be processed by other means, such as mechanical recycling.
- Advanced recycling may be suitable for product steward schemes to address plastic waste, such as almost 100,000 tonnes of agricultural plastics and over 800,000 tonnes of food plastic packaging. It is highly suited to the recovery of 300,000 tonnes of flexible plastic packaging.
- The use of advanced recycling encourages pathways that are circular, rather than linear, by retaining material in the economy as part of a transition away from non-renewable resources.
- Advanced recycling can produce a range of high-quality recycled polymers for reuse, including food contact compliant plastics, as well as a range of secondary products that can enter markets in place of virgin materials.
- There is increasing global and local demand for recycled polymers. Global market demand for recycled plastics will continue to grow. Top global brands (representing 20% of all global packaging) average 6.2% recycled plastics in packaging where most have targets of 25% (and greater) to reach by 2025.
- Australia has unique technical expertise that would be suited to launching an advanced recycling industry for waste plastics, leveraging existing infrastructure (e.g. refineries or steam crackers) to recycle plastic wastes. Australia's polymer and plastics manufacturing supply chain is essential to realising benefits of advanced recycling and improved recycling rates of plastics.
- Technology for advanced recycling of plastic wastes exists at various scales in Australia, with four examples provided in this report.

Following industry engagement and assessment of themes through the PESTLE framework, the pathway for establishing an advanced recycling industry for plastics in Australia requires the following for success:

- A national discussion about advanced recycling to improve awareness of the range of technologies available, and to facilitate an understanding of the advantages and the differences to waste-to-energy technologies.
- An innovation approach to support pilots, trials with plastic wastes, collaboration across the supply chain and an innovation network to support scale up coordinated, for example, with a national centre.
- Harmonisation of government definitions, policy and approvals to support greater adoption of advanced recycling.
- Government support and engagement, which is essential for launching a new advanced recycling industry.
- Greater differentiation between advanced recycling of plastics and waste-to-energy technologies.
- Full collaboration across the entire supply chain, including waste managers, technology providers, polymer manufacturers, refinery operators, plastics manufacturers/recyclers and brand owners, to match demand with supply of recycled polymers.
- Techno-economic and LCA studies to provide further evidence that technologies are commercially and environmentally sound.
- Adoption of globally recognised certification processes to provide chain of custody verification and market confidence for recycled polymers and plastics that were processed through advanced recycling technologies.

To develop an advanced recycling industry for plastics in Australia and achieve Australia's resource recovery targets by 2025, it is important to establish a collective and clear vision that promotes research, development, innovation, scale up, collaboration and appropriate policy design. Australia has all the critical elements necessary to launch a new industry of advanced recycling for plastics, which supports greater recovery, recycling and reuse of materials consistent with improved circularity and sustainable economic development.

List of organisations consulted

- Amcor
- Australian Food and Grocery Council
- Australian Paper Recovery
- BASF
- Brightmark
- Chemistry Australia
- Cleanaway
- Dow Chemical (Australia)
- Integrated Recycling
- IQ Energy Australia
- Licella
- LyondellBasell
- Nestlé
- Pact Group
- Plastic Energy
- Plastic Forests
- Plastoil
- PPG Australia PTY Ltd
- Qenos
- Red Group
- Sealed Air
- SUEZ
- Taghleef Industries
- Viva Energy
- Woolworths

References

ABC News 2021, 'ExxonMobil closes Altona oil refinery after review finds it is not economically viable', ABC News, 10 February.

Acquisition, RC 2020, 'Roth CH Acquisition I to combine with PureCycle Technologies, accelerating a revolution in plastics recycling through impact investing', Intrado GlobeNewsWire, viewed 22 April, 2021, <http://www.globenewswire.com/news-release/2020/11/16/2127251/0/en/Roth-CH-Acquisition-I-to-Combine-With-PureCycle-Technologies-Accelerating-a-Revolution-in-Plastics-Recycling-Through-Impact-Investing.html>.

AM News 2021, 'The KitKat that's the sign of a break in Australia's waste challenge', Australian Manufacturing, viewed 15 March, 2021, <https://www.australianmanufacturing.com.au/138176/the-kitkat-thats-the-sign-of-a-break-in-australias-waste-challenge?utm_source=rss&utm_medium=rss&utm_campaign=the-kitkat-thats-the-sign-of-a-break-in-australias-waste-challenge#>.

Antonakou, EV & Achilias, DS 2013, 'Recent advances in polycarbonate recycling: a review of degradation methods and their mechanisms', Waste and Biomass Valorization, vol. 4, pp. 9–21.

APCO 2020, Our Packaging Future – A Collective Impact Framework to Achieve the 2025 National Packaging Targets, Sydney, Australia.

APCO 2019, Soft Plastic Packaging, APCO, Sydney, Australia.

Arabiourrutia, M, Elordi, G, Lopez, G, Borsella, E, Bilbao, J & Olazar, M 2012, 'Characterization of the waxes obtained by the pyrolysis of polyolefin plastics in a conical spouted bed reactor', Journal of Analytical and Applied Pyrolysis, vol. 94, pp. 230–237.

ARENA 2020a, 'Projects', viewed 25 April, 2021, <https://arena.gov.au/projects/?project-value-start=0&project-value-end=200000000&technology=bioenergy&page=2>.

ARENA 2020b, 'Second waste-to-energy plant gets green light', ARENAWIRE. Your feed of renewable energy content, viewed 25 April, 2021, <https://arena.gov.au/blog/second-waste-to-energy-plant-gets-green-light/>.

ASG 2021, 'PVC in PET bottle recycling', viewed 25 June, 2021, <https://www.petbottlewashingline.com/pvc-in-pet-bottle-recycling/>.

Australian Government 2021, National Plastics Plan, Department of Agriculture, Water and Environment, Canberra.

Australian Government 2019, National Waste Policy Action Plan 2019, Australian Department of Energy and Environment, Canberra.

Boesen, S, Bey, N & Niero, M 2019, 'Environmental sustainability of liquid food packaging: is there a gap between Danish consumers' perception and learnings from life cycle assessment?', Journal of Cleaner Production, vol. 210, pp. 1193–1206.

Bora, RR, Wang, R & You, F 2020, 'Waste polypropylene plastic recycling toward climate change mitigation and circular economy: energy, environmental, and technoeconomic perspectives', ACS Sustainable Chemistry and Engineering, vol. 8, no. 43, pp. 16350–16363.

Burgess, K 2018, 'Foy Group walks away from plastics-to-fuel plant in Hume', The Canberra Times, 14 January, Canberra, Australia.

Butler, E, Devlin, G & McDonnell, K 2011, 'Waste polyolefins to liquid fuels via pyrolysis: review of commercial state-of-the-art and recent laboratory research', Waste Biomass Valor, vol. 2, pp. 227–255.

Carbios 2020, 'Carbios produces first clear plastic bottles from enzymatically recycled textile waste', viewed 15 February, 2021, <https://carbios.fr/en/carbios-produces-first-clear-plastic-bottles-from-enzymatically-recycled-textile-waste/>.

Center for Health, E & J 2021, 'PVC policies across the world', viewed 25 June, 2021, <http://www.chej.org/pvcfactsheets/PVC_Policies_Around_The_World.html>.

Chen, W-T, Jin, K & Wang, N-H 2019, 'Use of supercritical water for the liquefaction of polypropylene into oil', ACS Sustainable Chemistry & Engineering, vol. 7, no. 4, pp. 3749–3758.

Closed Loop Partners 2019, Accelerating Circular Supply Chains for Plastics: A Landscape of Transformational Technologies that Stop Plastic Waste, Keep Materials in Play and Grow Markets.

COAG 2020, Phasing out Exports of Waste Plastic, Paper, Glass and Tyres, Canberra.

Crippa, M, De Wilde, B, Koopmans, R, Leyssens, J, Linder, M, Muncke, J, Ritschkoff, A-C, Van Doorsselaer, K, Vells, C & Wagner, M 2019, A Circular Economy for Plastics – Insights from Research and Innovation to Inform Policy and Funding Decision, M De Smet & M Linder (eds), European Commission, Brussels, Belgium.

Davies, K, Kosior, E, Han, M, Mann, L, Egan, B & Singh, S 2021, Closed Loop Reprocessing of FG rHDPE in 2-Litre Milk Bottles.

DAWE 2021, 'National Product Stewardship Investment Fund', Department of Environment, Water and Agriculture, viewed 20 May, 2021, <https://www.environment.gov.au/protection/waste/product-stewardship/national-product-stewardship-investment-fund>.

DEE 2019, Australian Waste Exports, 2018–19, Canberra.

DELWP 2020, Recycling Victoria – A New Economy, Department of Environment, Land, Water and Plan, Melbourne.

Demetrious, A & Crossin, E 2019, 'Life cycle assessment of paper and plastic packaging waste in landfill, incineration, and gasification-pyrolysis', Journal of Material Cycles and Waste Management, vol. 21, no. 4, pp. 850–860.

Devasahayam, S, Bhaskar Raju, G & Mustansar Hussain, C 2019, 'Utilization and recycling of end of life plastics for sustainable and clean industrial processes including the iron and steel industry', Materials Science for Energy Technologies, vol. 2, no. 3, pp. 634–646.

Dilkes-Hoffman, LS, Pratt, S, Laycock, B, Ashworth, P & Lant, PA 2019, 'Public attitudes towards plastics', Resources, Conservation and Recycling, vol. 147, no. January, pp. 227–235.

Donaj, PJ, Kaminsky, W, Buzeto, F & Yang, W 2012, 'Pyrolysis of polyolefins for increasing the yield of monomers' recovery', Waste Management, vol. 32, no. 5, pp. 840–846.

Ellen MacArthur Foundation 2020a, Enabling a Circular Economy for Chemicals with the Mass Balance Approach, Ellen MacArthur Foundation.

Ellen MacArthur Foundation 2020b, The Global Commitment 2020, Ellen MacArthur Foundation.

Ellen MacArthur Foundation 2016, The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action, Ellen MacArthur Foundation.

ReNew ELP 2020, 'ReNew ELP', viewed 16 February, 2021, <https://renewelp.co.uk/>.

Emami, S & Nikje, MMA 2019, 'Environmentally benign chemical recycling of polycarbonate wastes: comparison of micro- and nano-TiO_2 solid support efficiencies', Green Processing and Synthesis, vol. 8, no. 1, pp. 108–117.

Envisage Works 2020, Recovered Resources Market Bulletin – Nov 2020, Sustainability Victoria, Melbourne, Australia.

Erdogan, S 2020, 'Recycling of waste plastics into pyrolytic fuels and their use in IC engines', in B Llamas, MFOR Romero & D Sillero (eds), Sustainable Mobility, IntechOpen.

Gala, A, Guerrero, M, Guirao, B, E. Domine, M & M Serra, J 2020, 'Characterization and distillation of pyrolysis liquids coming from polyolefins segregated of MSW for their use as automotive diesel fuel', Energy & Fuels, vol. 34, no. 5, pp. 5969–5982.

Geels, FW 2011, 'The multi-level perspective on sustainability transitions: responses to seven criticisms', Environmental Innovation and Societal Transitions, vol. 1, no. 1, pp. 24–40.

George, N & Kurian, T 2014, 'Recent developments in the chemical recycling of postconsumer poly(ethylene terephthalate) waste', Industrial and Engineering Chemistry Research, vol. 53, pp. 14185–14198.

Gershman, B & Bratton, I 2013, Gasification of Plastics from Municipal Solid Waste in the United States, Fairfax.

Giuliano, A, Freda, C & Catizzone, E 2020, 'Techno-economic assessment of bio-syngas production for methanol synthesis: a focus on the water–gas shift and carbon capture sections', Bioengineering, vol. 7, no. 3, pp. 1–18.

Goldberg, O, Haig, S & McKinlay, R 2019, Non-Mechanical Recycling of Plastics.

Grause, G, Buekens, A, Sakata, Y, Okuwaki, A & Yoshioka, T 2011, 'Feedstock recycling of waste polymeric material', Journal of Material Cycles and Waste Management, vol. 13, no. 4, pp. 265–282.

Greenpeace 2020, Deception by the Numbers, Washington, D.C.

Hannam, P 2019, 'Plastics-to-oil waste firm faces "tremendous" hurdles to set up in NSW', Sydney Morning Herald, 7 July, Sydney, Australia.

Hardesty, BD, Wilcox, C, Lawson, TJ, Lansdell, M & van der Velde, T 2014, Understanding the Effects of Marine Debris on Wildlife, Hobart.

Hicks, R 2020, 'Cheap virgin plastic is being sold as recycled plastic – it's time for better recycling certification', Eco-Business, viewed 10 May, 2021, <https://www.eco-business.com/news/cheap-virgin-plastic-is-being-sold-as-recycled-plastic-its-time-for-better-recycling-certification/>.

Hopewell, J, Dvorak, R & Kosior, E 2009, 'Plastics recycling: challenges and opportunities', Philosophical Transactions of the Royal Society B: Biological Sciences, vol. 364, no. 1526, pp. 2115–2126.

Hundertmark, T, Mayer, M, Mcnally, C, Simons, TJ & Witte, C 2018, How Plastics-Waste Recycling Could Transform the Chemical Industry, McKinsey & Company.

International Renewable Energy Agency & Methanol Institute 2021, Innovation Outlook Renewable Methanol, Abu Dhabi.

Jeswani, H, Krüger, C, Russ, M, Horlacher, M, Antony, F, Hann, S & Azapagic, A 2021, 'Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery', Science of the Total Environment, vol. 769.

JGC Holdings Corporation 2020, 'Accelerating the promotion of gasification chemical recycling of plastic waste – conclusion of an EUP relicensing contract', News Release, viewed 28 June, 2021, <https://www.jgc.com/en/news/2020/20201006.html>.

Jia, H, Ben, H, Luo, Y & Wang, R 2020, 'Catalytic fast pyrolysis of poly (ethylene terephthalate) (PET) with zeolite and nickel chloride', Polymers, vol. 12.

Khadem, N 2017, 'Australian entrepreneur Priyanka Bakaya aims for new recycling facility in Australia by 2019', The Sydney Morning Herald, 4 December, Sydney, Australia.

Krüger, C 2020, 'Evaluation of pyrolysis with LCA – 3 case studies', BASF, no. July.

Kumar, S & Singh, RK 2011, 'Recovery of hydrocarbon liquid from waste high density polyethylene by thermal pyrolysis', Brazilian Journal of Chemical Engineering, vol. 28, no. 4, pp. 659–667.

Lee, RP, Tschoepe, M & Voss, R 2021, 'Perception of chemical recycling and its role in the transition towards a circular carbon economy: a case study in Germany', Waste Management, vol. 125, pp. 280–292.

Levaggi, L, Levaggi, R, Marchiori, C & Trecroci, C 2020, 'Waste-to-energy in the EU: the effects of plant ownership, waste mobility, and decentralization on environmental outcomes and welfare', Sustainability (Switzerland), vol. 12, no. 14, pp. 1–12.

Licella Holdings 2021, 'Licella together with Coles, Nestlé, LyondellBasell and iQ Renew announce study into Australian-first for recycling', viewed 20 May, 2021, <https://www.licella.com.au/news/licella-together-with-coles-nestle-lyondellbasell-and-iq-renew-announce-study-into-australian-first-for-recycling/>.

Loop Industries 2021, 'Loop Industries. Leading the sustainable plastic revolution', viewed 25 April, 2021, <https://www.loopindustries.com/en/>.

Lopez, G, Artetxe, M, Amutio, M, Bilbao, J & Olazar, M 2017, 'Thermochemical routes for the valorization of waste polyolefinic plastics to produce fuels and chemicals. A review', Renewable and Sustainable Energy Reviews, pp. 346–368.

Macdonald-Smith, A 2021, 'Refinery closure triggers 150 job cuts at chemical plant', Australian Financial Review, 19 May.

Marcantonio, V, De Falco, M, Capocelli, M, Bocci, E, Colantoni, A & Villarini, M 2019, 'Process analysis of hydrogen production from biomass gasification in fluidized bed reactor with different separation systems', International Journal of Hydrogen Energy, vol. 44, no. 21, pp. 10350–10360.

Miandad, R, Barakat, MA, Aburiazaiza, AS, Rehan, M & Nizami, AS 2016, 'Catalytic pyrolysis of plastic waste: A review', Process Safety and Environmental Protection, vol. 102, Institution of Chemical Engineers, pp. 822–838.

Miskolczi, N, Bartha, L & Angyal, A 2009, 'Pyrolysis of polyvinyl chloride (PVC)-containing mixed plastic wastes for recovery of hydrocarbons', Energy & Fuels, vol. 23, no. 5, pp. 2743–2749.

Muhammad, C, Onwudili, JA & Williams, PT 2015, 'Thermal degradation of real-world waste plastics and simulated mixed plastics in a two-stage pyrolysis-catalysis reactor for fuel production', Energy and Fuels, vol. 29, no. 4, pp. 2601–2609.

O'Farrell, K 2019, 2018–19 Australian Plastics Recycling Survey – National Report, Canberra.

Oboirien, BO & North, BC 2017, 'A review of waste tyre gasification', Journal of Environmental Chemical Engineering, pp. 5169–5178.

Panda, AK, Singh, RK & Mishra, DK 2010, 'Thermolysis of waste plastics to liquid fuel. A suitable method for plastic waste management and manufacture of value added products – a world prospective', Renewable and Sustainable Energy Reviews, pp. 233–248.

Parliament of Australia 2020, From Rubbish to Resources: Building a Circular Economy, Commonwealth of Australia, Canberra, Australia.

Patel, D, Moon, D, Tangri, N & Wilson, M 2020, All Talk and No Recycling: An Investigation of the US Chemical Recycling Industry, Global Alliance for Incinerator Alternatives, Berkeley, CA.

Pedersen, Thomas, H & Conti, F 2017, 'Improving the circular economy via hydrothermal processing of high-density waste plastics', Waste Management, vol. 68, pp. 24–31.

Phipps, L 2019, 'The 5 things you need to know about chemical recycling', GreenBiz.

Pickin, J, Wardle, C, Farrell, KO, Nyunt, P, Donovan, S, Wardle, C & Grant, B 2020, National Waste Report 2020, Canberra.

Plasteurope 2018, 'Vinyloop: closure of operation in Italy: phthalates issue under REACH brings down European PVC recycling project', Plasteurope.com.

Plastic Energy 2021, 'Plastic Energy', viewed 10 February, 2021, <https://plasticenergy.com/#Intro>.

PolyStyreneLoop 2021, 'PolyStyreneLoop', viewed 22 April, 2021, <https://polystyreneloop.eu/>.

Polystyvet 2020, 'Polystyvert', viewed 22 April, 2021, <http://www.polystyvert.com/en/>.

Powell, D 2021, 'Coles, Nestlé in plans to build first-ever soft plastics recycling plant', The Age, 17 March.

Powerhouse Energy Group 2021, 'The Sustainable Hydrogen Company', viewed 26 June, 2021, <https://www.powerhouseenergy.co.uk/>.

PureCycle 2021, 'PureCycle', viewed 22 April, 2021, <https://purecycletech.com/>.

Pyrowave 2021, 'Pyrowave technology', viewed 10 May, 2021, <https://www.pyrowave.com/en/pyrowave-technology>.

Qureshi, MS, Oasmaa, A, Pihkola, H, Deviatkin, I, Tenhunen, A, Mannila, J, Minkkinen, H, Pohjakallio, M & Laine-Ylijoki, J 2020, 'Pyrolysis of plastic waste: opportunities and challenges', Journal of Analytical and Applied Pyrolysis, vol. 152, no. March.

Ragaert, K, Delva, L & Van Geem, K 2017, 'Mechanical and chemical recycling of solid plastic waste', Waste Management, vol. 69, pp. 24–58.

Ragaert, K, Huysveld, S, Vyncke, G, Hubo, S, Veelaert, L, Dewulf, J & Du Bois, E 2020, 'Design from recycling: a complex mixed plastic waste case study', Resources, Conservation and Recycling, vol. 155, no. March 2019, p. 104646.

Rahimi, AR & Garciá, JM 2017, 'Chemical recycling of waste plastics for new materials production', Nature Reviews Chemistry, vol. 1, pp. 1–11.

Randell, P, Baker, B & O'Farrell, K 2020, 'Used tyres supply chain and fate analysis report', no. June, pp. 1–60.

Rane, AV, Abitha, VK, Sabnis, A, Kathalewar, M, Jamdar, V, Patil, S & Jayaja, P 2015, 'A greener and sustainable approach for converting polyurethane foam rejects into superior polyurethane coatings', Chemistry International, vol. 1, no. 4, pp. 184–195.

Read, R 2021, 'Waste export ban on mixed plastics: is Australia ready?', Waste Management Review, no. May, pp. 61–62.

Recycling Technologies 2021, 'Chemical recycling 101', Plastipedia, viewed 17 March, 2021, <https://www.bpf.co.uk/plastipedia/chemical-recycling-101.aspx#_edn1>.

Retamal, M, Dominish, E, Wander, A & Whelan, J 2020, Environmentally Responsible Trade in Waste Plastics in the Asia Pacific Region.

Ritchie 2019, ‘The state of waste in Australia – a 2019 review’, Inside Waste.

Rubio, MR 2021, ‘Everything you need to know about PVC recycling’, viewed <https://www.bioenergyconsult.com/recycling-polyvinyl-chloride/>.

Saperatec 2020, ‘Saperatec back to values’, viewed 22 April, 2021, <https://www.saperatec.de/en/saperatec-en.html>.

Saptoadi, H, Rohmat, TA & Sutoyo 2016, ‘Combustion of char from plastic wastes pyrolysis’, AIP Conference Proceedings, American Institute of Physics Inc.

Schandl, H, King, S, Walton, A, Kaksonen, A, Tapsuwan, S & Baynes, T 2021, Circular Economy Roadmap for Plastics, Glass, Paper and Tyres – Pathways for Unlocking Future Growth Opportunities for Australia, Canberra.

Schyns, ZOG & Shaver, MP 2021, ‘Mechanical recycling of packaging plastics: a review’, Macromolecular Rapid Communications, vol. 42, no. 3, pp. 1–27.

Seshasayee, MS & Savage, PE 2020, ‘Oil from plastic via hydrothermal liquefaction: production and characterization’, Applied Energy, vol. 278, p. 115673.

Sharuddin, SDA, Daud, MAW & Aroua, MK 2016, ‘A review on pyrolysis of plastic wastes’, Energy Conversion and Management, vol. 115, pp. 308–326.

Sheel, A & Pant, D 2018, ‘Chemical depolymerization of polyurethane foams via glycolysis and hydrolysis’, Recycling of Polyurethane Foams, pp. 67–75.

Shen, Y 2020, ‘A review on hydrothermal carbonization of biomass and plastic wastes to energy products’, Biomass and Bioenergy, p. 105479.

Shen, Y, Zhao, R, Wang, J, Chen, X, Ge, X & Chen, M 2016, ‘Waste-to-energy: dehalogenation of plastic-containing wastes’, Waste Management, pp. 287–303.

Sherwood, J 2020, ‘Closed-loop recycling of polymers using solvents’, Johnson Matthey Technology Review, vol. 64, no. 1, pp. 4–15.

Shulman, VL 2019, ‘Tire recycling’, Waste, pp. 489–515.

Solis, M & Silveira, S 2020, ‘Technologies for chemical recycling of household plastics – a technical review and TRL assessment’, Waste Management, vol. 105, pp. 128–138.

Sparrow, N 2020, ‘Chemical recycling startup thinks globally, acts locally’, Plastics Today.

Sphera 2020, Project ChemCycling – Environmental Evaluation Based on Life Cycle Assessment (LCA), BASF.

Sphera Solutions 2020, Evaluation of Pyrolysis with LCA – 3 Case Studies, BASF.

Staub, C 2021, ‘Chemical recycling now at the center of national plastics debate’, Plastics Recycling Update, Portland, OR.

Sustainability Victoria 2021, ‘Engaging communities on waste’, viewed 4 June, 2021, <https://www.sustainability.vic.gov.au/recycling-and-reducing-waste/delivering-waste-and-recycling-services/kerbside-recycling/educating/engaging-communities-on-waste>.

Tullo, AH 2020, ‘Companies are placing big bets on plastics recycling. Are the odds in their favor?’, Chemical & Engineering News.

TyreStewardship Australia, Sustainability Victoria & Department of the Environment and Science 2018, Tyre Pyrolysis and Gasification Technologies: A Brief Guide for Government and Industry. An independent guide on tyre pyrolysis and gasification plant technology in Australia, Collingwood, VIC.

UK Government 2021, ‘Introduction of Plastic Packaging Tax’, Gov.UK, viewed 16 June, 2021, <https://www.gov.uk/government/publications/introduction-of-plastic-packaging-tax-from-april-2022/introduction-of-plastic-packaging-tax-2021>.

Vince, M-L 2015, ‘Central Coast plastics fuelling the future’, ABC News, 21 May.

Vollmer, I, Jenks, MJF, Roelands, MCP, White, RJ, Harmelen, T Van, Wild, P De, Laan, GP Van Der, Meirer, F, Keurentjes, JTF & Weckhuysen, BM 2020, ‘Beyond mechanical recycling : giving new life to plastic waste’, Angewandte Chemie International Edition in English, vol. 59, pp. 15402–15423.

Weeden, GS, Soepriatna, NH & Wang, N-HL 2015, ‘Method for efficient recovery of high-purity polycarbonates from electronic waste’, Environmental Science & Technology, vol. 49, no. 4, pp. 2425–2433.

World Waste to Energy 2020, ‘The future of gasification’, viewed 28 June, 2021, <https://worldwastetoenergy.com/the-future-of-gasification/>.

WWF 2020, Plastic Revolution to Reality: A Roadmap to Halve Australia’s Single-Use Plastic Litter, WWF.

Wyss, KM, Beckham, JL, Chen, W, Luong, DX, Hundi, P, Raghuraman, S, Shahsavari, R & Tour, JM 2021, ‘Converting plastic waste pyrolysis ash into flash graphene’, Carbon, vol. 174, pp. 430–438.

Yamada, S, Shimizu, M & Miyoshi, F 2004, Thermoselect Waste Gasification and Reforming Process.

Yang, Y, Rock, Liew, K, Tamothran, AM, Shin, Foong, Y, Nai, Peter, Yek, Y, Poh, Chia, W, Thuan, Tran, V, Peng, W, Su, & Lam, S 2021, ‘Gasification of refuse-derived fuel from municipal solid waste for energy production: a review’, Environmental Chemistry Letters, vol. 1.

Yu, J, Sun, L, Ma, C, Qiao, Y & Yao, H 2016, ‘Thermal degradation of PVC: a review’, Waste Management, pp. 300–314.

Zhao, YB, Lv, XD & Ni, HG 2018, ‘Solvent-based separation and recycling of waste plastics: a review’, Chemosphere, vol. 209, pp. 707–720.

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

Contact us
1300 363 400
csiro.au/contact
csiro.au

For further information
CSIRO Manufacturing
Sarah King
+61 3 5246 4747
sarah.king@csiro.au
csiro.au/manufacturing

B&M | 21-00312

APPENDIX 2

COMMUNITY AND STAKEHOLDER ENGAGEMENT REPORT DECEMBER 2021

Herein contains the report ‘Advanced chemical recycling of plastics in Altona’ as provided by Capire Consulting Group on 22 December 2021.

Advanced chemical recycling of plastics in Altona

Community and Stakeholder Engagement Report

22 December 2021

capire

COMMUNITY

The term community refers to a group of people that has something in common such as identity, behaviours, interests or values. A community often share a sense of place in a given geographical area (e.g. a country, city, town, or neighbourhood) or in virtual space through communication platforms.

STAKEHOLDER

The word stakeholder refers to individuals, groups or organisations with a stake or interest in the outcome of a decision. Stakeholders may also have the ability to influence the decision given their role or position.

ENGAGEMENT

Engagement is defined as a planned process with the purpose of working with communities and stakeholders to inform decisions, share knowledge and strengthen relationships.

Introduction

Purpose of this document

This document provides an overview of the promotion, communication and engagement activities undertaken by Capire Consulting Group on behalf of Licella. The engagement program was carried out throughout 2021.

This document presents a record of feedback from participants collected through a range of engagement activities. It is not intended as a social research report. Rather, this report presents the breadth and depth of feedback received.

This document has been prepared for Licella to inform regulatory approval processes at local and state government levels.

Community feedback will be considered alongside operational and technical considerations to help Licella make decisions about the design and commissioning of advanced chemical recycling in Altona.

About Capire

Capire Consulting Group (Capire) is a specialist community engagement firm. Capire was engaged by Licella to assist in the design, delivery and reporting of community engagement to support the advanced chemical recycling of plastics in Altona.

Capire worked collaboratively with Licella throughout 2021. The engagement approach was developed to align with guidance prepared by International Association of Public Participation (IAP2).

Project Background

Licella are developing a proposal for an advanced chemical recycling facility in Melbourne’s West to recycle soft plastics into a food grade quality product.

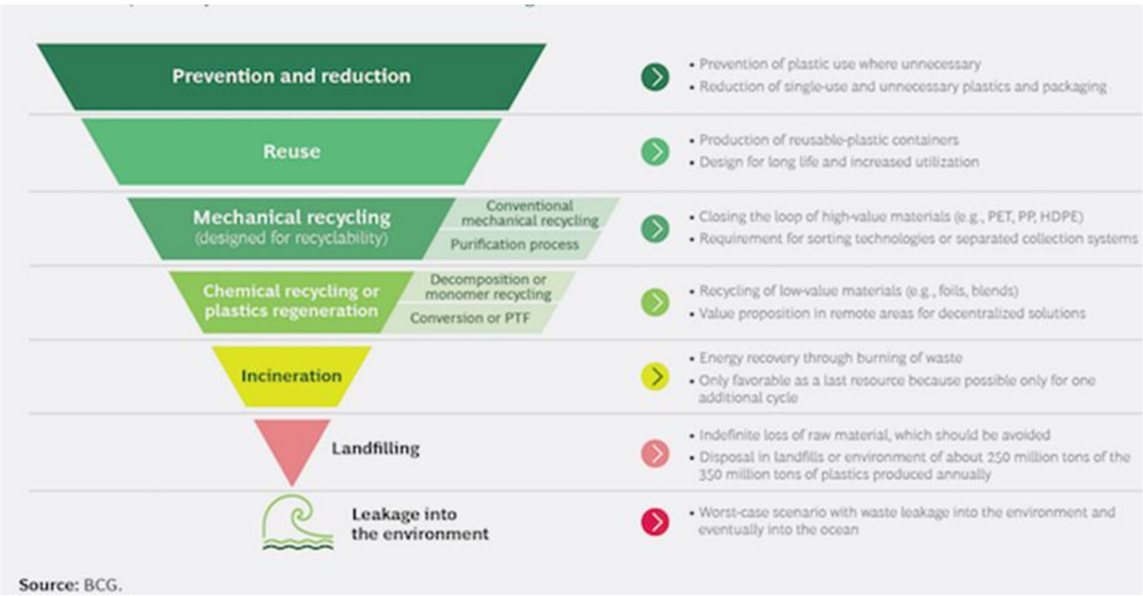
The project is in partnership with Coles, Nestle, LyondellBasell. Amcor and iQ Renew.

The proposal is looking at the former Dow Chemical site in the Altona Chemical Complex in Melbourne’s West.

The core facility will use an innovative Australian technology called CAT-HTR (Catalytic Hydrothermal Reactor). The application of this technology to plastics recycling provides a higher order solution to traditional mechanical soft plastics recycling. The facility will process a minimum of 20,000 tonnes per year and a maximum of 120,000 tonnes per year.

As demonstrated in image 1 below, the technology occupies an elevated position on the waste hierarchy above mechanical recycling for the soft plastics waste stream. The key point of difference is the ability for this technology to regenerate food-grade quality soft plastics.

Image 1 shows where an advanced recycling facility sits on the waste hierarchy. Understandably, the aim is to prevent plastic use and reduce single use plastic packaging. However, notwithstanding elimination of plastic use – the chemical recycling process provides a way to manage plastic waste in a way that is low emissions and that repurposes the plastic. The process can ultimately be repeated until all plastic circulation within our industries is recycled within the circular economy.



Source: BCG.

Image 1 The Waste Hierarchy

Licella engaged Capire Consulting Group to plan and deliver a range of community and stakeholder engagement activities. The purpose of the engagement is to understand community and stakeholder concerns and issues with the proposed facility and identify options to mitigate those concerns through the proposal. The objectives of the engagement were to:

- Determine the technical, economic, and environmental benefits of a local advanced recycling industry
- Build community and stakeholder understanding of the Cat-HTR™ technology, advanced recycling and how this contributes to a circular economy
- Build trust in Licella and their partners
- Identify community and stakeholder concerns early in the development of the proposal
- Engage with key stakeholders to develop a baseline of what issues need to be addressed in the Development Licence application process
- Work with key stakeholders to develop options which mitigate community concerns and issues to the greatest extent possible.

Clear negotiables and non-negotiables were defined and communicated to stakeholders during the engagement process to ensure they understand how their contribution may influence decisions. This ensured stakeholder expectations were managed at the outset, and continually reinforced to alleviate any potential for misunderstanding during the engagement.

Table 1 Proposal negotiables and non-negotiables

Negotiables	Non-negotiables
Positioning within the site (micro siting), e.g., move away from road or to the back corner of the block.	Spacing between the facility and housing (e.g. the minimum required separation distances between industry and sensitive land uses).
Waste preparation and sorting is negotiable as to whether it is done on site or off site. • If done on site the hours negotiable, e.g., only during the day and not sorted at night • If done off-site traffic management plan will need to be negotiated.	Site location (based on appropriate zoning and other technical restrictions).
Visual amenity from the street – site layout is negotiable. e.g., micro-siting of certain buildings can be negotiated.	The height of the reactors.
The colour of stacks can be changed.	The use of the Cat-HTR™ technology and advanced recycling process.
Volume – If this proposal is a success, Licella would be looking to scale operations up to processing capability of 120,000 tonnes of feedstock per annum. The initial application is for 20,000 tonnes per annum	Hours of operation (24/7).
Works scheduling during construction, e.g., can negotiate no work on weekends, no night works etc.	
Methods of engagement of engagement with community and stakeholders.	
Procurement strategy – the use of contractors during construction and operations is negotiable. There is an opportunity to use local content and workforce.	

Engagement Risks

During preliminary engagement, risks emerged regarding the engagement process. Overall, environmental organisations and community groups were supportive of Licella's objectives to find a solution to soft plastic recycling, but key points will need to be addressed and mitigated so the community can feel involved and comfortable with the proposal. Risks identified through preliminary engagement are summarised in Table 2. The risks identified were managed or mitigated throughout the engagement process.

Table 2 Preliminary risks and proposed mitigation

Risk	**Description**	**Risk rating**	**Mitigation**
Poor community perception of the proposal	Historical issues about air quality and waste managed at Altona will create negative association for Licella	High	Develop key messages and communications material in line with "risk communication" principles that clearly convey and acknowledge community concerns.
Low levels of understanding	People mis-understand / mis-trust information about Licella's proposed technology and process	High	Ensure people are provided ample time and multiple opportunities to engage in the technical detail. Conduct an education campaign with independent experts publicly assessing the proposed technology / processes
Low levels of understanding	The Cat-HTR™ technology is complex, and it may be challenging to break through pre-conceived notions of chemical recycling	Moderate	Develop and distribute materials that explain Licella and the technology in plain English, supported by visual materials and follow up conversations
Low trust in proposal	Trust in Licella is eroded as people don't feel involved or heard in the process	Moderate	Engage with stakeholders early and ensure that people have time to process information and can make informed submissions. Clearly convey the timeline of engagement to date on collateral and online. Facilitate personal relationships between stakeholders and Licella.
Engagement conversations are dominated by the loudest voices	There are a variety of different stakeholders and community groups with potentially polarising views and varied interests in the proposal	Moderate	Ensure that participants are representative of the targeted stakeholder groups identified as priority. Promote the opportunities to be involved in the community engagement

Risk	Description	Risk rating	Mitigation
			process widely across the community. Use a range of techniques to provide participants different ways to contribute to face-to-face activities such as worksheets or dotmocracy (dot voting).
Proposal is political	Elected Councillors may use polarised community views on the proposal as political tool.	Moderate	Facilitate 1:1 conversation with each Councillor to understand potential questions or concerns about the project. Provide briefing packs with accessible information to explain the technology and process and articulating the local benefits including reduced air quality emissions (on balance), local jobs, local investments.

Engagement Approach

Underpinning the engagement activities are three goals including:

1. Build the community knowledge and understanding of the CAT-HTR™ technology.
2. Establish relationships between the community, Licella and planning authorities as a basis for trust building.
3. Inform decisions about strategies that mitigate community concerns with the proposal.

Engagement Stages

The engagement program was stepped out into two phases:

- Phase 1: foundational engagement, desk top study, interviews with environmental advocacy groups and community networks to identify type of issues community are concerned with and their preferred approach to being consulted.
- Phase 2: community presentations and focus group sessions to understand specific community concerns of the proposal and determine satisfactory mitigation strategies.

There are two more additional phases of engagement planned following planning and environmental approvals. These phases include:

- Phase 3: procurement and construction, communicating progress and managing impacts of the community, to keep community and stakeholders informed during construction process.
- Phase 4: Commissioning, convening community reference groups, conducting site tours and community education campaign about the role of advanced recycling in sustainability and circular economy.

Assumptions and limitations

This report details the participants' perceptions, concerns and ideas as expressed during the engagement activities. Capire is confident this report provides a true account of the feedback provided.

Engagement and COVID-19

The engagement approach was designed to ensure that activities could continue while maintaining the safety of the public, staff and team members due to planned lockdowns throughout the pandemic. These were further strengthened in response to the ongoing Covid-19 stay-at-home orders throughout the engagement period.

These included:

- Holding all workshops online via Zoom and providing phone call drop-in sessions and enhanced opportunities for web and email enquiries or submissions to substitute for face-to-face community events
- Increase focus on targeted promotion through phone and email of community networks in the local area
- Working with existing community reference groups and community leaders, including elected officials.

Summary of participants

Overall participation

During phase 1, Capire engaged relevant environmental groups and community groups proximate to the proposed Altona Cat-HTR™ site. The purpose of the preliminary engagement was to test interest and concern with advanced/chemical recycling of soft plastics in general.

Licella's advanced recycling project was not specifically mentioned during the initial interviews. The project was introduced following an announcement of the feasibility study of a local advanced recycling industry and potential sites in Victoria.

The peak environmental advocacy groups were selected based on their reputable and broad reaching influence on recycling issues at local and national levels, and included:

- Boomerang Alliance
- World Wide Fund for Nature (WWF)
- Australian Conservation Foundation
- Geelong Sustainability
- Environment Victoria.

Local community networks were selected based on their connections to the local community in Altona, their broad and diverse reach across communities and specific interest, and included:

- Hobsons Bay City Councillors
- Inner West Air Quality Network (formerly reference group)
- Friends of Stony Creek
- Somers Parade Kindergarten
- Altona Little Athletics
- Altona Badminton Club
- Altona Yacht Club
- Altona Tennis Club
- Altona East Phoenix Soccer Club
- Altona Laverton Historical Society
- Nature West (environmental community network).

Capire also engaged with EPA Victoria and Hobsons Bay City Council, critical stakeholders to enable the planned facility to proceed.

Summary of findings

A summary of the key messages from initial conversations with these stakeholders included:

- Most community and stakeholder representatives are supportive of finding a local solution to soft plastics recycling
- Establishing trust and credibility within the community and environmental groups was considered paramount to success
- Fundamental concerns about the volumes of plastics still in circulation that end up in the environment
- Key concerns about cumulative local air quality impacts from industry on local community
- Concerns about the practicality and reliability of people taking their plastics to collection points for recycling and the manual extraction on assembly lines.

Air quality impacts

Air quality impacts represented the chief concern of community and stakeholder groups.

- Community is concerned the Australian Standards for air quality are not high enough and there is poor regulation of residual air emissions and pollution.
- There is a perception that there are ‘no safe levels’ of particulate matter to be emitted into the air.
- Community is concerned of the cumulative impact on air quality and feel air quality in Altona is already poor.
- There is a general mistrust of data modelling for air quality with the view that experts can manipulate a model to suit pre-determined conclusions.
- Community is concerned about residual waste products of recycling processes and how these are disposed of.
- Community is concerned about toxic waste and how the EPA regulates this waste stream generally.

Road congestion and truck movements

Stakeholder raised the ongoing critical impact truck movements have on the overall public health and amenity of the community throughput the West.

- Community is concerned about additional truck movements in and around residential communities throughout the West including Laverton and Altona.
- The main concern is the risk and impact of additional truck movements along Millers Road, a common route trucks take to avoid tolls.
- Community is seeking assurances the movement of trucks to and from the site would use Kororoit Creek Road.

Competing with Waste-to-Energy

Stakeholders note the large number of recycling facilities currently being developed and the risk of creating unwanted assets and illegal stockpiling of waste.

- Community is concerned about the reliability and validity of industries which provide solutions to complex issues such as waste recycling. The risk is associated with where the ‘feedstock’ for the recycling comes from and how it is sorted.
- On the other side of the equation, community feel once a facility is operating, industry will be driven to “feed a hungry beast” with disregard to original intentions of a project.
- Community is wary of stated performance of technology. They require evidence on international experience and comparison of real data between technology options.
- Previous proposals in the area show a fear of “cheap technology” which does not meet best-practice standards.

Detailed Issues raised during engagement

Throughout the engagement process key questions were raised by community and stakeholders. Representatives of Licella addressed the questions during technical presentations, 1:1 meetings and stakeholder meetings. The following written response to each question documented and responded accordingly and sent to stakeholders.

Table 3 Community and stakeholder questions and responses

No	Question	Answer
1	Have you operated a plant anywhere else in the world or in Australia?	The Cat-HTR technology for processing end-of-life plastics is a breakthrough new technology. Licella's patented Catalytic Hydro-Thermal Reactor (Cat-HTR) technology was developed in Australia and has successfully been demonstrated on four scales of pilot plants at Licella's advanced engineering facility in Somersby NSW. Commercial Cat-HTR facilities are currently under construction in the UK and Japan. The proposed Altona facility will likely be the third commercial Cat-HTR facility to become operational in the world. As such, design and operational experience from the UK and Japan will likely be available.
2	We are nervous about pollutants and new industries, why are you setting up in metro, why not outside of Melbourne?	The site at Altona Dow Chemical has the correct industrial zoning for our operations. This site has all of the utilities that we need including recycled industrial water supply, trade-waste water discharge, potable water supply, natural gas supply, industrial electricity connection and nitrogen supply. The site has an excellent road connection so that the trucks that service our site can come directly to and from the freeway without passing through any nearby residential or commercial areas. Most of the energy used for our operations will be from electricity and we will be contracting green electricity supply for our industrial use.
3	What is the upper limit of plastics throughput?	We will be processing end-of-life plastics that would otherwise go to landfill. We plan is to commence operations at Stage 1 - 20,000 tonnes per year feedstock. Additional stages will be considered based on the economics of the project. Assuming this happens then we plan to increase feedstock throughput in stages, probably in 20kt increments as availability of waste plastics is determined. We believe in time this could increase to 120,000 tonnes per year.
4	What is the nature of the product? Is it	The Cat-HTR produces 2 main products. The principal product is a synthetic crude oil called "plasticrude". This product will be tankered to a facility such as the Geelong Viva Refinery. The second product is a "product gas" which is formed during the processing of the end-of-life plastic feedstock. The gas is

	flammable? It will burn, right?	collected and used as fuel onsite. These products are designed to substitute traditional fossil fuels and are designed to burn in similar manner to their traditional counterparts. Processing of the end-of-life feedstock along with storage of the products will be carried out in accordance with relevant Australian Standards in correctly designed and rated equipment and storage tanks.
5	What is the total storage volume of synthetic crude at stage 1 of the project?	In Stage 1 it is planned to manufacture 44 tonnes per day of plasticrude. Total storage capacity for plasticrude is estimated to be 583 tonnes which will allow for 13.4 days production if required. Tankers will transport the product from site 2 or 3 days per week.
6	How will product be stored on site?	The oil products will be stored in tanks. The tanks will be built and maintained to all relevant Australian Standards. The gas product will be used as part of the Cat-HTR process or sold to nearby customers (such as EnviroPacific). If there is any excess gas this will be combusted.
7	How many trucks for stage 1?	In Stage 1 operations there will be ~ 40 truck movements per week. Trucking will take place Monday to Saturday.
8	What is the catalyst used in the process? (reference to catalytic hydrothermal reaction)	When water reaches its supercritical state, it acts as a catalyst to assist in the depolymerisation of the plastics.
9	Are there sulphur compounds in the feed plastics?	In general there are no sulphur compounds in the feed plastic. The qualifier for this is that, whilst the plastics will be cleaned, any sulphur residue on the plastics remaining after the plastic is discarded may get into the process. Most residue not removed during plastics pre-cleaning will dissolve into the superheated water and be removed in the water cleaning process.
10	What happens to residual waste segregated from soft plastics such as metals?	Wherever possible residual contaminants such as metals will be collected and recycled.
11	Any odour emissions to be concerned about?	Feedstock end-of-life plastics will be baled and loaded into 40ft containers by others then delivered to site. The containers of plastics will not be opened until the feedstock is to be fed into the process. In Stage 1, 3 x containers will be emptied per day.

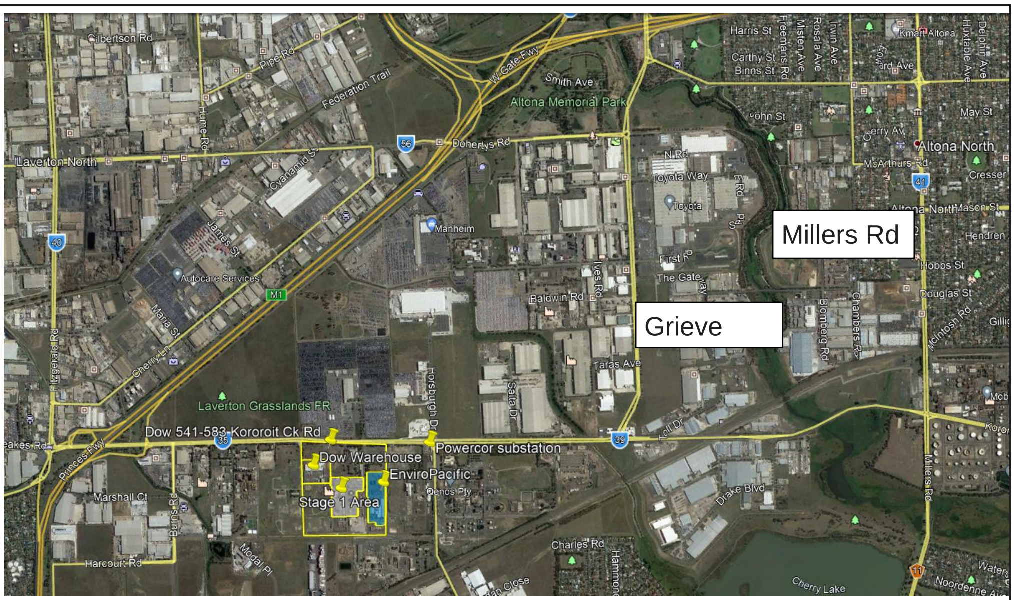
<table>
<tr><td></td><td></td><td>Any odours from the waste plastic will be managed within process shed.</td></tr>
<tr><td>12</td><td>Will the offloading shed have some ventilation system? Will you monitor odour?</td><td>The offloading shed will have an open end to allow for the containers of plastics to be delivered and emptied. It is not planned to monitor odour. Licella has extensive knowledge with Municipal Recycling Facilities) MRFs through the development of this project and the experience with MRFs (which handle much larger waste volumes) is that odours are minimal and restricted to inside the shed.</td></tr>
<tr><td>13</td><td>What is the threshold level of ammonium odour in air? Will the facility exceed this?</td><td>The table below shows the EPA limits for Ammonia and the modelling that has been done for the facility and how this reflects against these limits. As can be seen in all cases its under significantly under 1% of the EPA allowable level.
<table>
<tr><td colspan="4"><i>EPA allowable levels for Ammonia (NH3)</i></td></tr>
<tr><td></td><td><i>1 hour av.</i></td><td><i>1 day av.</i></td><td><i>1 year av.</i></td></tr>
<tr><td>ppm</td><td>4.6</td><td>1.7</td><td>0.1</td></tr>
<tr><td colspan="4"><i>Modelling Max ammonia within 400m</i></td></tr>
<tr><td>ppm</td><td>0.0015</td><td>0.0035</td><td>0.00009</td></tr>
<tr><td>%age of EPA level</td><td>0.03</td><td>0.02</td><td>0.09</td></tr>
</table></td></tr>
<tr><td>14</td><td>Is there gas emissions control?</td><td>We will adopt industry best practice to treat the emissions from the boiler which will be similar to a natural gas boiler. We are currently investigating options.</td></tr>
<tr><td>15</td><td>Any particulate matter?</td><td>We do not expect particulate matter. The Cat-HTR is a hydrothermal process, and product gas is manufactured when the end-of-life plastic breaks down in the presence of water. Any particulates that are present are trapped in the water system and are processed though the water treatment plant.</td></tr>
<tr><td>16</td><td>Any fugitive emissions from the gas produced? Eg CO emissions?</td><td>Fugitive emissions contained in the supercritical boiler exhaust are very low levels of NOx, SOx and NH3 (which has been described earlier). Because the supercritical boiler has almost complete combustion of the product gas, there will be negligible CO.
The modelling shows:
<table>
<tr><td colspan="3"><i>EPA allowable levels for NOx*</i></td></tr>
<tr><td></td><td><i>1 hour av.</i></td><td><i>1 year av.</i></td></tr>
</table></td></tr>
</table>

ppm	0.12	0.03
Modelling Max NOx within 400m before scrubbing		
ppm	0.0056	0.00042
%age of EPA level	4.6	1.4
Modelling Max NOx within 400m after scrubbing		
ppm	0.00112	0.000084
%age of EPA level	0.92	0.28

* *Note: NOx does not have EPA 1 day av.*

EPA allowable levels for SOx			
	1 hour av.	*1 day av.*	*1 year av.*
ppm	0.2	0.08	0.08
Modelling Max NOx within 400m before scrubbing			
ppm	0.00044	0.000118	0.000041
%age of EPA level	0.22	0.23	0.21

17	Extra trucks on Millers Road?	Given the location of our site to the freeway, there is no reason why trucks servicing our site should travel on Millers Rd. and we will make it a condition of delivery that they do not except in exceptional circumstances e.g. if the freeway is closed
18	What if there is breakdown on Kororoit Creek Road or if truck drivers avoid tolls?	Kororoit Creek Rd is a four lane road. It would be most unusual for Kororoit Creek Rd to be blocked. However, if Kororoit Creek Rd was blocked, then trucks could use Grieve Parade to access our site, not Millers Rd.

		
19	What pressure the boiler is running at?	Specific operating conditions are confidential information however the supercritical boiler will be designed to be capable of operation up to 300bar (30MPa). Commercial operating pressure are expected to be much lower than that.
20	How many people will work at the plant?	For Stage 1 - 53 jobs during construction; 22 jobs at site for operations; 57 indirect jobs once operations commence.
21	Locals employed?	Yes locals will be able to apply for jobs.
22	Will there be a visible steam plume? Or a cooling tower?	The site will have a small cooling tower. It will be located 320m back from Kororoit Rd behind the boundary tree line and behind several buildings. Under certain weather conditions there may be a visible moisture plume however it is not expected to be of visual significance from Kororoit Creek Rd.
23	Are there safety systems in place for catastrophic failure of the boiler?	The supercritical boiler has an over-pressure relief valve, will have safety control systems and its construction and operations will meet all relevant Australian Standards and Vic WH&S operational requirements for boilers.
24	When will the plant be operational?	Our schedule has Stage 1 commencing operations mid 2023.

25	Where will the waste product come from?	We expect to source end-of-life plastics from several suppliers including RedCycle, Amcor and several MRFs.

Conclusions

Overall, the engagement presented some clear themes as well as highlighting some challenges that Licella will need to address during the construction and commissioning phases of the project.

There is general support for the objectives of Licella’s project - tackling non-recyclable plastics, developing clean technology industries locally and improving environmental outcomes across the waste industry. However, it is acknowledged that, despite implementing best practices, the new operation may present some risks and minor impacts to the local community.

Education and ongoing engagement will be essential to continue to build understanding across the Altona community about the role and operation of the Licella project in the context of managing Victoria’s waste challenges.

Ongoing community engagement will be essential throughout all subsequent stages of this project.

Next steps

Throughout 2021 ongoing Covid-19 stay-at-home orders have prevented Licella from meeting members of the community face to face. To ensure effective relationships are built with the community, Licella is planning to host a series of neighbourhood pop-ups and community events throughout 2022 to inform community about the project. Licella is committed to creating opportunities to provide further feedback and understand the best way to consult in the future will be sought.

APPENDIX 3
CHLORINE BALANCE ON SPIKED RUN

The following report is Commercial-in-Confidence and will not be disclosed as part of the public report.

COMMERICAL-IN-CONFIDENCE

SPP RUN REPORT

Chlorine Balance Small Pilot Plant (SPP) Run 30/10/2017

Commercial in Confidence

Prepared for

Internal Review, RenewELP

Document Status: Updated FINAL DRAFT
Prepared by: DK, JT, WNR
Approved by: WNR
Issue Date: 25/03/2020
Document Reference: Chlorine balance on spiked run 30_10_2017 update Mar2020.docx

APPENDIX 4

GREATER WESTERN WATER (GWW) APPROVED ACCEPTANCE CRITERIA FOR DISCHARGE TO THE TRADEWASTE SEWERAGE SYSTEM

Herein contains the document ‘Approved Acceptance Criteria for discharge to the sewerage system’ as provided by City West Water.

City West Water™

Approved Acceptance Criteria

for discharge to the sewerage system

Contents

Trade waste must comply with the Approved Acceptance Criteria set out in this document.

1 Physical characteristics

1.1 Temperature

The Occupier must not discharge trade waste with a temperature greater than 38°C.

1.2 Solids

a. The Occupier must not discharge trade waste containing gross solids, suspended solids or total dissolved solids except in accordance with this clause.

b. Gross solids contained in trade waste must:

   i. be able to pass through a bar screen with 13mm spaces between bars, and

   ii. have a quiescent settling velocity of not more than 3m/hour.

c. Where the total mass load of suspended solids exceeds 1,000 kg/day, the concentration of suspended solids must not exceed 10,000 mg/litre.

d. The total mass load of total dissolved solids must not exceed 200 kg/day.

e. The Occupier must not discharge waste containing fibrous material which, in the opinion of the Authorised Person is likely to cause obstructions in a drain or sewer.

1.3 Oils, fats and grease

a. The Occupier must not discharge trade waste containing any free or floating layer of oil, fat or grease.

b. The Occupier may discharge trade waste containing emulsified oil, fat or grease which, in the opinion of the Authorised Person, is biodegradable, if the emulsion is stable:

   i. at a temperature of 15° C, and

   ii. when it is in contact with raw sewage, and the resulting mixture has a pH no less than 4.5 and no greater than 10.0.

c. The Occupier must not discharge trade waste containing emulsified oil, fat or grease which, in the opinion of the Authorised Person is not biodegradable, if it contains more than 1,000 mg/litre of material recovered by a solvent prescribed by the Authorised Person as extractable matter when the emulsion:

   i. is stable at a temperature of 15° C, and

   ii. is in contact with raw sewage, and the resulting mixture has a pH no less than 4.5 and no greater than 10.0.

d. The Occupier must not discharge trade waste containing emulsified oil, fat or grease if it contains more than 200 mg/litre of material recovered by a solvent prescribed by the Authorised Person as extractable matter when the emulsion:

   i. is unstable at a temperature of 15°C, and

   ii. is in contact with raw sewage, and the resulting mixture has a pH no less than 4.5 and no greater than 10.0.

1.4 Organic liquids

a. The Occupier must not discharge trade waste containing any free or floating layer of organic liquid.

b. The Occupier must not discharge any trade waste which, in the opinion of the Authorised Person, may be:

   i. flammable, or

   ii. toxic or otherwise harmful or damaging to any person, drain, the sewerage system, any sewage treatment process, or any element of the environment which receives effluent after it has been treated.

c. The Authorised Person may, in writing, authorise the Occupier to undertake an act which would otherwise contravene sub-clause (b).

1.5 Latex emulsions

a. In this clause:

- "biodegradable" in relation to trade waste means that, in the opinion of the Authorised Person, the total organic carbon content of the trade waste would decrease by at least 90% when submitted to the sewage treatment process employed by City West Water or Melbourne Water for that waste
- "latex emulsion" includes an emulsion containing paint, adhesive, rubber, plastic or similar materials
- "stable latex emulsion" means a latex emulsion in which the solids deposited in a filter do not increase by more than 200 mg/litre when the emulsion:

   i. is at 15° C, and

   ii. is in contact with raw sewage, and the resulting mixture has a pH no less than 4.5 and no greater than 10.0.

b. The Occupier may discharge trade waste containing a biodegradable stable latex emulsion.

c. The Occupier must not discharge trade waste containing a stable latex emulsion which is not biodegradable at a concentration greater than 1,000 mg/litre of total solids.

d. The Occupier must not discharge trade waste containing an unstable latex emulsion.

1.6 Radioactive waste

The Occupier must only discharge trade waste which complies in all respects with the *Radiation Regulations 2007*, as amended from time to time.[1]

1.7 Colour

The Occupier must not discharge trade waste containing colour greater than 9 Adams-Nickerson (42) units, determined from the most pronounced colour obtained from a sample adjusted to a pH of not less than 7.0 and no greater than 8.0, following biological treatment by an activated sludge process.

---

[1] The Occupier must only discharge trade waste which complies with all aspects of the current radiation regulations available from www.health.vic.gov.au.

2 Chemical characteristics

2.1 pH value

The Occupier must not discharge trade waste with a pH value less than 6.0 or greater than 10.0, except as provided by Clause 2.3 (b) (ii).

2.2 Organic concentration

The Occupier must not discharge trade waste with a total mass load of 5-day biochemical oxygen demand in excess of 1,000 kg/day, unless its concentration is no greater than 4,000 mg/litre.

2.3 Nitrogen

The Occupier must not discharge trade waste with a concentration of:

a. total Kjeldahl nitrogen greater than 500 mg/litre; or

b. ammonia, plus ammoniacal ion (expressed as 'N') greater than:

   i. 50 mg/litre, except as provided by this clause.

   ii. 200 mg/litre, where –

   A. the trade waste discharge can only be received by Melbourne Water's Western Treatment Plant

   B. a risk assessment has been conducted

   C. the occupier can comply with a restricted pH range of 6.0 to 8.0 and

   D. the occupier has demonstrated to the Authorised Person, that commonly available waste minimisation technology has been applied to the best extent practicable.

2.4 Sulphur substances

a. Oxidised sulphur

   i. For the purposes of this clause, "oxidised sulphur" means the chemical substances expressed as S and known as sulphates, sulphites and thiosulphates.

   ii. The Occupier must not discharge trade waste containing oxidised sulphur with a concentration of 100 mg/litre or more, except as provided in this clause.

   iii. The Occupier must treat any trade waste with a concentration of oxidised sulphur greater than 600 mg/litre, before it is discharged.

   iv. Where trade waste prior to discharge would have a total concentration of oxidised sulphur of not less than 100 mg/litre and not more than 600 mg/litre, the Occupier must treat any stream of waste contributing to the discharge which has a concentration of oxidised sulphur greater than 600 mg/litre.

   v. The Occupier must use the best available technology, as determined by the Authorised Person, to treat any trade waste under sub-clause (iii) or (iv).

b. The Occupier must not discharge trade waste containing sulphide in a concentration greater than 1 mg/litre.

2.5 Metals

a. The Occupier must not discharge any element listed in Column 1 of Table A, except in accordance with this clause.

b. Where the daily mass load of any element discharged is between the lower limit specified in Column 2 and the upper limit specified in Column 3 for that element, trade waste must not exceed the concentration specified in Column 4.

c. Where the daily mass load of any element discharged is either lower than the limit specified in Column 2 or greater than the limit specified in Column 3, the Authorised Person must determine the maximum concentration of that element which the Occupier may discharge.

d. Where no entry is made in Column 2 and 3 for any element, trade waste must not exceed the concentration for that element specified in Column 4.

e. Where the Occupier has demonstrated to the Authorised Person, that it is unable to limit the concentration of the boron (as B) to the concentration specified in Table A, Column 4 using commonly available waste minimisation technology to the best extent practicable, the Occupier may discharge trade waste containing boron in a concentration no greater than 100 mg/litre.

f. Where the Occupier has demonstrated to the Authorised Person, that it is unable to limit the concentration of the manganese (as Mn) to the concentration specified in Table A, Column 4 using commonly available waste minimisation technology to the best extent practicable, the occupier may discharge trade waste containing manganese in a concentration no greater than 100 mg/litre.

Table A

Column 1: Element	Column 2: Grams/day	Column 3: Grams/day	Column 4: Milligrams per litre
Arsenic			1
Barium			150
Beryllium			30
Boron as B			25
Cadmium	0.4	20	2
Chromium	100	5,000	10
Cobalt			10
Copper	100	5,000	10
Iron	2,000	100,000	100
Lead	100	5,000	10
Manganese			10
Mercury	0.2	10	1
Molybdenum			10
Nickel	10	500	10
Selenium			10
Silver (based on analysis using aqua regis)	0.2	50	5
Thallium			20
Tin			10
Uranium (238)			30
Zinc	200	15,000	10

2.6 Halogens and halides

The Occupier must not discharge trade waste containing a substance listed in Table B with a concentration greater than is listed for that substance.

Table B

Substance	Maximum allowable concentration (milligrams per litre)
Bromine (expressed as Br_2)	5
Chlorine (expressed as Cl_2)	5
Fluoride	30
Iodine (expressed as I_2)	5

2.7 Cyanide

The Occupier must not discharge trade waste containing a cyanide concentration greater than 10 mg/litre.

2.8 Inhibitory chemicals

a. The Occupier must not discharge any trade waste which, when diluted to a 5% solution with sewage, would inhibit the microbiological sewage treatment process applicable to that trade waste by more than 20%.

b. The Authorised Person must determine the microbiological sewage treatment process referred to in sub-clause (a).

2.9 Organic acids

The Occupier must not discharge trade waste containing a substance listed in Table C with a concentration greater than is listed for that substance.

Table C

Substance	Maximum allowable concentration (milligrams per litre)
Acetic acid	1085
Acrylic acid	1015
Total phenoxyacetic acids	1000

2.10 Phenolic substances

The Occupier must not discharge trade waste containing a substance listed in Table D with a concentration greater than is listed for that substance.

Table D

Substance	Maximum allowable concentration (milligrams per litre)
Pentachlorophenol	5
Sum of phenol, monochlorophenol, dichlorophenol and their isomers	300
Tetrachlorophenol	5
Trichlorophenol	50

2.11 Aldehydes and ketones

The Occupier must not discharge trade waste containing a substance listed in Table E with a concentration greater than is listed for that substance.

Table E

Substance	Maximum allowable concentration (milligrams per litre)
Acetone	380
Acrolein	0.1
Formaldehyde (expressed as HCHO)	200
Methyl ethyl ketone (MEK, 2-Butanone)	90
Methyl isobutyl ketone (MIBK)	6.1

2.12 Nitriles

The Occupier must not discharge trade waste containing acrylonitrile at a concentration greater than 1.0 mg/litre.

2.13 Aromatic hydrocarbons

The Occupier must not discharge trade waste containing a substance listed in Table F with a concentration greater than is listed for that substance.

Table F

Substance	Maximum allowable concentration (milligrams per litre)
1,3 Dinitrobenzene	0.34
2,4 Dinitrotoluene	10.0
2,6 Dinitrotoluene	10.0
Acenaphthene	0.016
Benzene	1.0
Cumene	3.0
Ethylbenzene	2.0
Naphthalene	1.3
Nitrotoluene	5.0
Styrene	2.0
Toluene	2.0
Total xylenes	2.0

2.14 Halogenated aliphatic hydrocarbons

The Occupier must not discharge trade waste containing an halogenated aliphatic hydrocarbon listed in Table G in a concentration greater than is listed for that substance.

Table G

Substance	Maximum allowable concentration (milligrams per litre)
1,1 Dichloroethane	5
1,1 Dichloropropane	5
1,1,1 Trichloroethane	3
1,1,2 Trichloroethane	3
1,1,2,2 Tetrachloroethane	2
1,2 Dichloroethane	5
1,2 Dichloroethylene	5
1,2 Dichloropropane	5
1,3 Dichloropropane	0.001
Bromodichloromethane	1
Carbon tetrachloride	1
Chlorodibromomethane	5
Chloroethene (vinyl chloride monomer)	0.5
Dichlorodifluoromethane	1
Hexachlorobutadiene	0.001
Hexachloroethane	1
Methyl bromide	0.001
Methyl chloride	0.001
Methylene chloride	5
Tetrachloroethylene	1
Trichloroethylene	1
Trichlorofluoromethane	1
Trichloromethane (chloroform)	1

2.15 Aliphatic hydrocarbons

The Occupier must not discharge trade waste containing aliphatic hydrocarbons C5 to C9 at a concentration greater than 1.0 mg/litre.

2.16 Esters

The Occupier must not discharge trade waste containing a substance listed in Table H in a concentration greater than is listed for that substance.

Table H

Substance	Maximum allowable concentration (milligrams per litre)
Ethyl acrylate	1.5
Methyl methacrylate	30

2.17 Ethers

The Occupier must not discharge trade waste containing a substance listed in Table I with a concentration greater than is listed for that substance.

Table I

Substance	Maximum allowable concentration (milligrams per litre)
2-butoxyethanol	295
Butyl carbitol	2000
Tetrahydrofuran	75

2.18 Other organics

The Occupier must not discharge trade waste containing Epichlorohydrin at a concentration greater than 3.9mg/litre.

2.19 Pesticides and herbicides

The Occupier must not discharge trade waste containing a substance listed in Table J with a concentration greater than is listed for that substance.

Table J

Substance	Maximum allowable concentration (milligrams per litre)
Aldrin	0.001
Chlordane	0.006
DDT	0.003
Dieldrin	0.001
Glyphosate	10
Heptachlor	0.003
Lindane	0.100
Trifluralin	10

2.20 Halogenated aromatic hydrocarbons

a. The Occupier must not discharge trade waste containing halogenated aromatic hydrocarbons, except in accordance with this clause.

b. The Occupier must not discharge trade waste containing a substance listed in Table K in a concentration greater than is listed for that substance.

Table K

Substance	Maximum allowable concentration (milligrams per litre)
Polybrominated biphenyls (PBB's)	0.002
Polychlorinated biphenyls (PCB's)	0.002

2.21 Alcohols

The Occupier must not discharge trade waste containing a substance listed in Table L with a concentration greater than is listed for that substance.

Table L

Substance	Maximum allowable concentration (milligrams per litre)
2-Ethyl hexanol	155
Allyl alcohol (2-Propen-1-ol)	9.1
Ethanol	3765
Ethylene glycol	4000
Isobutanol	140
Isopropanol	1155
Methanol	615
Propylene glycol	4000

2.22 Chlorodibenzo-p-dioxins and chlorodibenzo-furans

a. The Occupier must not discharge any trade waste containing any of the full range of chlorodibenzo-p-dioxin and chlorodibenzo-furan congeners, except in accordance with this clause.

b. Subject to sub-clauses (c), (d) and (e), the Occupier must not discharge trade waste containing any of the full range of chlorodibenzo-p-dioxin and chlorodibenzo-furan congeners in a concentration greater than the NATO total toxic equivalent of 40.0 ng/l.

c. Notwithstanding sub-clause (b), the Authorised Person may at any time in writing require the Occupier not to discharge trade waste containing any of the full range of chlorodibenzop-dioxin and chlorodibenzo-furan congeners in a concentration greater than the NATO total toxic equivalent of 20.0 ng/l.

d. Subject to sub-clause (e), the Occupier must not discharge trade waste containing any 2, 3, 7, 8 tetrachlorodibenzo-p-dioxin congeners in a concentration greater than the NATO total toxic equivalent of 20.0 ng/l.

e. Notwithstanding sub-clause (d), the Authorised Person may at any time require the Occupier not to discharge any 2, 3, 7, 8 tetrachlorodibenzo-p-dioxin congeners in a concentration greater than the NATO total toxic equivalent of 5.0 ng/l.

2.23 Other substances

An Occupier must not discharge trade waste containing any substance not otherwise mentioned in this document:

a. in a concentration greater than 1µg/l.

b. where the discharge or release of which to any element of the environment is restricted or prohibited by any legislation applying in Victoria.

c. in quantities or of a quality that in the opinion of the Authorised Person would or is reasonably likely to endanger human life, compromise the safety of a person or of the works, or significantly adversely affect the operation of a sewage treatment plant or any part of the environment.

2.24 Headspace air

The Occupier must not discharge trade waste to a sewer, which at the nearest point of the sewer accessible by humans from the point of discharge, in any respect fails to comply with every relevant Safe Work Australia Exposure Standard relating to the Time Weighted Average (TWA) exposure levels.

City West Water™

City West Water
ABN 70 066 902 467
Locked Bag 350
Sunshine Vic 3020

Account and general enquiries 131 691
Faults and emergencies 132 642
Interpreter service 131 450
Internet citywestwater.com.au
Email enquiries@citywestwater.com.au

APPENDIX 5

ANALYSIS RESULTS OF 5 X PROCESS GAS SAMPLES TAKEN AT THE LICELLA ADVANCED RECYCLING FACILITY, SOMERSBY, NSW

Herein contains the results from the analysis of five process gas samples taken at the Licella Advanced Recycling Facility in Somersby, NSW.

Table: analytical results from the analysis of five process gas samples taken at the Licella Advanced Recycling Facility in Somersby, NSW

ADVANCED RECYCLING FACILITY, SOMERSBY, NSW

Analytes	units	PG20200 930A	PG2020 1019A	PG2018 0320	PG2018 0323	PG2018 0816	Average
Analytical results for permanent gases							
Hydrogen	% v/v	4.1	4.1	2.6	2.8	3.7	**3.46**
Carbon dioxide	% v/v	4.1	1.4	10	14	3.2	**6.54**
Oxygen	% v/v	<0.02	<0.02	0.028	0.09	0.11	**0.05**
Nitrogen	% v/v	8.4	7.1	1.6	5.2	0.68	**4.60**
Argon	% v/v	<0.02	<0.02	<0.02	<0.02	<0.02	**<0.02**
Carbon monoxide	% v/v	1.7	11	<0.02	<0.02	0.74	**2.69**
Analytical results for Hydrocarbons							
Methane	% v/v	13	13	19	20	20	**17.00**
Ethylene	% v/v	0.9	0.94	0.7	0.7	0.71	**0.79**
Ethane	% v/v	15	16	17	14	20	**16.40**
Propylene	% v/v	6.1	6.3	4.4	4.6	5.8	**5.44**
Propane	% v/v	19	17	19	15	22	**18.40**
Iso-butylene	% v/v			4.9	4.8	3.6	**4.43**
Iso-Butane	% v/v	4.2	3.3	5.1	5.7	4	**4.46**
n-Butane	% v/v	5.7	4.1			4	**3.45**
Cyclobutane	% v/v					0.36	**0.36**
Butane	% v/v			1	0.7	4.4	**2.03**
Other C4s	% v/v	5.5	4.8				**5.15**
Pentanes	% v/v	9.8	8.5	7.1	8.2	8.3	**8.38**
Hexanes	% v/v	2.6	2.3	6.9	3.6	2.5	**3.58**
Heptanes	% v/v	0.2	0.26	0.2	0.3	0.29	**0.25**
Octanes	% v/v	<0.1	<0.1	0.1	0.1	<0.1	**<0.1**
nonanes				<0.1	<0.1	<0.1	**<0.1**
decanes				<0.1	<0.1	<0.1	**<0.1**
Analytical results for aromatics							
benzene	ppm v/v	240	250				**245**
toluene	ppm v/v	300	240				**270**
ethylbenzene	ppm v/v	26	79				**53**
m&p-xylenes	ppm v/v	7.9	24				**16**
o-xylenes	ppm v/v	1.6	7.8				**5**
chlorobenzene	ppm v/v	< 0.05	< 0.05				**< 0.05**
dichlorobenzene	ppm v/v	< 0.05	< 0.05				**< 0.05**
trichlorobenzene	ppm v/v	< 0.05	< 0.05				**< 0.05**
trimethylbenzene	ppm v/v	1.2	11				**6.10**
naphthalene	ppm v/v	0.42	0.32				**0.37**

List 2 Analytical results							
1,4- Dioxane	ppm v/v	0.7	2				**1.35**
Acrolein	ppm v/v	< 2	< 5.0				**< 5.0**
Methanol	ppm v/v	17.2	1.3				**9.25**
NOx	ppm v/v	< 0.5	< 0.1				**< 0.5**
SOx	ppm v/v	< 0.5	< 0.1				**< 0.5**
HCN	ppm v/v	26	16.5				**21.25**
H2S	ppm v/v	8.5	1.9				**5.20**
CS2	ppm v/v	0.18	0.72				**0.45**

APPENDIX 6

RISK ASSESSMENT FOR ARV ALTONA FACILITY AIR EMISSIONS

Herein contains the criteria and assessment of risks associated with the ARV Altona Facility air emissions.

A. Introduction

The purpose of this Risk Assessment is to examine the risk from air emissions when Advanced Recycling Victoria Pty Ltd (ARV) has its Altona Advanced Recycling facility using Cat-HTR technology operational.

The approach used in this risk assessment methodology is consistent with "AS/NZS ISO 31000 Risk Management - Principles and Guidelines".

B. Risk Assessment

1. Hazards Identified

The first stage of this methodology is in hazard identification. To ensure all potential hazards associated with air emissions when the ARV Altona facility is operational were identified, the over-arching hazards are listed:

a) Feedstock quality at collection.
b) Feedstock preparation and removal of contaminants
c) Product Gas manufacture
d) Combustion of Product Gas

2. Risk Analyses

2.1 Likelihood

Best practice dictates that where there is scientific uncertainty, a cautious approach is warranted which will in turn identify a higher level of risk. Each identifiable potential impact can be assigned a likelihood between ‘remote’ and ‘almost certain’.

Table 2.1 - Evaluating likelihood

Likelihood	Description	Probability	Interest/Effect On Demographic
Remote	May occur in exceptional circumstances	<1%	Few interested
Unlikely	Not expected to occur in most circumstances	1 – 20%	Some affected
Possible	May occur	21 - 49%	Many affected
Likely	Probably will occur	50 – 85%	Majority affected
Almost Certain	Expected to occur	>85%	Almost all affected

2.2 Consequence

The consequence of an impact used in the risk assessment is the reasonably foreseeable consequence. Several of the elements are interrelated and a consequence is major if any one of the elements has a predicted major impact.

Table 2.2 – Evaluating consequence

Consequence	Minimal	Minor	Moderate	Major	Catastrophic
A. Magnitude					
Spatial	Event contained within facility perimeter	Event affects immediate neighbours within industrial zone	Event impacts nearby residential or other sensitive receptors	Event impacts regionally but within region/state	Event has impact nationally
Intensity	Very Low	Low	Moderate	High	Very high
B. Temporal					
Duration	Single	Few events	Several events	Multiple events	Ongoing events
Timing	Once or twice	Occasional	Infrequent	Regular	Permanent
C. Ecological					
Values	No Value	Value to individuals	Value to local area	Value to the regional area	National Value
Sensitivity	Will recover quickly	Some changes to ecosystem functioning and it will take a bit of time to recover	Moderate change to ecosystem functioning and it will take some time to recover	Significant change to ecosystem functioning and it will take a long time to recover	Ecosystem will not become functional as it was and it will not recover
D. Social					
Number of people	Some people indirectly impacted	Some people directly impacted or several indirectly	Several people directly impacted or many indirectly	Large number of people directly impacted	Loss of life
Heritage	Impact on item of minimal significance	Impact on multiple items of low significance	Impact on significant item	Impact on multiple significant items	Major impact on protected item
Political	Single negative press article	Multiple negative press articles	Significant public interest	Leads to an inquiry	Change of government
Economic	Minimal Costs	Several tens of thousands of dollars in costs	Half million dollars in costs	One million dollars in costs	Several million dollars in costs

2.3 Risk Evaluation

Risk is evaluated using the risk matrix below.

Table 2.3

Consequence	Minimal	Minor	Moderate	Major	Catastrophic
Likelihood					
Remote	Negligible	Negligible	Very low	Low	Medium
Unlikely	Negligible	Very low	Low	Medium	High
Possible	Very low	Low	Medium	High	Very high
Likely	Low	Medium	High	Very high	Significant
Almost certain	Medium	High	Very high	Significant	Significant

3. Risk Assessment For ARV Altona Facility Air Emissions

The following table is a risk assessment conducted by ARV which estimates the residual risk that the Altona Advanced Recycling facility will have when it is operational and has air emissions. Tables 2.1, 2.2 and 2.3 are used to determine the Residual Risk Rating.

Item	Hazard/Risk	Controls In Place	Residual Risk After Controls Are Operational and Working		
			Likelihood	Consequence	Risk Rating
(a) Feedstock quality at collection					
1	Feedstock contains large amounts of contamination and/or harmful additives	• The selection of sources of waste plastic feedstock will be scrutinised and QA tested so that it is unlikely that large amounts of contaminants or harmful additives will be in the delivered feedstock plastic before the feedstock is prepared for processing.	Unlikely	Minor	**Very low**
2	Contaminants and/or harmful additives that are in feedstock will result in high amounts of noxious gas being formed during Cat-HTR process	• The selection of sources of waste plastic feedstock will be scrutinised and QA tested so that it is unlikely that there will contaminants or harmful additives in the delivered feedstock plastic that will result in the Product Gas having "difficult-to-deal-with" gasses in its exhaust gas. • Due to the dominant liquid phase present in the hydrothermal processes, the majority of remnant contaminants or additives will remain in the water phase and not report to the Process Gas. • Experience will be gained from the UK Cat-HTR facility operations that will commence in 2022 as to any types of waste plastic that will cause issues with managing the Product Gas exhaust fumes. • If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers.	Unlikely	Minor	**Very low**
3	There will be a variability in the feedstock that is processed that will result in changing amounts of	• The selection of sources of waste plastic feedstock will be scrutinised and QA tested so that it is unlikely that there will contaminants or harmful additives in the delivered feedstock plastic that will result in the Product Gas having "difficult-to-deal-with" gasses in its exhaust gas.			

	contaminants and/or harmful additives	- Due to the dominant liquid phase present in the hydrothermal processes, the majority of remnant contaminants or additives will remain in the water phase and not report to the Process Gas. - Experience will be gained from the UK Cat-HTR facility operations that will commence in 2022 as to any types of waste plastic that will cause issues with managing the Product Gas exhaust fumes. - If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers.			
(b) Feedstock preparation and removal of contaminants					
1	Plastic preparation won't adequately remove contaminants and/or harmful plastic additives	- Experience in feedstock preparation equipment design and operations is already being gained at various sites in Australia and the world including the iQRenew SPEC facility at Tuggerah, NSW. This experience in the design and operations of plastics preparation facilities is resulting in the increased removal of contaminants, thereby minimising the contaminant issues in the Cat-HTR process. - Due to the dominant liquid phase present in the hydrothermal processes, the majority of remnant contaminants or additives will remain in the water phase and not report to the Process Gas. - Experience will be gained from the UK Cat-HTR facility operations that will commence in 2022 as to any types of waste plastic that will cause issues with managing the Product Gas exhaust fumes. - If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers.	Unlikely	Minor	**Very low**
(c) Product Gas manufacture					

1	The Process Gas manufacture process will result in a gas that, when burnt, will have many harmful types of exhaust fumes	• The selection of sources of waste plastic feedstock will be scrutinised and QA tested so that it is unlikely that there will contaminants or harmful additives in the delivered feedstock plastic that will result in the Product Gas having “difficult-to-deal-with” gasses in its exhaust gas. • Experience will be gained from the UK Cat-HTR facility operations that will commence in 2022 as to any types of issues with managing the manufacture of Product Gas such that there are minimal problems with exhaust fumes. • If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers.	Unlikely	Minor	**Very low**
2	There will be a variability in the feedstock that is processed that will result in changing amounts of contaminants and/or harmful additives and the manufacturing process won’t be able to minimize or eliminate the Product Gas and its exhaust fumes from containing harmful gasses	• The selection of sources of waste plastic feedstock will be scrutinised and QA tested so that it is unlikely that large amounts of contaminants or harmful additives will be in the delivered feedstock plastic before the feedstock is prepared for processing, • Due to the dominant liquid phase present in the hydrothermal processes, the majority of remnant contaminants or additives will remain in the water phase and not report to the Process Gas. • Experience will be gained from the UK Cat-HTR facility operations that will commence in 2022 as to any types of waste plastic that will cause issues with managing the Product Gas exhaust fumes. • If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers.	Remote	Minor	**Negligible**
(d) Combustion of Product Gas					
1	The way in which the Process Gas is combusted either in the Supercritical	• The Altona facility will use the same plant and equipment as the UK operations that will commence in 2022. Experience will be gained from the UK Cat-HTR facility operations as to any types of problems that can occur	Unlikely	Minor	**Very low**

	steam generator, the Standard Boiler or the Flare will result in exhaust fumes that contain uncontrolled amounts of harmful fumes	with combustion of the Product Gas that will cause issues with managing the Product Gas exhaust fumes. • Boilers are designed to have high levels of combustion of their gas fuel, thereby minimizing the amount of noxious exhaust fumes. • If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers. • Air emission modelling has predicted that emission levels of NOx, SOx and Ammonia will be very low. The area that will be subject to exhaust fumes is the area around the Cat-HTR facility. If needed, real-time air monitoring can be installed in the Cat-HTR industrial complex. • Given the 1.3km buffer zone to residential areas, Stage 1 operations will have a negligible impact from air emissions on neighbouring residential areas.			
2	The constituent gas types within the Process Gas results in uncontrolled amounts of harmful fumes being produced after combustion	• The selection of sources of waste plastic feedstock will be scrutinised and QA tested so that it is unlikely that there will contaminants or harmful additives in the delivered feedstock plastic that will result in the Process Gas having “difficult-to-deal-with” gasses in its exhaust fumes. • Due to the dominant liquid phase present in the hydrothermal processes, the majority of remnant contaminants or additives will remain in the water phase and not report to the Process Gas. • Experience will be gained from the UK Cat-HTR facility operations that will commence in 2022 as to any types of issues with managing the manufacture of Process Gas such that there are minimal problems with exhaust fumes. • If it is seen at the UK facility that harmful pollutant fumes are being exhausted at levels that need remedial action then the design of the Altona facility can be modified to include flue gas exhaust scrubbing systems such as Catalytic Converters, Wet Lime Scrubbers and Packed Bed Scrubbers.	Unlikely	Minor	**Very low**

APPENDIX 7

ALTONA CAT-HTR FACILITY AIR EMISSION MODELLING AND IMPACT ASSESSMENT

Herein contains the report ‘Altona Cat-HTR facility air emission modelling and impact assessment’ as prepared for Attexo, by Synergetics, on 27 September 2021.

SYNERGETICS

Altona Cat-HTR facility air emission modelling and impact assessment

prepared for

Attexo

27 September 2021

Altona Cat-HTR facility air emission modelling and impact assessment

for

Attexo

Report version	Date	Prepared by	Reviewed by	Comments
F01	27 September 2021	JB, NG	DC	

Prepared by:

James Brett
BE(Hons) BSc MEngSc PhD
Principal Modelling Engineer

Nitheesh George
BEng MS PhD
Modelling Engineer

Reviewed by:

Dave Collins
BE(Hons) MBA PhD FIEAust FAIE CIH MAIOH CPEng RBP
Principal Engineer

Table of Contents

List of Tables

List of Figures

Abbreviations

AGL	Above ground level
BoM	Bureau of Meteorology
Cat-HTR	Catalytic Hydrothermal Reactor™
EPA	Environment Protection Authority
GLC	Ground level concentration
HP boiler	High pressure boiler
IRSD (SEIFA)	Index of Relative Socio-economic Disadvantage (Socio-Economic Indexes for Areas)
LP boiler	Low pressure boiler
Nm^3	Normal m^3, Volume at a temperature of 0°C and pressure of 1.0325 bar

Executive summary

Licella propose to construct an Advanced Recycling Catalytic Hydrothermal Reactor (Cat-HTR™) facility at 541-583 Kororoit Creek Road, Altona. The process is designed to convert end-of-life plastic wasteinto usable products consisting of ”plasticrude”, heavy fraction bitumen oil and process gas.

The process includes a high temperature reaction, with heat provided by gas fired boilers. Approximately half of the process gas generated by the process will be consumed to heat the boilers, with the remainder either sold or consumed in a flare, depending on process needs and market demand.

Synergetics Consulting Engineers were engaged by Attexo to undertake dispersion modelling for the proposed facility and assess the likely ground level concentrations (GLCs) of exhaust emissions on surrounding land in accordance with relevant EPA Victoria design criteria and methodology (EPA Vic, 2013a) and (EPA Vic, 2021).

A total of five years of historical data was modelled in accordance with EPA Victoria requirements.

The results of modelled GLCs were as follows:

- Background emission levels were between 13% and 43% of allowable emission levels.
- Even including background levels, when the Advanced Recycling facility was operational all areas modelled had emission levels that were always less than 50% of the respective EPA Victoria design criteria.
- GLCs at sensitive receptors were not materially changed above background levels of air emissions.

It would be appropriate to verify these conclusions with emission measurements from the ReNewELP Teesdale UK facility when available.

1 Introduction

Licella propose to construct an Advanced Recycling Catalytic Hydrothermal Reactor (Cat-HTR™) facility at 541-583 Kororoit Creek Road, Altona. This facility will convert end-of-life plastic waste to usable products consisting of ”plasticrude”, heavy fraction bitumen oil and process gas.

The process includes a high temperature reaction, with heat provided by gas fired boilers. Approximately half of the process gas generated by the facility will be consumed to heat the boilers, with the remainder either sold or consumed in a flare, depending on facility needs and market demand.

Synergetics Consulting Engineers were engaged by Attexo to undertake dispersion modelling for the proposed facility and assess the likely ground level concentrations (GLCs) of exhaust emissions on surrounding land in accordance with relevant EPA Victoria legislation (EPA Vic, 2013a) and (EPA Vic, 2021).

This report describes the site, processes and emissions, the meteorology, modelling methodology, results and conclusions.

2 Site description

2.1 Site layout

The proposed Cat-HTR facility will be located at 541-583 Kororoit Creek Road, Altona, as marked in Figure 1. Land use within a 5 km radius consists of a mixture of industrial, and residential uses, with the closest residential land use approximately 1.4 km away from the probable location of the stacks. Nearby sensitive receptors are numbered in Figure 1, these include residential properties, and schools. Distances to the sensitive receptors are listed in Table 1. A review of the 2016 Index of Relative Socio-economic Disadvantage (IRSD) SEIFA[1] reveals that all five quintiles are present in the assessment domain, which is typical for land near industrial estatesin a large city like Melbourne.

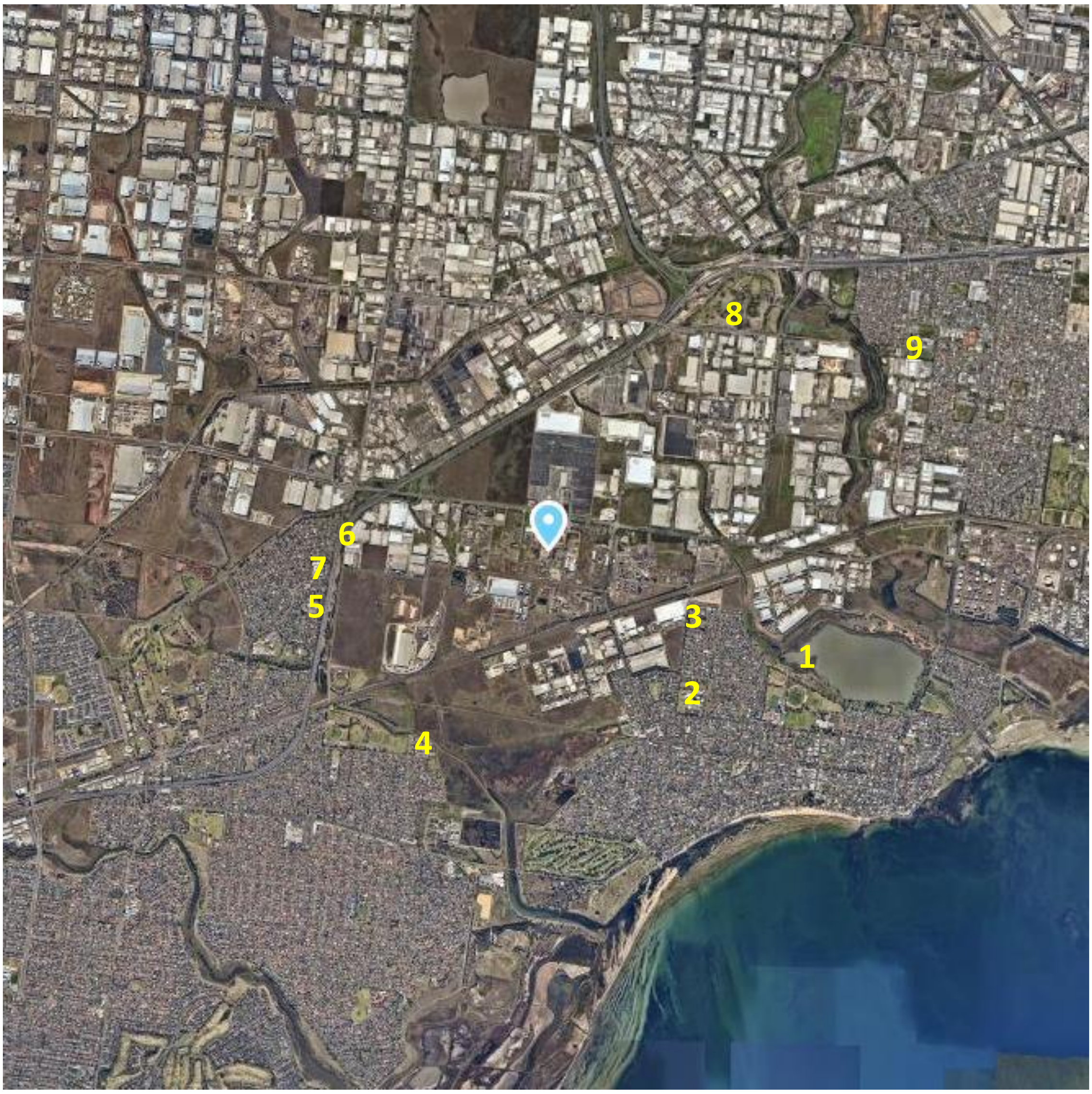


Figure 1 - The subject site and the surrounding land use. The nearby sensitive receptors are numbered. Image sourced from Nearmap (2021). North is to the top of the image.

---

[1] Scores were reviewed using the interactive map tool at https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/2033.0.55.001~2016~Main%20Features~IRSD%20Interactive%20Map~15

Table 1 - Sensitive receptors[2].

Receptor	Distance from site	Direction from site
1. Cherry Lake	2350	SE
2. Altona College	1650	SW
3. Residential Properties (Charles Rd)	1370	SE
4. Residential Properties (Hibiscus Ct)	1970	SW
5. St Martin de Porres Primary school	2140	W
6. Residential Properties (Tyquin St)	1950	W
7. Western Autistic School	2050	W
8. Altona Memorial Park	2470	NE
9. Emmanual College St Paul's Campus	3800	NE

The surrounding landscape is relatively flat, as shown by the topology map in Figure 2, with small elevation variations of up to 20 m over a distance of several kilometres.

Figure 2 – Topological levels for a 10 km by 10 km domain centred on the proposed site blue to green scale ranges from 0 to 39m relative to sea level respectively. The yellow star marks the facility location. Topographic map sourced from https://en-au.topographic-map.com.

---

[2] Sensitive receptors are used to understand potential impacts of a facility for nearby sites where sensitive or vulnerable individuals are more likely to spend time. Impacts at these locations are assessed in addition a more general assessment that covers the entire area.

The site currently includes a mixture of buildings with heights of less than 10 m, and several large storage tanks. Site works will be required to setup the new facility, with some of the existing structures to be reused. The site will include emission stacks for two boilers, one low and one high pressure, and the flare. The detailed site layout is not finalised, however it was assumed that stacks will be 25 m tall, with nearby buildings kept to 10 m or less to minimise anybuilding downwash. Modelled stack details are shown in Table 2[3].

Table 2 – Modelled stack properties and emission rates. Values are adapted from (SLR, 2020) in consultation with Licella and Attexo.

	HP boiler	LP boiler	Flare
Stack internal diameter (m)	0.3	0.2	2
Exhaust height (m AGL)	25	25	25
Temperature (°C)	350	240	850
O_2 content (% dry)	2.9	2.8	2.9
Moisture content (%$H_2$0)	14.8	14.8	14.8
Actual flow rate (Am^3/s)	1.7	0.7	5.3
Velocity (m/s)	24	23	2
Volume flow rate (Nm^3/s dry, 3% O_2)	0.64	0.33	1.11
SO_x emissions (mg/Nm^3)	35	35	35
SO_x emission rate (g/s)	0.022	0.012	0.039
NO_2 emissions (mg/Nm^3)	200	200	200
NO_2 emission rate (g/s)	0.128	0.066	0.222
NH_3 emissions (mg/Nm^3)	15	15	15
NH_3 emission rate (g/s)	0.0096	0.0050	0.017

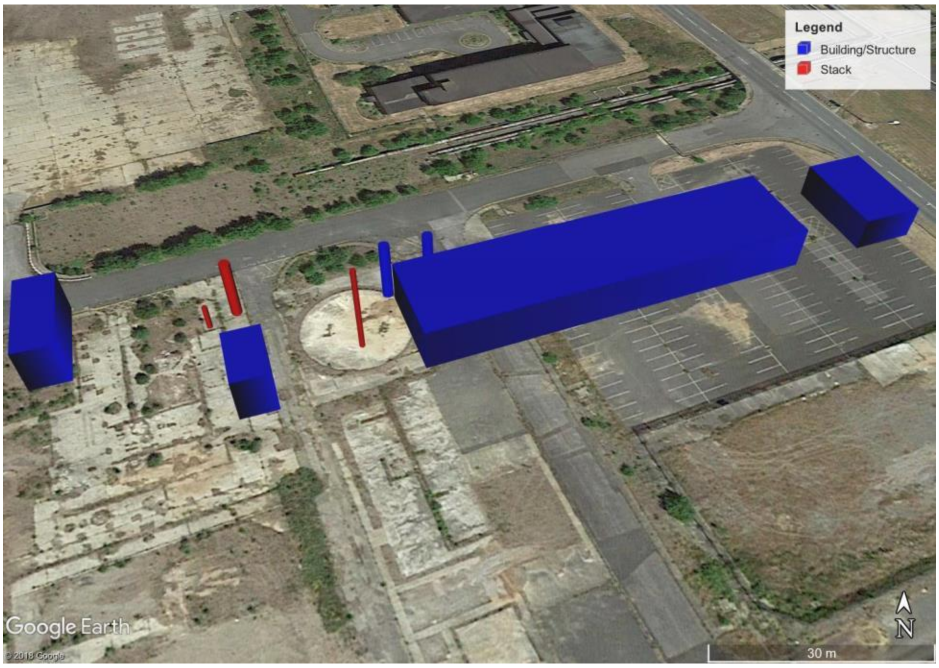


Figure 3 – Representative site layout for the planned similar facility in the UK (SLR, 2020).

---

[3] These stack properties have been adapted from a ReNewELP Teesdale UK facility using the CAT-HTR process (SLR, 2020), with stack heights increased to 25 m to minimise the chance of downwash. Ammonia emissions from the flare have also been allowed for, with the same concentration as the boilers.

2.2 Process description

The facility process diagram is shown in Figure 4. The process begins with waste receipt and preparation, during which the feed stock is assessed to remove inappropriate material. Following preparation, the feed stock is fed into the Cat-HTR where the reaction takes place. The Cat-HTR is also supplied with supercritical water from the boilers. The boilers can be powered through either natural gas (typically during start up) or process gas.

2.3 Emissions

The likely emissions from the Cat-HTR technology are not yet available, however Licella have provided the following information which helps to provide some insight into the likely emissions:

- A facility in the UK (the ReNewELP Teesdale UK facility) utilising the Licella technology is expected to be operational in 2022, at which time stack sampling and accurate emission information will become available.
- The UK facility has received planning approval based on a submission which modelled only NOx, SO_2 and NH_3, with other pollutants not considered to be significant.
- Licella is currently gaining experience with a pilot scale facility in NSW which to-date has been used to produce, sample, analyse and assess the process gas. The process gas was found to have a high calorific value of 39 MJ/kg, with similar properties to natural gas.
- The Licella technology requires that the feedstock be carefully monitored to avoid contamination by halogen containing plastics such as PVC.
- Based on testing by Licella, chlorine that does enter the process will remain in solution in the process water, with negligible chlorine in the process gas.
- Particulates and carbon monoxide and VOCs are not expected to be material due to the near complete combustion within the boilers.
- Boiler start-up will be fired with natural gas.
- Emissions during start-up are expected to be similar to operating on process gas and have not been modelled.
- The Cat-HTR reactions occur within a sealed process and fugitive emissions are expected to be negligible.

The modelling in this report follows the same approach undertaken for the UK facility, focusing on NOx, SO_2 and NH_3, for the air dispersion modelling. The same emission rates as the UK facility have been adopted, as the same boiler design is intended to be installed. It has conservatively been assumed that NH_3 will also be emitted from the flare.

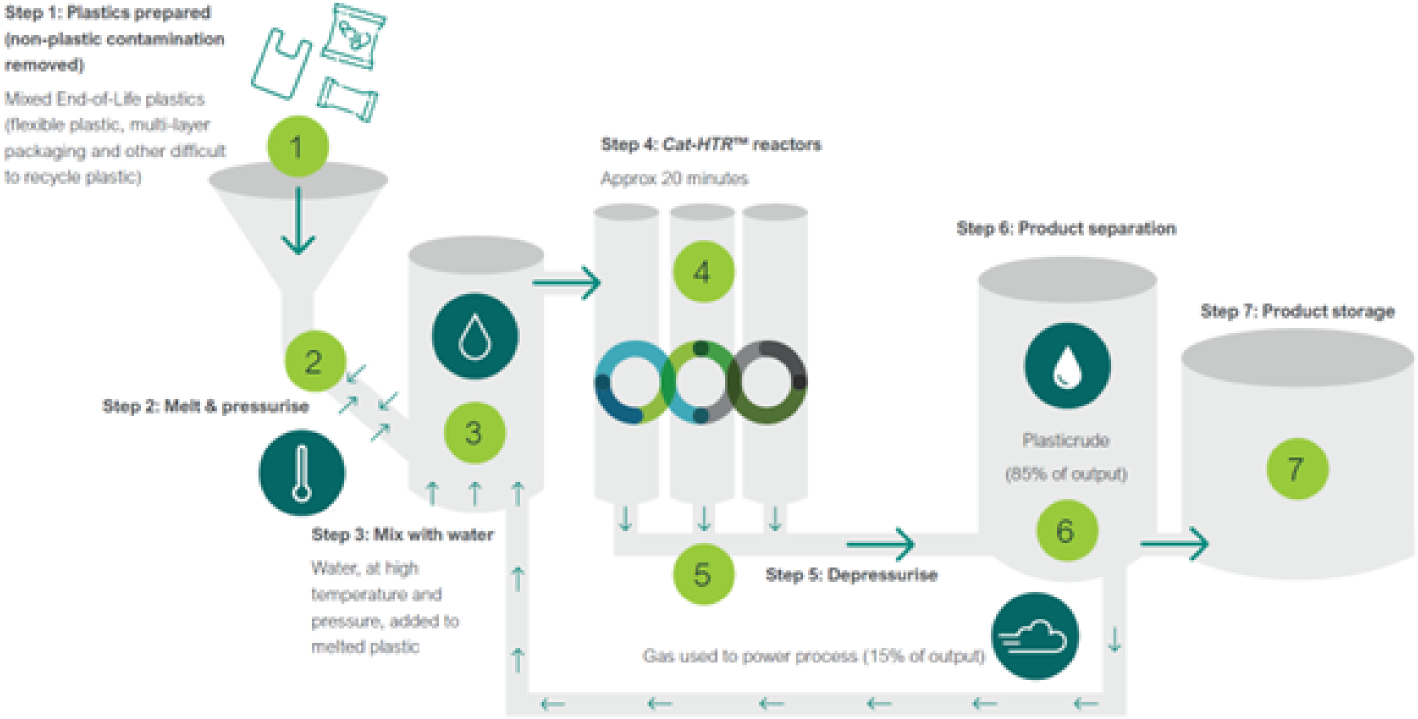


Figure 4 – Facility process flow chart (Image provided by Licella).

3 Methodology

3.1 Assessment criteria and emissions

Emission rates were modelled for a single scenario with emissions from both boilers and the flare. During operations where the excess process gas is sold rather than burned, emissions are likely to be less than the modelled case, and was not considered.

Assessment criteria, expressed as GLCs, are also listed in Table 3.

Table 3 - Modelled emission rates and relevant assessment criterion.

Substance	Assessment criteria				Emissions (g/s) at point of discharge to atmosphere		
	Averaging period	**GLC (ppm)**	**Source**	**Expressed as**	**HP boiler**	**LP boiler**	**Flare**
NO_x	1 hour[4]	0.12	(Vic., 2021)	NO_2	0.128	0.066	0.222
	1 Year[5]	0.03					
SO_2	1 hour[6]	0.2	(Vic., 2021)	SO_2	0.0224	0.0116	0.0389
	1 day[7]	0.08					
	1 year	0.02					
NH_3	1 hour	4.6	(EPA Vic, 2021)[8]	NH_3	0.0096	0.0096	0.0166
	1 day	1.7					
	1 year	0.1					

3.2 Model selection and configuration

Emission dispersion was modelled using AERMOD[9]. In addition to the sensitive receptors listed in Table 1, focusing on the nearest houses, schools and other sensitive locations, gridded GLCs receptors covered a 10 x 10 km domain, with a 50 m grid spacing, centered on the proposed facility were also modelled as specified by (EPA Vic, 2013a). The stacks were modelled as point sources, and GLCs were calculated for hourly, 24 h and annual averaging times. Building downwash was not modelled as it is expected that buildings will be less than 40% of the stack height.

---

[4] 1 hour averaging period – maximum ground level concentration averaged over one hour. One day of exceedance per year permitted

[5] 1 Year averaging period – maximum ground level concentration averaged over one year.

[6] One day of exceedance per year permitted

[7] 1 day averaging period – maximum ground level concentration averaged over one day. One day of exceedance per year permitted

[8] This guideline is currently in draft format, however it has been adopted for this assessment as it is expected to be finalised prior to the facility being completed. Ammonia has a 99.9th percentile assessment basic under the draft guideline but has been conservatively assessed as a 100th percentile basis instead to provide added assurance given the draft nature of (EPA Vic, 2021).

[9] Version 18081 using the methodology specified in (EPA Vic, 2013a).

3.3 Background GLCs

Time varying background GLCs have been included in the results for all relevant and available substances. The background sources considered are:

- NO_2 – The EPA Victoria monitoring site in Altona North was used for background NO_2 GLCs for this modelling.
- SO_2 - The EPA Victoria monitoring site in Altona North was used for background NO_2 GLCs for this modelling.

The Altona North monitoring station is expected to be representative of conditions near sensitive receptors in Altona.

Background data was not available for Ammonia, but their absence is not likely to be significant due to the very low Ammonia results observed due to this facility.

The available background data was processed to match the period of the meteorological data (see Section 4). Where data gaps were present they were filled with representative data as follows:

- For periods of one to three consecutive hours of missing data, the period was filled the average GLC either size of the missing data.
- For more than three consecutive hours, a representative background value of 70% of the annual maximum was applied.

4 Meteorological data

AERMOD compatible meteorological data for the site was generated from historical data recorded by the Bureau of Meteorology (BoM), with surface observations from the BoM Station at Laverton RAAF Base. This station is located approximately 4 km from the modelled emission location, in similar topography and similar distance from the coast. Half hourly interval samples were used for all variables except wind speed and direction, for which one minute interval data was used[10].

Upper atmosphere data is needed to calculate mixing heights, but as it is not recorded at Laverton RAAF Base, this data were sourced from the nearest available site, the BoM Station at Melbourne Airport.

Five calendar years of data was processed, in accordance with (EPA Vic, 2013b), covering the period from 2015 to 2019 inclusive[11].

Site wind conditions are summarised as follows:

- northerly winds are most common;
- north easterly winds are the least common;
- hourly average wind speeds below 10 km/hr account for 25% of all conditions; and
- hourly average wind speeds 40 km/hr and above account for approximately 0.75% of the assessed period.

These conditions are not expected to result in unusual or unfavourable dispersion as they are relatively typical. Wind roses are provided in Appendix A if more detail is required.

---

[10] Details on the Laverton RAAF Base BoM station can be found at http://www.bom.gov.au/clim_data/cdio/metadata/pdf/siteinfo/IDCJMD0040.086077.SiteInfo.pdf .

[11] Where critical data was missing from the BoM records, the day was removed from the sampling period, and an additional day's data from a substitute year (2014) was added to the meteorological files. No discernible seasonal bias was observed in the missing data.

5 Results

5.1 Summary

The modelled GLC, for the gridded receptors[12], based on the maximum measured emissions profile, are listed in Table 4 for each assessed substance. The modelled GLC at the sensitive receptors is included in Table 7. All modelled GLCs are less than the relevant assessment criterion.

---

[12] The gridded receptors cover the entire 10 km by 10 km domain, with the highest exposure location listed in the table.

Table 4 - Modelled maximum GLC showing maximum level for any gridded receptor[13].

Substance	Assessment criteria		Facility emission only		Background only		Facility with background	
	Averaging period	GLC (ppm)	Modelled value (ppm)	% of criterion	Recorded value (ppm)	% of criterion	Modelled value (ppm)	% of criterion
NO_x	1 hour	0.12	0.0056	4.6%	0.052	43%	0.055	45%
	1 Year	0.03	0.00042	1.4%	.010	34%	0.011	36%
SO_2	1 hour	0.2	0.00044	0.22%	0.062	31%	0.062	31%
	1 day	0.08	0.00018	0.23%	0.019	24%	0.019	24%
	1 year	0.02	0.000041	0.21%	.0026	13%	.0027	13%
NH_3	1 hour	4.6	0.0015	0.03%	-	-	-	-
	1 day	1.7	0.00035	0.02%	-	-	-	-
	1 year	0.1	0.00009	0.09%	-	-	-	-

---

[13] The hourly and daily values are the highest modelled value (100th percentile) for the 40,000 gridded receptors, i.e. the most affected location in the domain. Values for each modelled year are in Appendix D.

Table 5 - Modelled maximum[14] GLC showing maximum level for any sensitive receptor.

Substance	Assessment criteria		Facility emission only		Background only		Facility with background	
	Averaging period	GLC (ppm)	Modelled value (ppm)	% of criterion	Recorded value (ppm)	% of criterion	Modelled value (ppm)	% of criterion
NO_x	1 hour	0.12	0.0013	1.10%	0.052	43%	0.052	43%
	1 Year	0.03	0.00001	0.04%	.010	34%	.010	34%
SO_2	1 hour	0.2	0.00012	0.06%	0.062	31%	0.062	31%
	1 day	0.08	0.00001	0.01%	0.019	24%	0.019	24%
	1 year	0.02	0.00000	0.01%	0.0026	13%	0.0026	13%
NH_3	1 hour	4.6	0.00031	0.01%	-	-	-	-
	1 day	1.7	0.00002	<0.01%	-	-	-	-
	1 year	0.1	<0.00001	<0.01%	-	-	-	-

---

[14] 100% percentile values, for the five year modelled period. Values for each modelled year are in Appendix D.

As NO_2 has the highest levels, a contour plot of 100th percentile hourly NO_2 GLCs has been included, as shown in Figure 5, to demonstrate the pattern of the modelled dispersion. The highest GLCs are concentrated around the stack, in land zoned industrial, with GLCs closer to the sensitive receptors not materially different from background.

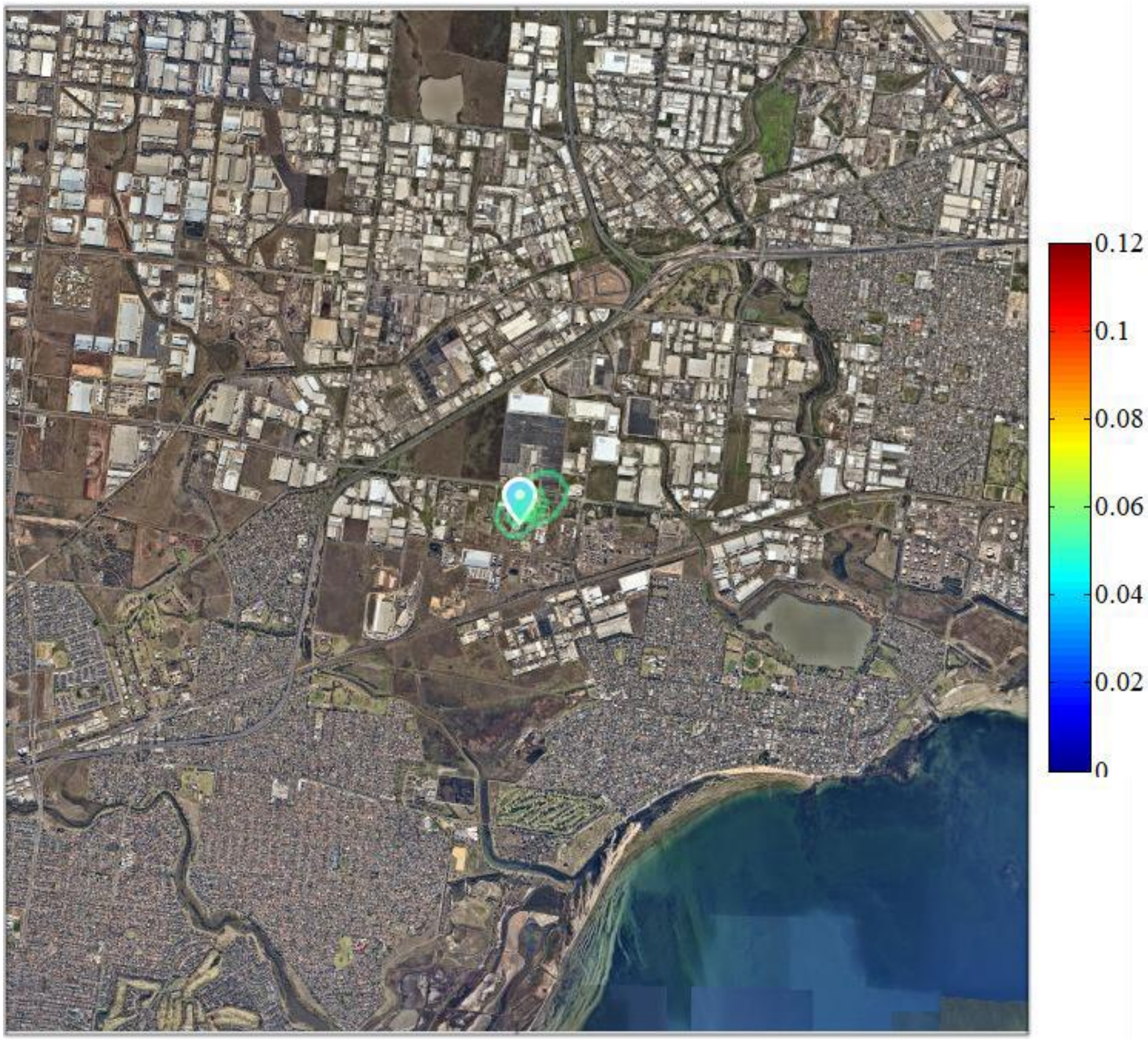


Figure 5 - Contours of highest 1 hour averaging period NO_2 GLC, including background, in ppm. The top contour level (red = 0.12 ppm) on the scale corresponds to the relevant criterion, and does not occur on the plot due to the low GLC. The GLC is nearly uniform due to the low contribution of the site compared to the background.

Reported GLCs for SO_2 and NH_3 are not materially changed by the operation of the facility at either gridded or sensitive receptors.

6 Conclusions

A total of five years of historical data was modelled in accordance with EPA Victoria requirements.

The results of the modelling of GLCs were as follows:

- Background emission levels were between 13% and 43% of allowable emission levels.
- Even including background levels, when the Advanced Recycling facility was operational all areas modelled had emission levels that were always less than 50% of the respective EPA Victoria design criteria.
- GLCs at sensitive receptors were not materially changed above background levels of air emissions.

It would be appropriate to verify these conclusions with emission measurements from the ReNewELP Teesdale UK facility when available.

7 References

EPA Vic. (2013a). *Guidance notes for using the regulatory air pollution model AERMOD in Victoria.* EPA Victoria.

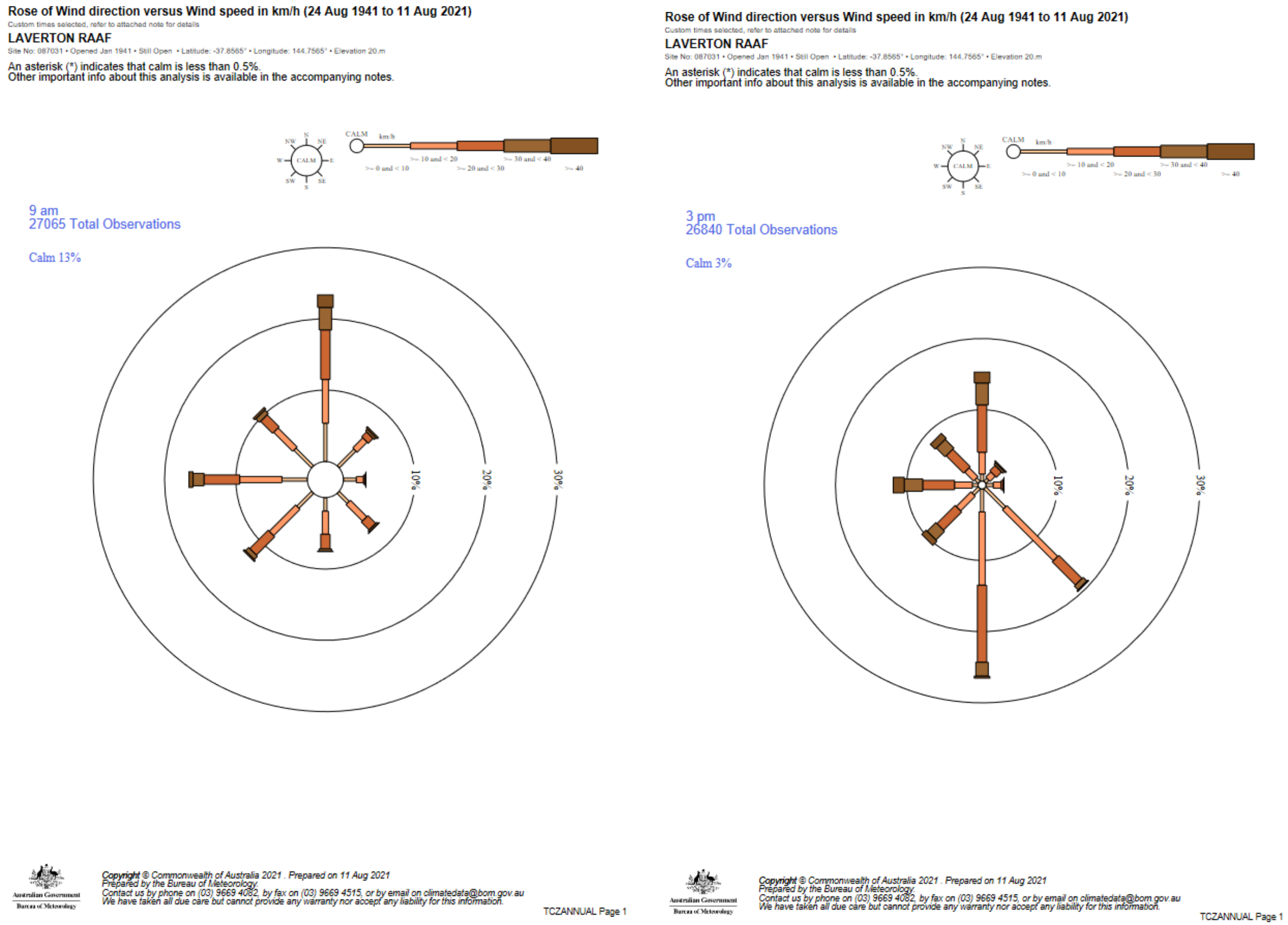
EPA Vic. (2013b). *Construction of input meteorological data files for EPA Victoria's regulatory air pollution model (AERMOD).* EPA Victoria.

EPA Vic. (2021). *Guideline for assessing and miniminsing air pollution in Victoria, Draft publication 1961.* EPA Victoria, May 2021.

SLR. (2020). *WILTON HYDROTHERMAL UPGRADING FACILITY ENVIRONMENTAL PERMIT APPLICATION, Air Emissions Risk Assessment.*

Vic. (2021). *Environmental Reference Standard.* Victorian Government Gazette, 26 May 2021.

Appendix A. Wind roses



Rose of Wind direction versus Wind speed in km/h (24 Aug 1941 to 11 Aug 2021)
Custom times selected, refer to attached note for details

LAVERTON RAAF
Site No: 087031 • Opened Jan 1941 • Still Open • Latitude: -37.8565° • Longitude: 144.7565° • Elevation 20.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

9 am
27065 Total Observations

Calm 13%

TCZANNUAL Page 1

Rose of Wind direction versus Wind speed in km/h (24 Aug 1941 to 11 Aug 2021)
Custom times selected, refer to attached note for details

LAVERTON RAAF
Site No: 087031 • Opened Jan 1941 • Still Open • Latitude: -37.8565° • Longitude: 144.7565° • Elevation 20.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

3 pm
26840 Total Observations

Calm 3%

TCZANNUAL Page 1

Figure 6 - 9am (left) and 3pm wind roses for the Laverton RAAF meteorological station

Appendix B. Discrete numbered receptor GLC

Subs	Averaging period	Assess. criteria (ppm)	1		2		3		4		5		6		7		8		9	
			Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria
NO_x	1 h	0.12	5.2E-02	43%	5.2E-02	43%	5.2E-02	43%	5.2E-02	43%	5.2E-02	43%	5.2E-02	43%	5.2E-02	43%	5.2E-02	43%	5.2E-02	43%
SO_2	1 h	0.2	6.2E-02	31%	6.2E-02	31%	6.2E-02	31%	6.2E-02	31%	6.2E-02	31%	6.2E-02	31%	6.2E-02	31%	6.2E-02	31%	6.2E-02	31%
	1 day	0.08	1.9E-02	24%	1.9E-02	24%	1.9E-02	24%	1.9E-02	24%	1.9E-02	24%	1.9E-02	24%	1.9E-02	24%	1.9E-02	24%	1.9E-02	24%
NH_3	1 h	4.6	3.0E-04	0.01%	3.1E-04	0.01%	2.9E-04	0.01%	3.2E-04	0.01%	3.1E-04	0.01%	2.4E-04	0.01%	2.2E-04	0.00%	3.1E-04	0.01%	2.6E-04	0.01%
	1 day	1.7	1.6E-05	0.00%	2.4E-05	0.00%	2.3E-05	0.00%	1.9E-05	0.00%	1.4E-05	0.00%	1.6E-05	0.00%	1.7E-05	0.00%	2.2E-05	0.00%	1.2E-05	0.00%

Note: Values in the above table include background contributions where applicable. For details on facility contributions compared to background GLCs see Section 5.

Appendix C. Maximum gridded receptor GLC for each year

Substance	Averaging period	Assessment criteria (ppm)	2015		2016		2017		2018		2019	
			Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria
NO_x	1 h	0.12	4.5E-02	37%	5.0E-02	41%	5.5E-02	45%	4.4E-02	36%	4.5E-02	37%
	1 year	0.03	8.9E-03	30%	9.0E-03	30%	1.1E-02	36%	9.2E-03	30%	1.0E-02	34%
SO2	1 h	0.2	6.2E-02	31%	4.4E-02	22%	4.9E-02	25%	5.3E-02	27%	3.5E-02	18%
	1 day	0.08	1.9E-02	24 %	1.3E-02	17%	1.4E-02	18%	1.6E-02	20%	8.1E-03	10%
	1 year	0.02	2.7E-03	13%	2.3E-03	12%	2.4E-03	12%	2.6E-03	13%	2.2E-03	11%
NH_3	1 h	4.6	1.0E-03	0.02%	1.1E-03	0.02%	1.3E-03	0.03%	1.5E-03	0.03%	9.4E-04	0.02%
	1 day	1.7	3.1E-04	0.02%	3.2E-04	0.02%	3.2E-04	0.02%	3.5E-04	0.02%	3.3E-04	0.02%
	1 year	0.1	8.8E-05	0.09%	7.4E-05	0.07%	7.5E-05	0.07%	8.3E-05	0.08%	7.3E-05	0.07%

Note: Values in the above table include background contributions where applicable. For details on facility contributions compared to background GLCs see Section 5.

Appendix D. Maximum sensitive receptor GLC for each year

Substance	Averaging period	Assessment criteria (ppm)	2015		2016		2017		2018		2019	
			Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria	Modelled value (ppm)	% of criteria
NO_x	1 h	0.12	4.4E-02	37%	4.7E-02	39%	5.2E-02	43%	4.4E-02	36%	4.4E-02	36%
	1 year	0.03	8.5E-03	28%	8.8E-03	29%	1.0E-02	34%	8.8E-03	29%	9.9E-03	33%
SO2	1 h	0.2	6.20E-02	31%	4.4E-02	22%	4.9E-02	25%	5.3E-02	27%	3.5E-02	18%
	1 day	0.08	1.9E-02	24%	1.3E-02	16%	1.4E-02	17%	1.6E-02	19%	8.0E-03	10%
	1 year	0.02	2.6E-03	13%	2.3E-03	12%	2.4E-03	12%	2.5E-03	13%	2.2E-03	11%
NH_3	1 h	4.6	2.9E-04	0.01%	3.0E-04	0.01%	3.2E-04	0.01%	3.1E-04	0.01%	2.8E-04	0.01%
	1 day	1.7	2.0E-05	0.00%	1.8E-05	0.00%	2.3E-05	0.00%	2.4E-05	0.00%	2.0E-05	0.00%
	1 year	0.1	2.3E-06	0.00%	2.1E-06	0.00%	2.6E-06	0.00%	2.1E-06	0.00%	2.3E-06	0.00%

Note: Values in the above table include background contributions where applicable. For details on facility contributions compared to background GLCs see Section 5.

APPENDIX 8
ALTONA CAT-HTR FACILITY AIR EMISSION MODELLING AND IMPACT ASSESSMENT

Herein contains the report ‘Second run of Altona Cat-HTR facility air emission modelling and impact assessment using European Union emission levels for a waste incineration plant’ as prepared for Licella, by Synergetics, on 4 May 2022.

SYNERGETICS

Second run of Altona Cat-HTR facility air emission modelling and impact assessment using European Union emission levels for a waste incineration plant

prepared for

Licella

4 May 2022

Altona Cat-HTR facility air emission modelling and impact assessment

for

Licella

Report version	Date	Prepared by	Reviewed by	Comments
F01	4 May 2022	JB, NG, CC	DC	

Prepared by:

James Brett
BE(Hons) BSc MEngSc PhD
Principal Modelling Engineer

Nitheesh George
BEng MS PhD
Senior Modelling Engineer

Chiara Cementon
PhBSc(Hons)
Graduate Scientist

Reviewed by:

Dave Collins
BE(Hons) MBA PhD FIEAust FAIE CIH MAIOH CPEng RBP
Principal Engineer

Contents

Abbreviations

AGL	Above ground level
BoM	Bureau of Meteorology
Cat-HTR	Catalytic Hydrothermal Reactor™
EPA	Environment Protection Authority
GLC	Ground level concentration
HP boiler	High pressure boiler
IRSD (SEIFA) for Areas)	Index of Relative Socio-economic Disadvantage (Socio-Economic Indexes
LP boiler	Low pressure boiler
Nm^3	Normal m^3, Volume at a temperature of 0°C and pressure of 1.0325 bar

Executive summary

Licella propose to construct an Advanced Recycling Catalytic Hydrothermal Reactor (Cat-HTR™) facility at 541-583 Kororoit Creek Road, Altona. The process is designed to convert end-of-life plastic waste into usable products such as synthetic crude oil (plasticrude), heavy fraction bitumen oil and process gas. .

The process includes a high temperature reaction, with heat provided by gas fired boilers. Approximately half of the process gas generated will be consumed to heat the boilers, with the remainder either sold or consumed in a flare, depending on process needs and market demand.

Synergetics Consulting Engineers undertook and reported on modelling of this facility during 2021 (Synergetics, 2021) based on estimated emission levels. Following receipt of the 2021 report, EPA Victoria requested that Licella provide additional modelling covering the facility operating at the European Union emission levels for a waste incineration plant[1].

This report summarises the additional modelling written as a supplemental report to (Synergetics, 2021).

The modelled GLCs were as follows:

- Background emission levels were between 48% and 88% of Air Pollution Assessment Criteria (APAC) (EPA Vic, 2022) for NO_2 and SO_2, with exceedances in APAC for $PM_{2.5}$ and PM_{10} due to events such as bushfires.
- $PM_{2.5}$ and PM_{10} levels were not materially increased by the facility.
- All other substances were increased by at most 3% of the APAC compared to background, and remained with the background criteria.
- GLCs at sensitive receptors were not materially changed above background levels by the air emissions.

It would be appropriate to verify these conclusions when emission measurements from the ReNewELP Teesdale UK facility are available.

---

[1] While the proposed facility is not a waste incineration plant, it is our understanding that EPA are utilising these levels to provide a conservative assessment in the absence of process-specific emission measurements.

1 Introduction

Licella propose to construct an Advanced Recycling Catalytic Hydrothermal Reactor (Cat-HTR™) facility at 541-583 Kororoit Creek Road, Altona. The process is designed to convert end-of-life plastic waste into usable products such as synthetic crude oil (plasticrude), heavy fraction bitumen oil and process gas.

The process includes a high temperature reaction, with heat provided by gas fired boilers. Approximately half of the process gas generated by the process will be consumed to heat the boilers, with the remainder either sold or consumed in a flare, depending on process needs and market demand.

Synergetics Consulting Engineers previously undertook modelling of this facility based on available test reports and emissions estimates (Synergetics, 2021). Following receipt of this report, EPA requested that Licella provide additional modelling covering the facility operating at the European Union emission levels for a waste incineration plant[2].

This report details the findings of the additional modelling and should be considered supplemental to (Synergetics, 2021).

---

[2] While the proposed facility is not a waste incineration plant, it is our understanding that EPA are utilising these levels to provide a conservative assessment in the absence of process specific measurements.

2 Site description

2.1 Site layout

The proposed Cat-HTR facility will be located at 541-583 Kororoit Creek Road, Altona, marked in Figure 1. Land use within a 5 km radius consists of a mixture of industrial, and residential, with the closest residential land use approximately 1.4 km away from the probable location of the stacks. Nearby sensitive receptors such as residential properties, and schools are numbered in Figure 1. These receptors are the same as those used in (Synergetics, 2021), and further details can be found in that report.

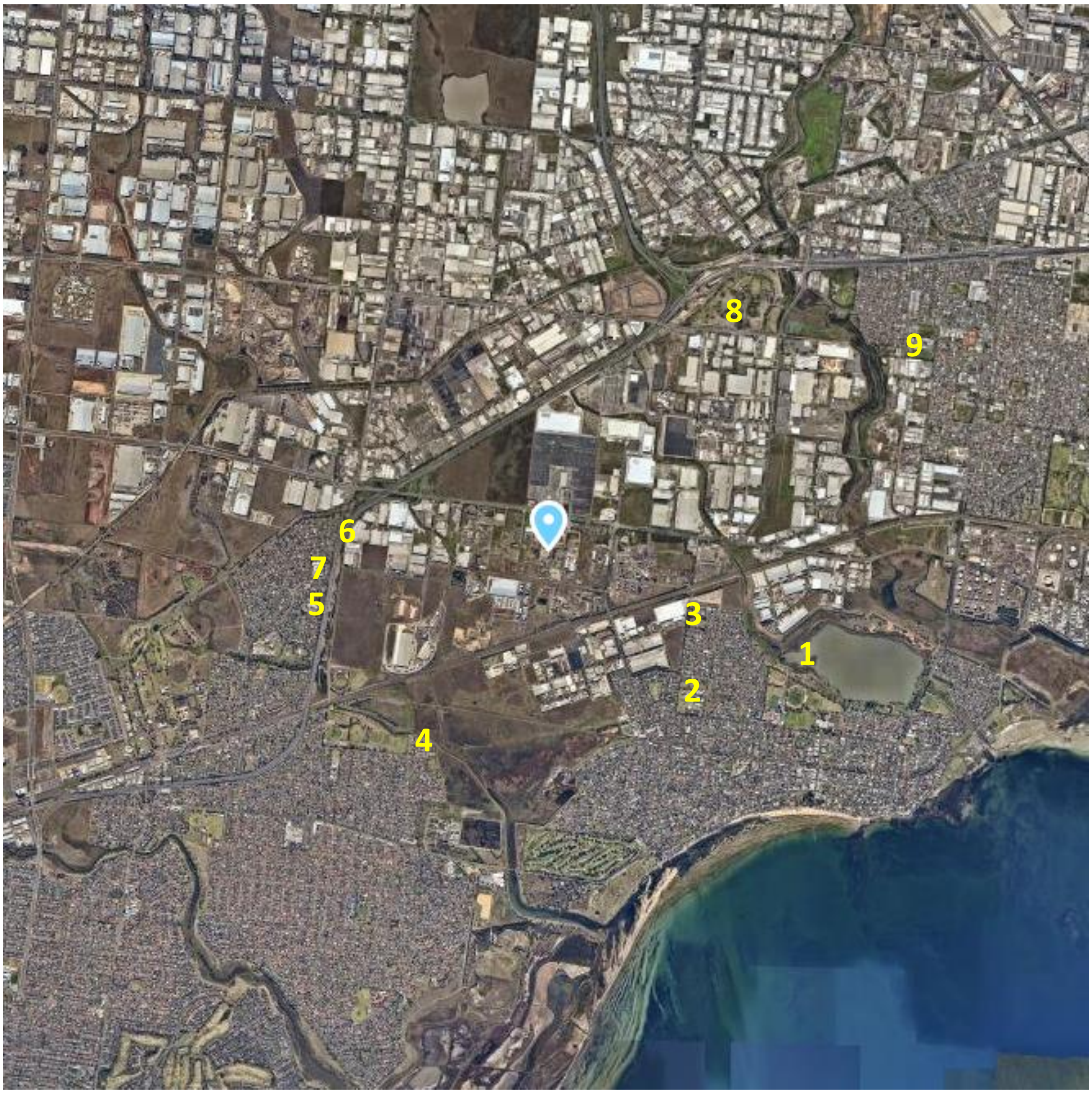


Figure 1 - The subject site and the surrounding land use. The nearby sensitive receptors are numbered. Image sourced from Nearmap (2021). North is to the top of the image.

The site currently includes a mixture of buildings, with heights of less than 10 m, and several large storage tanks. Site works will be required to construct the new facility, with some of the existing structures to be reused. The site will include three emission sources for: one low pressure (LP) boiler stack; one high pressure (HP) boiler stack; and a flare tower. The detailed site layout is not finalised, however it was assumed that emission sources will be 25 m tall, with nearby buildings kept to 10 m or less to minimise any building downwash. Modelled stack details are shown in Table 1[3].

Table 1 – Modelled stack properties and emission rates. Stack values are adapted from (SLR, 2020) in consultation with Licella.

Parameter	**HP boiler**	**LP boiler**	**Flare**
Stack internal diameter (m)	0.3	0.2	2
Exhaust height (m AGL)	25	25	25
Temperature (°C)	350	240	850
O_2 content (% dry)	2.9	2.8	2.9
Moisture content (%H_20)	14.8	14.8	14.8
Actual flow rate (Am^3/s)	1.7	0.7	5.3
Velocity (m/s)	24	23	2
Volume flow rate (Nm^3/s dry, 3% O_2)	0.64	0.33	1.11
SO_x emissions (mg/Nm^3)	30	30	30
SO_x emission rate (g/s)	0.035	0.018	0.060
NO_2 emissions (mg/Nm^3)	120	120	120
NO_2 emission rate (g/s)	0.14	0.071	0.24
NH_3 emissions (mg/Nm^3)	10	10	10
NH_3 emission rate (g/s)	0.012	0.0060	0.020
Cd emissions (mg/Nm^3)	0.02	0.02	0.02
Cd emission rate (g/s)	0.000023	0.000012	0.000040
CO emissions (mg/Nm^3)	50	50	50
CO emission rate (g/s)	0.058	0.030	0.10
Dioxins emissions (mg/Nm^3)	0.00000008	0.00000008	0.00000008
Dioxins emission rate (g/s)	9.2E-11	4.8E-11	1.6E-10
HCl emissions (mg/Nm^3)	6	6	6
HCl emission rate (g/s)	0.0070	0.0040	0.012
HF emissions (mg/Nm^3)	1	1	1
HF emission rate (g/s)	0.0012	0.00060	0.0020
Hg emissions (mg/Nm^3)	0.02	0.02	0.02
Hg emission rate (g/s)	2.3E-05	1.2E-05	4E-05
$PM_{2.5}$ emissions (mg/Nm^3)	5	5	5
$PM_{2.5}$ emission rate (g/s)	0.0058	0.0030	0.010
PM_{10} emissions (mg/Nm^3)	5	5	5
PM_{10} emission rate (g/s)	0.0058	0.0030	0.010

---

[3] These stack properties have been adapted from a ReNewELP Teesdale UK facility using the CAT-HTR process (SLR, 2020), with stack heights increased to 25 m to minimise the chance of downwash. Ammonia emissions from the flare have also been allowed for, with the same concentration as the boilers.

2.2 Emissions

In line with the request by EPA to consider EU directive emission for a waste incineration plant, values were assumed to be consistent with the levels for BAT- AEL (Best Available Techniques – Air Emission Levels) from (EU, 2019). Where a range of values were presented for BAT-AEL, the highest emission level was assumed. These emission limits were assumed to simultaneously apply to the high pressure boiler, low pressure boiler and the flare stacks. In addition the following comments apply:

- Boiler start-up will be fired with natural gas.
- Emissions during start-up are expected to be similar to operating on process gas and have not been modelled.
- The Cat-HTR reactions occur within a sealed process and fugitive emissions are expected to be negligible.

3 Methodology

3.1 Assessment criteria and emissions

Emission rates were modelled for a single scenario with emissions from both boilers and the flare. During operations where the excess process gas is sold rather than burned, emissions are likely to be less than the modelled case, and was not considered.

Assessment criteria, expressed as APACs, are also listed in Table 2.

Table 2 - Modelled emission rates and relevant assessment criteria.

Substance	**Assessment criteria**					**Emissions (g/s) at point of discharge to atmosphere**		
	Aver. period	**APAC**	**Units**	**Source**	**Expressed as**	**HP boiler**	**LP boiler**	**Flare**
NO_x	1 h[4]	0.08	ppm	(Vic., 2022)	NO_2	0.14	0.071	0.24
	1 yr[5]	0.015	ppm					
SO_2	1 h	0.075	ppm	(Vic., 2022)	SO_2	0.035	0.018	0.060
	24 h[6]	0.02	ppm					
NH_3	1 h	3200	µg/m^3	(EPA Vic, 2022)	NH_3	0.012	0.0060	0.020
	24 h	1184	µg/m^3					
	1 yr	70	µg/m^3					
Cd	1 h	18	µg/m^3	(EPA Vic, 2022)	Cd	0.000023	0.000012	0.00004
	24 h	0.03	µg/m^3					
	1 yr	0.005	µg/m^3					
CO	8 h	9	ppm	(Vic., 2022)	CO	0.058	0.030	0.10
Dioxins	1 yr	0.00004	µg/m^3	(EPA Vic, 2022)	Dioxins	9.2x10^{-11}	4.8x10^{-11}	1.6x10^{-10}
HCl	1 h	2100	µg/m^3	(EPA Vic, 2022)	HCl	0.0070	0.0036	0.012
	1 yr	20	µg/m^3					
HF	24 h	2.9	µg/m^3	(EPA Vic, 2022)	HF	0.0012	0.00060	0.0020
Hg	1 yr	1	µg/m^3	(EPA Vic, 2022)	Hg	0.000023	0.000012	0.00004
$PM_{2.5}$	24 h	25	µg/m^3	(Vic., 2022)	$PM_{2.5}$	0.0058	0.0030	0.010
	1 yr	8	µg/m^3					
PM_{10}	24 h	50	µg/m^3	(Vic., 2022)	PM_{10}	0.0060	0.0030	0.010
	1 yr	20	µg/m^3					

---

[4] 1 hour averaging period – maximum ground level concentration averaged over one hour. 99.9% value for any year is assessed

[5] 1 Year averaging period – maximum ground level concentration averaged over one year.

[6] 24 hour averaging period – maximum ground level concentration averaged over one day.

3.2 Model selection and configuration

Emission dispersion was modelled using AERMOD[7]. In addition to the sensitive receptors marked in Figure 1, gridded GLCs receptors covered a 10 x 10 km domain, with a 50 m grid spacing, centered on the proposed facility were also modelled as specified by (EPA Vic, 2013a). The emission sources were modelled as elevated point sources, and GLCs were calculated for hourly, 8h, 24 h and annual averaging times. Building downwash was not modelled on the basis that buildings will be less than 40% of the stack height.

3.3 Background GLCs

Time varying background GLCs have been included in the results for all relevant and available substances. The background sources considered are:

- NO_2 – The EPA Victoria monitoring site in Altona North was used for background NO_2 GLCs for this modelling.
- SO_2 - The EPA Victoria monitoring site in Altona North was used for background SO_2 GLCs for this modelling.
- $PM_{2.5}$ - The EPA Victoria monitoring site in Footscray was used for background $PM_{2.5}$ GLCs for this modelling.
- PM_{10} - The EPA Victoria monitoring site in Brooklyn was used for background PM_{10} GLCs for this modelling.

The Altona North monitoring station is expected to be representative of conditions near sensitive receptors in Altona. For particulate measurements, the Brooklyn site was the nearest available source for PM_{10}, however as it does not record $PM_{2.5}$, Footscray was selected as the most appropriate facility.

Background data was not available for other substances, however considering the low emission levels of these substances and lack of nearby sources expected to produces large background concentrations this is no expected to be significant.

The available background data was processed to match the period of the meteorological data (see Section 4). Where data gaps were present they were managed as follows:

- For periods of one to three consecutive hours of missing data, the period was filled using the average GLC either size of the missing data.
- For more than three consecutive hours, a representative background value of the 70th percentile value over the five years was used.

---

[7] Version 18081 using the methodology specified in (EPA Vic, 2013a).

4 Meteorological data

AERMOD compatible meteorological data for the site was generated from historical data recorded by the Bureau of Meteorology (BoM), with surface observations from the BoM Station at Laverton RAAF Base. This station is located approximately 4 km from the modelled emission location, in similar topography and similar distance from the coast. Half hourly interval samples were used for all variables except wind speed and direction, for which one minute interval data was used[8].

Upper atmosphere data is needed to calculate mixing heights, but as it is not recorded at Laverton RAAF Base, this data were sourced from the nearest available site, the BoM Station at Melbourne Airport.

Five calendar years of data was processed in accordance with (EPA Vic, 2013b), covering the period from 2015 to 2019 inclusive[9].

Site wind conditions are summarised as follows:

- northerly winds are most common;
- north easterly winds are the least common;
- hourly average wind speeds below 10 km/hr account for 25% of all conditions; and
- hourly average wind speeds 40 km/hr and above account for approximately 0.75% of the assessed period.

These conditions are not expected to result in unusual or unfavourable dispersion. Wind roses are provided in Appendix A if more detail is required.

---

[8] Details on the Laverton RAAF Base BoM station can be found at http://www.bom.gov.au/clim_data/cdio/metadata/pdf/siteinfo/IDCJMD0040.086077.SiteInfo.pdf .

[9] Where critical data was missing from the BoM records, the day was removed from the sampling period, and an additional day's data from a substitute year (2014) was added to the meteorological files. No discernible seasonal bias was observed in the missing data.

5 Results

5.1 Summary

The modelled GLC, for the gridded receptors[10], based on the maximum measured emissions profile, are listed in Table 3 for each assessed substance. The modelled GLC at the sensitive receptors are included in Table 5. Other than $PM_{2.5}$ and PM_{10}, all modelled GLCs are less than the relevant assessment criterion.

5.2 Particulate matter

The two particulate substances, $PM_{2.5}$ and PM_{10}, both have reported concentrations in excess of the assessment criteria due to high background events such as bushfires. The emissions due to the facility alone are minimal, with values of less than 1% of the assessment criteria.

---

[10] The gridded receptors cover the entire 10 km by 10 km domain, with the highest exposure location listed in the table.

Table 3 - Modelled maximum GLC showing maximum level for any gridded receptor[11].

Substance	Assessment criteria			Facility emission only		Background only		Facility with background	
	Averaging period	**APAC**	**Units**	**Modelled value**	**% of criterion**	**Recorded value**	**% of criterion**	**Modelled value**	**% of criterion**
NO$_x$	1 hour	0.08	ppm	0.0036	4.5%	0.040	49%	0.042	52%
	1 Year	0.015	ppm	0.00042	2.8%	0.0096	64%	0.0099	66%
SO$_2$	1 hour	0.075	ppm	0.00065	0.87%	0.036	48%	0.036	48%
	1 day	0.02	ppm	0.00032	1.6%	0.018	88%	0.018	89%
NH$_3$	1 hour	3200	µg/m^3	0.61	0.019%	-	-	-	-
	1 day	1184	µg/m^3	0.30	0.43%	-	-	-	-
	1 year	70	µg/m^3	0.070	0.10%	-	-	-	-
Cd	1 hour	18	µg/m^3	0.0012	0.007%	-	-	-	-
	1 day	0.03	µg/m^3	0.00060	2.0%	-	-	-	-
	1 year	0.005	µg/m^3	0.00014	2.8%	-	-	-	-
CO	8 hours	9	ppm	0.0022	0.024%	-	-	-	-
Dioxins	1 year	0.00004	µg/m^3	5.62E-10	0.001%	-	-	-	-
HCl	1 hour	2100	µg/m^3	0.37	0.018%	-	-	-	-
	1 year	20	µg/m^3	0.042	0.21%	-	-	-	-
HF	1 day	2.9	µg/m^3	0.030	1.0%	-	-	-	-
Hg	1 year	1	µg/m^3	0.00014	0.014%	-	-	-	-
PM$_{2.5}$	1 day	25	µg/m^3	0.15	0.60%	34	140%	34	140%
	1 year	8	µg/m^3	0.035	0.44%	7.4	93%	7.5	93%
PM$_{10}$	1 day	50	µg/m^3	0.15	0.30%	140	280%	140	280%
	1 year	20	µg/m^3	0.035	0.18%	23	110%	23	110%

---

[11] The hourly values are 99.9th percentile for the 40,000 gridded receptors, i.e. the most affected location in the domain. Values for each modelled year are in Appendix D.

Table 4 - Modelled maximum[12] GLC showing maximum level for any sensitive receptor.

Substance	Assessment criteria			Facility emission only		Background only		Facility with background	
	Averaging period	APAC	Units	Modelled value	% of criterion	Recorded value	% of criterion	Modelled value	% of criterion
NO_x	1 hour	0.08	ppm	0.0010	1.3%	0.040	49%	0.040	50%
	1 Year	0.015	ppm	0.000012	0.082%	0.0096	64%	0.0096	64%
SO_2	1 hour	0.075	ppm	0.00018	0.24%	0.036	48%	0.036	48%
	1 day	0.02	ppm	0.000017	0.087%	0.018	88%	0.018	88%
NH_3	1 hour	3200	µg/m^3	0.17	0.005%	-	-	-	-
	1 day	1184	“	0.017	0.024%	-	-	-	-
	1 year	70	“	0.0021	0.0030%	-	-	-	-
Cd	1 hour	18	“	0.00034	1.1%	-	-	-	-
	1 day	0.03	“	0.000033	0.11%	-	-	-	-
	1 year	0.005	“	0.0000041	0.014%	-	-	-	-
CO	8 hours	9	ppm	0.00020	0.002%	-	-	-	-
Dioxins	1 year	0.00004	µg/m^3	1.7E-11	0.00%	-	-	-	-
HCl	1 hour	2100	“	0.10	0.005%	-	-	-	-
	1 year	20	“	0.0012	0.006%	-	-	-	-
HF	1 day	2.9	“	0.0017	0.057%	-	-	-	-
Hg	1 year	1	“	0.0000041	0.00%	-	-	-	-
$PM_{2.5}$	1 day	25	“	0.0083	0.033%	34	140%	34	140%
	1 year	8	“	0.0010	0.013%	7.4	93%	7.4	93%
PM_{10}	1 day	50	“	0.0083	0.017%	140	280%	140	280%
	1 year	20	“	0.0010	0.005%	23	110%	23	110%

---

[12] 100% percentile values, for the five year modelled period. Values for each modelled year are in Appendix D.

As NO_2 has the highest levels due to the facility, a contour plot of 99.9th percentile hourly NO_2 GLCs has been included, as shown in Figure 2, to demonstrate the pattern of the modelled dispersion. A zoomed in version of this plot is included in Figure 3. The highest GLCs are concentrated around the stacks, in land zoned industrial, with GLCs closer to the sensitive receptors not materially different from background.

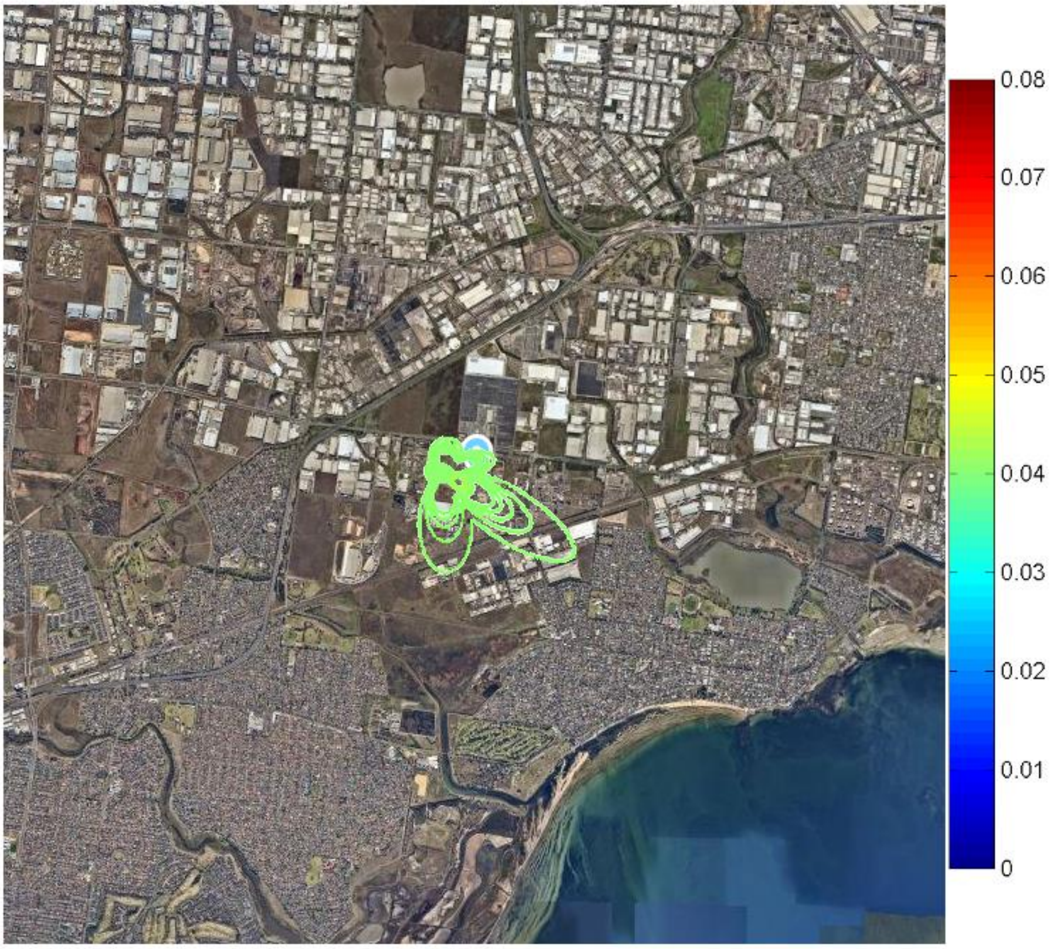


Figure 2 - Contours of highest 1 hour averaging period NO_2 GLC based on 2017[13] data, including background, in ppm. A 10 km by 10 km area around the site is shown. The top contour level (red = 0.12 ppm) on the scale corresponds to the relevant criterion, and does not occur on the plot due to the low GLC. The GLC is nearly uniform (ranging from 0.040 to 0.042) due to the low contribution of the site compared to the background.

---

[13] 2017 was selected as it had the highest concentration of NO_2.

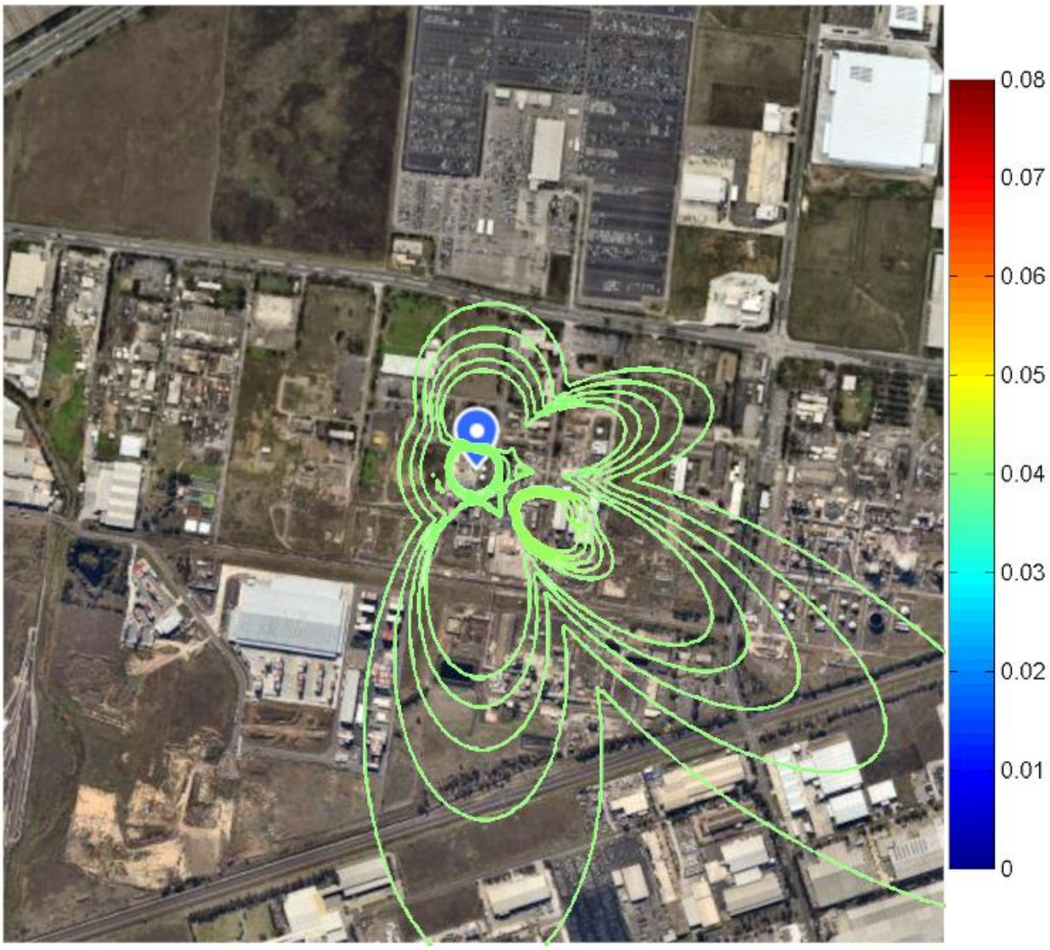


Figure 3 - Contours of highest 1 hour averaging period NO_2 GLC based on 2017 data, including background, in ppm. A 2 km by 2 km area around the site is shown. The top contour level (red = 0.12 ppm) on the scale corresponds to the relevant criterion, and does not occur on the plot due to the low GLC. The GLC is nearly uniform (ranging from 0.040 to 0.042) due to the low contribution of the site compared to the background.

Annual GLCs for Cadmium (Cd) are plotted in Figure 4 to demonstrate the effect of the facility emissions on long averaging times. The contour levels are all significantly lower than the APAC, and are concentrated on the facility and the surrounding industrial land. This is consistent with the very low concentrations at sensitive receptors as reported in Table 4.

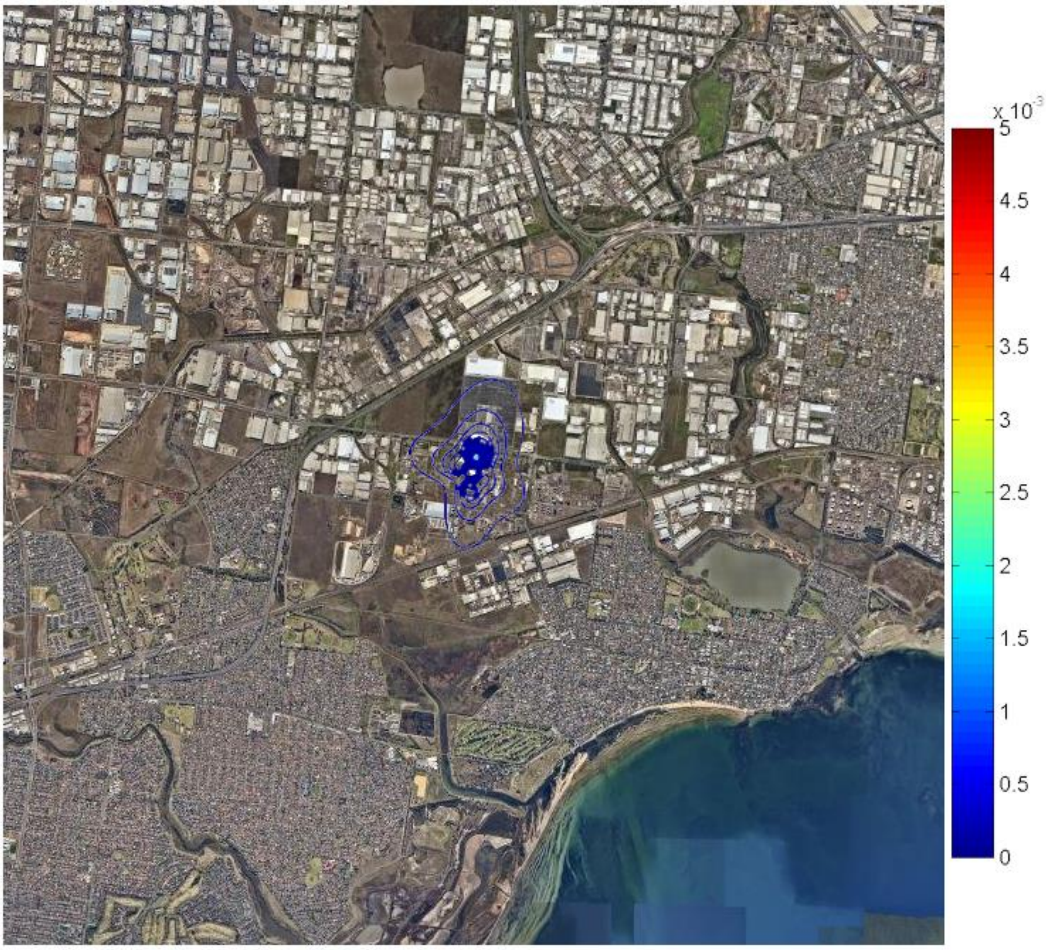


Figure 4 - Contours of highest annual averaging period Cd GLC based on 2015 data, not including background, in μg/m^3. The top contour level (red = 0.005 μg/m^3) on the scale corresponds to the relevant criterion, and does not occur on the plot due to the low GLC.

6 Conclusions

A total of five years of historical data was modelled in accordance with EPA Victoria requirements based on emission levels assuming the facility operating at the European Union emission levels for a waste incineration plant to provide a conservatively high assumed emission level.

The modelled GLCs were as follows:

- Background emission levels were between 48% and 88% of Air Pollution Assessment Criteria (APAC) (EPA Vic, 2022) for NO_2 and SO_2, with exceedances in APAC for $PM_{2.5}$ and PM_{10} due to events such as bushfires.
- $PM_{2.5}$ and PM_{10} levels were not materially increased by the facility.
- All other substances were increased by at most 3% of the APAC compared to background, and remained with the background criteria.
- GLCs at sensitive receptors were not materially changed above background levels by the air emissions.

It would be appropriate to verify these conclusions when emission measurements from the ReNewELP Teesdale UK facility are available.

7 References

EPA Vic. (2013a). *Guidance notes for using the regulatory air pollution model AERMOD in Victoria.* EPA Victoria.

EPA Vic. (2013b). *Construction of input meteorological data files for EPA Victoria's regulatory air pollution model (AERMOD).* EPA Victoria.

EPA Vic. (2022). *Guideline for assessing and miniminsing air pollution in Victoria (for air pollutioin managers and specialists,Publication 1961.* EPA Victoria, February 2022.

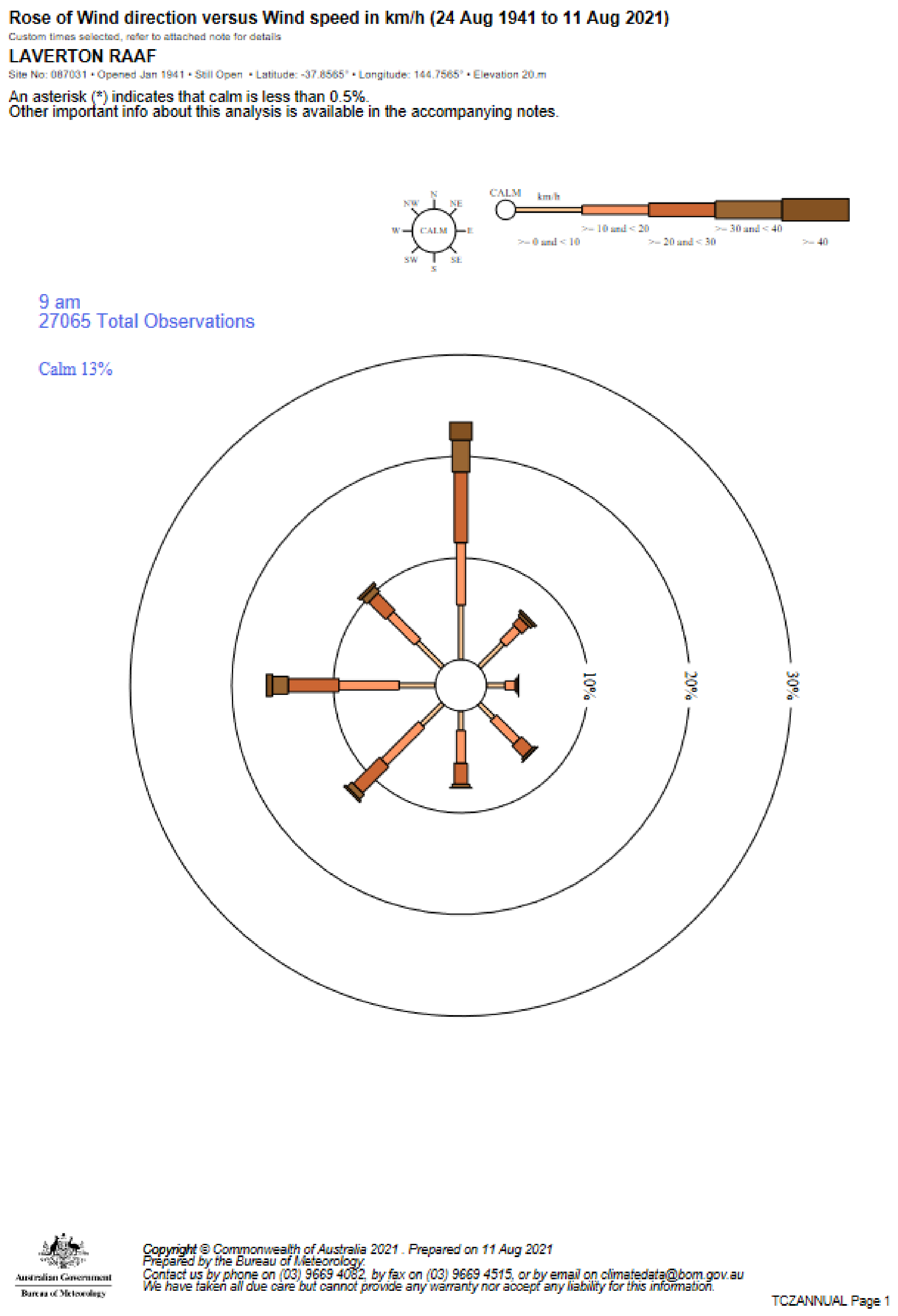
EU. (2019). *Commission Implementing Decision (EU) 2019/2010 of 12 November 2019, establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for waste incineration.*

SLR. (2020). *WILTON HYDROTHERMAL UPGRADING FACILITY ENVIRONMENTAL PERMIT APPLICATION, Air Emissions Risk Assessment.*

Synergetics. (2021). *Altona Cat-HTR facility air emission modelling and impact assessment, 22 November 2021.*

Vic. (2022). *Environmental Reference Standard, Ammendment.* Victorian Government Gazette, 29 March 2022.

Appendix A. Wind roses



Rose of Wind direction versus Wind speed in km/h (24 Aug 1941 to 11 Aug 2021)

Custom times selected, refer to attached note for details

LAVERTON RAAF

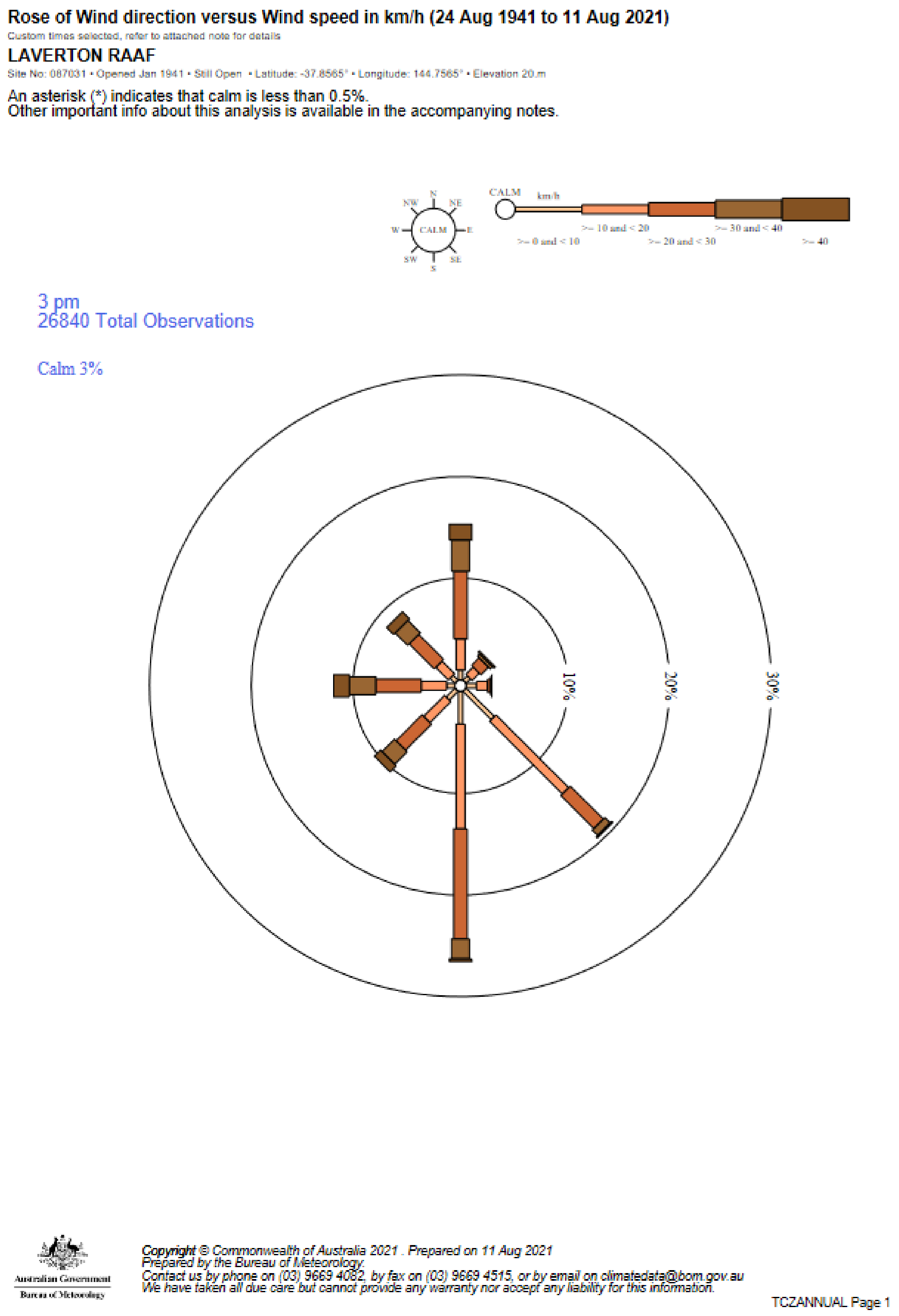
Site No: 087031 • Opened Jan 1941 • Still Open • Latitude: -37.8565° • Longitude: 144.7565° • Elevation 20.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

9 am
27065 Total Observations

Calm 13%

TCZANNUAL Page 1



Rose of Wind direction versus Wind speed in km/h (24 Aug 1941 to 11 Aug 2021)

Custom times selected, refer to attached note for details

LAVERTON RAAF

Site No: 087031 • Opened Jan 1941 • Still Open • Latitude: -37.8565° • Longitude: 144.7565° • Elevation 20.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

3 pm
26840 Total Observations

Calm 3%

TCZANNUAL Page 1

Figure 5 - 9am (left) and 3pm wind roses for the Laverton RAAF meteorological station

Appendix B. Discrete numbered receptor GLC

Substance	Assessment criteria			1		2		3		4		5		6		7		8		9	
	Averaging period	AQAC	Units	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria
NO$_x$	1 hour	0.08	ppm	0.040	49%	0.040	50%	0.040	49%	0.039	49%	0.039	49%	0.039	49%	0.039	49%	0.039	49%	0.039	49%
	1 Year	0.015	ppm	9.6E-03	64%	0.010	64%	0.010	64%	0.010	64%	0.010	64%	0.010	64%	0.010	64%	0.010	64%	0.010	64%
SO$_2$	1 hour	0.075	ppm	0.036	48%	0.036	48%	0.036	48%	0.036	48%	0.036	48%	0.036	48%	0.036	48%	0.036	48%	0.036	48%
	1 day	0.02	ppm	0.018	88%	0.018	88%	0.018	88%	0.018	88%	0.018	88%	0.018	88%	0.018	88%	0.018	88%	0.018	88%
NH$_3$	1 hour	3200	µg/m^3	0.11	0.003%	0.15	0.005%	0.17	0.005%	0.112	0.003%	0.090	0.003%	0.105	0.003%	0.104	0.003%	0.107	0.003%	0.072	0.002%
	1 day	1184	“	0.012	0.001%	0.017	0.001%	0.016	0.001%	0.015	0.001%	0.012	0.001%	0.012	0.001%	0.013	0.001%	0.013	0.001%	0.010	0.001%
	1 year	70	“	0.0010	0.001%	0.0019	0.003%	0.0021	0.003%	0.0009	0.001%	0.0005	0.001%	0.0010	0.001%	0.0008	0.001%	0.0014	0.002%	0.0005	0.001%
Cd	1 hour	18	“	0.000220	0.001%	0.000308	0.002%	0.000340	0.002%	0.000224	0.001%	0.000179	0.001%	0.000210	0.001%	0.000209	0.001%	0.000214	0.001%	0.000144	0.001%
	1 day	0.03	“	0.000024	0.081%	0.000033	0.11%	0.000033	0.11%	0.000029	0.097%	0.000024	0.080%	0.000024	0.079%	0.000025	0.084%	0.000026	0.086%	0.000020	0.065%
	1 year	0.005	“	0.000002	0.040%	0.000004	0.076%	0.000004	0.083%	0.000002	0.035%	0.000001	0.021%	0.000002	0.039%	0.000002	0.032%	0.000003	0.055%	0.000001	0.019%
CO	8 hours	9	ppm	0.00013	0.001%	0.00018	0.002%	0.00020	0.002%	0.00014	0.002%	0.00013	0.001%	0.00014	0.002%	0.00015	0.002%	0.00015	0.002%	0.00012	0.001%
Dioxins	1 year	0.00004	µg/m^3	7.9E-12	0.00%	1.5E-11	0.00%	1.7E-11	0.00%	7.0E-12	0.00%	4.2E-12	0.00%	7.7E-12	0.00%	6.4E-12	0.00%	1.1E-11	0.00%	3.7E-12	0.00%
HCl	1 hour	2100	“	0.066	0.003%	0.092	0.004%	0.102	0.005%	0.067	0.003%	0.054	0.003%	0.063	0.003%	0.063	0.003%	0.064	0.003%	0.043	0.002%
	1 year	20	“	0.00060	0.003%	0.0011	0.006%	0.0012	0.006%	0.00053	0.003%	0.00031	0.002%	0.00058	0.003%	0.00048	0.002%	0.00082	0.004%	0.00028	0.001%
HF	1 day	2.9	“	0.0012	0.042%	0.0017	0.057%	0.0016	0.057%	0.0015	0.050%	0.0012	0.041%	0.0012	0.041%	0.0013	0.044%	0.0013	0.044%	0.0010	0.034%
Hg	1 year	1	“	0.0000020	0.0002%	0.0000038	0.0004%	0.0000041	0.0004%	0.0000018	0.0002%	0.0000010	0.0001%	0.0000019	0.0002%	0.0000016	0.0002%	0.0000027	0.0003%	0.0000009	0.0001%
PM$_{2.5}$	1 day	25	“	34	137%	34	137%	34	137%	34	137%	34	137%	34	137%	34	137%	34	137%	34	137%
	1 year	8	“	7.4	93%	7.4	93%	7.4	93%	7.4	93%	7.4	93%	7.4	93%	7.4	93%	7.4	93%	7.4	93%
PM$_{10}$	1 day	50	“	142	283%	142	283%	142	283%	142	283%	142	283%	142	283%	142	283%	142	283%	142	283%
	1 year	20	“	22.9	115%	22.9	115%	22.9	115%	22.9	115%	22.9	115%	22.9	115%	22.9	115%	22.9	115%	22.9	115%

Note: Values in the above table include background contributions where applicable. For details on facility contributions compared to background GLCs see Section 5.

Appendix C. Maximum gridded receptor GLC for each year

Substance	Assessment criteria			2015		2016		2017		2018		2019	
	Averaging period	AQAC	Units	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria
NO_x	1 hour	0.08	ppm	0.036	45%	0.039	49%	0.041	52%	0.036	45%	0.037	46%
	1 Year	0.015	ppm	0.0083	55%	0.0085	57%	0.010	66%	0.0085	57%	0.010	63%
SO_2	1 hour	0.075	ppm	0.036	48%	0.032	43%	0.032	43%	0.033	44%	0.025	33%
	1 day	0.02	ppm	0.018	89%	0.012	62%	0.013	65%	0.015	73%	0.007	37%
NH_3	1 hour	3200	µg.m^{-3}	0.61	0.019%	0.59	0.018%	0.61	0.019%	0.59	0.018%	0.60	0.019%
	1 day	1184	µg.m^{-3}	0.28	0.023%	0.28	0.024%	0.27	0.023%	0.30	0.025%	0.28	0.023%
	1 year	70	µg.m^{-3}	0.070	0.100%	0.059	0.084%	0.060	0.085%	0.066	0.095%	0.058	0.083%
Cd	1 hour	18	µg.m^{-3}	0.0012	0.007%	0.0012	0.007%	0.0012	0.007%	0.001173	0.007%	0.0012	0.007%
	1 day	0.03	µg.m^{-3}	0.00055	1.8%	0.00056	1.9%	0.00054	1.8%	0.00060	2.0%	0.00055	1.8%
	1 year	0.005	µg.m^{-3}	0.00014	2.8%	0.00012	2.4%	0.00012	2.4%	0.00013	2.7%	0.00012	2.3%
CO	8 hours	9	ppm	0.0021	0.024%	0.0022	0.024%	0.0022	0.024%	0.0022	0.024%	0.0022	0.024%
Dioxins	1 year	0.00004	µg.m^{-3}	5.6E-10	0.001%	4.7E-10	0.001%	4.8E-10	0.001%	5.3E-10	0.001%	4.7E-10	0.001%
HCl	1 hour	2100	µg.m^{-3}	0.37	0.017%	0.35	0.017%	0.37	0.018%	0.35	0.017%	0.36	0.017%
	1 year	20	µg.m^{-3}	0.042	0.21%	0.035	0.18%	0.036	0.18%	0.040	0.20%	0.035	0.17%
HF	1 day	2.9	µg.m^{-3}	0.028	0.96%	0.028	0.96%	0.027	0.93%	0.030	1.0%	0.028	0.96%
Hg	1 year	1	µg.m^{-3}	0.00014	0.014%	0.00012	0.012%	0.00012	0.012%	0.00013	0.013%	0.00012	0.012%
$PM_{2.5}$	1 day	25	µg.m^{-3}	22	90%	26	103%	34	137%	31	123%	29	117%
	1 year	8	µg.m^{-3}	7.4	92%	6.6	83%	7.5	93%	7.4	92%	7.2	89%
PM_{10}	1 day	50	µg.m^{-3}	119	237%	82	164%	72	145%	69	139%	142	283%
	1 year	20	µg.m^{-3}	21.9	110%	20.0	100%	22.6	113%	21.6	108%	22.9	115%

Note: Values in the above table include background contributions where applicable. For details on facility contributions compared to background GLCs see Section 5.

Appendix D. Maximum sensitive receptor GLC for each year

Substance	Assessment criteria			2015		2016		2017		2018		2019	
	Averaging period	AQAC	Units	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria	Modelled value	% of criteria
NO$_x$	1 hour	0.08	ppm	0.036	45%	0.038	48%	0.040	50%	0.035	44%	0.035	44%
	1 Year	0.015	ppm	0.0079	53%	0.0082	54%	0.010	64%	0.0082	54%	0.0092	61%
SO$_2$	1 hour	0.075	ppm	0.036	48%	0.032	42%	0.032	42%	0.032	43%	0.025	33%
	1 day	0.02	ppm	0.018	88%	0.012	60%	0.013	64%	0.014	71%	0.0073	36%
NH$_3$	1 hour	3200	µg.m^{-3}	0.17	0.005%	0.15	0.005%	0.16	0.005%	0.14	0.004%	0.15	0.005%
	1 day	1184	µg.m^{-3}	0.017	0.001%	0.014	0.001%	0.016	0.001%	0.015	0.001%	0.016	0.001%
	1 year	70	µg.m^{-3}	0.0018	0.003%	0.0019	0.003%	0.0021	0.003%	0.0018	0.003%	0.0019	0.003%
Cd	1 hour	18	µg.m^{-3}	0.00034	0.002%	0.00031	0.002%	0.00032	0.002%	0.00028	0.002%	0.000304	0.002%
	1 day	0.03	µg.m^{-3}	0.000033	0.11%	0.000029	0.097%	0.000033	0.11%	0.000030	0.10%	0.000031	0.10%
	1 year	0.005	µg.m^{-3}	0.000004	0.07%	0.000004	0.076%	0.000004	0.083%	0.000004	0.070%	0.000004	0.077%
CO	8 hours	9	ppm	0.00016	0.002%	0.00017	0.002%	0.00020	0.002%	0.00015	0.002%	0.00018	0.002%
Dioxins	1 year	0.00004	µg.m^{-3}	1.4E-11	0.00%	1.5E-11	0.00%	1.7E-11	0.00%	1.4E-11	0.00%	1.5E-11	0.00%
HCl	1 hour	2100	µg.m^{-3}	0.10	0.005%	0.092	0.004%	0.096	0.005%	0.085	0.004%	0.091	0.004%
	1 year	20	µg.m^{-3}	0.0011	0.005%	0.0011	0.006%	0.0012	0.006%	0.0011	0.005%	0.0012	0.006%
HF	1 day	2.9	µg.m^{-3}	0.0017	0.057%	0.0014	0.050%	0.0016	0.056%	0.0015	0.052%	0.0016	0.054%
Hg	1 year	1	µg.m^{-3}	0.0000036	0.0004%	0.0000038	0.0004%	0.0000041	0.0004%	0.0000035	0.0004%	0.0000039	0.0004%
PM$_{2.5}$	1 day	25	µg.m^{-3}	22	90%	26	103%	34	137%	31	123%	29	117%
	1 year	8	µg.m^{-3}	7.3	91%	6.6	82%	7.4	93%	7.3	91%	7.1	89%
PM$_{10}$	1 day	50	µg.m^{-3}	119	237%	82	164%	72	145%	69	139%	142	283%
	1 year	20	µg.m^{-3}	21.9	110%	20.0	100%	22.6	113%	21.6	108%	22.9	115%

Note: Values in the above table include background contributions where applicable. For details on facility contributions compared to background GLCs see Section 5.

APPENDIX 9

HUMAN HEALTH RISK ASSESSMENT

Herein contains the report ‘Licella Advanced Plastics Recycling Facility: Human Health Risk Assessment’ as prepared for Licella Holdings Pty Ltd, by EnRiskS, on 19 May 2022.

Licella Advanced Plastics Recycling Facility: Human Health Risk Assessment

Prepared for: Licella Holdings Pty Ltd

19 May 2022

Document History and Status

Report Reference	LIC/22/PLRE001
Revision	B – Final
Date	19 May 2022
Previous Revisions	A – Draft (11 May 2022)

Limitations

Environmental Risk Sciences has prepared this report for the use of Licella Holdings Ltd in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in the Section 1 of this report.

The methodology adopted, and sources of information used are outlined in this report. Environmental Risk Sciences has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information contained in the reports provided for use in this assessment was false.

This report was prepared in April/May 2022 and is based on the information provided and reviewed at that time. Environmental Risk Sciences disclaims responsibility for any changes that may have occurred after this time.

This work is copyright. Apart from any use permitted under the Copyright Act 1968, no part may be reproduced by any process, nor may any other exclusive right be exercised, without the permission of enRiskS. Any reference to all or part of this report by third parties must be attributed to enRiskS (2022).

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Table of Contents

Appendices

Glossary of Terms and Abbreviations

Term	Definition
ABS	Australian Bureau of Statistics
Acute exposure	Contact with a substance that occurs once or for only a short time (up to 14 days)
Absorption	The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs
Adverse health effect	A change in body function or cell structure that might lead to disease or health problems
ATSDR	Agency for Toxic Substances and Disease Register
AAQ	Ambient air quality
ANZECC	Australia and New Zealand Environment and Conservation Council
Background level	An average or expected amount of a substance or material in a specific environment, or typical amounts of substances that occur naturally in an environment.
Biodegradation	Decomposition or breakdown of a substance through the action of micro-organisms (such as bacteria or fungi) or other natural physical processes (such as sunlight).
Body burden	The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.
Carcinogen	A substance that causes cancer.
Chronic exposure	Contact with a substance or stressor that occurs over a long time (more than one year) [compare with acute exposure and intermediate duration exposure].
CO	Carbon monoxide
DEFRA	Department for Environment, Food & Rural Affairs
DEH	Australian Department of Environment and Heritage
Detection limit	The lowest concentration of a substance that can reliably be distinguished from a zero concentration.
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An ‘exposure dose’ is how much of a substance is encountered in the environment. An ‘absorbed dose’ is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.
EPA	Environment Protection Authority
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Also includes contact with a stressor such as noise or vibration. Exposure may be short-term [acute exposure], of intermediate duration, or long term [chronic exposure].
Exposure assessment	The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.
Exposure pathway	The route a substance takes from its source (where it began) to its endpoint (where it ends), and how people can come into contact with (or get exposed) to it. An exposure pathway has five parts: a source of contamination (such as chemical substance leakage into the subsurface); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receptor population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.
Genotoxic carcinogen	These are carcinogens that have the potential to result in genetic (DNA) damage (gene mutation, gene amplification, chromosomal rearrangement). Where this occurs, the damage may be sufficient to result in the initiation of cancer at some time during a lifetime.

Term	Definition
Guideline value	Guideline value is a concentration in soil, sediment, water, biota or air (established by relevant regulatory authorities such as the NSW Department of Environment and Conservation (DEC) or institutions such as the National Health and Medical Research Council (NHMRC), Australia and New Zealand Environment and Conservation Council (ANZECC) and World Health Organization (WHO)), that is used to identify conditions below which no adverse effects, nuisance or indirect health effects are expected. The derivation of a guideline value utilises relevant studies on animals or humans and relevant factors to account for inter and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health and the environment. Dependent on the source, guidelines would have different names, such as investigation level, trigger value and ambient guideline.
HHRA	Human health risk assessment
HI	Hazard Index
IARC	International Agency for Research on Cancer
Inhalation	The act of breathing. A hazardous substance can enter the body this way [see route of exposure].
Intermediate exposure Duration	Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].
LGA	Local Government Area
LOR	Limit of Reporting
Metabolism	The conversion or breakdown of a substance from one form to another by a living organism.
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides
NSW	New South Wales
NSW EPA	NSW Environment Protection Authority
OEH	NSW Office of Environment and Heritage
OEHHA	Office of Environmental Health Hazard Assessment, California Environment Protection Agency (Cal EPA)
PM	Particulate matter
$PM_{2.5}$	Particulate matter of aerodynamic diameter 2.5 µm and less
PM_{10}	Particulate matter of aerodynamic diameter 10 µm and less
Point of exposure	The place where someone can come into contact with a substance present in the environment [see exposure pathway].
Population	A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).
Receptor population	People who could come into contact with hazardous substances [see exposure pathway].
Risk	The probability that something would cause injury or harm.
Route of exposure	The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].
SEIFA	Socio-Economic Index for Areas
SO_2	Sulfur dioxide
TCEQ	Texas Commission on Environmental Quality
Toxicity	The degree of danger posed by a substance to human, animal or plant life.
Toxicity data	Characterisation or quantitative value estimated (by recognised authorities) for each individual chemical substance for relevant exposure pathway (inhalation, oral or dermal), with special emphasis on dose-response characteristics. The data are based on based on available toxicity studies relevant to humans and/or animals and relevant safety factors.

Term	Definition
Toxicological profile	An assessment that examines, summarises, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.
Toxicology	The study of the harmful effects of substances on humans or animals.
TSP	Total suspended particulates
UK	United Kingdom
US	United States
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound
WHO	World Health Organization
$\mu g/m^3$	Micrograms per cubic metre

Executive Summary

Introduction

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Licella Holdings Ltd to undertake a Human Health Risk Assessment (HHRA) for an advanced plastics recycling facility at 541-583 Kororoit Creek Road, Altona, Victoria (the “site”) (refer to **Figure 2.4**). The project will be known as the Altona Advanced Recycling Facility and will use a catalytic hydrothermal reactor (i.e. Cat-HTR^{TM}). The operator of the project will be Advanced Recycling Victoria Pty Ltd (wholly owned subsidiary of Licella Holdings Ltd (ARV 2022).

The project proposes to take waste plastics (ones that cannot be mechanically recycled) and convert them into useable chemicals and hydrocarbon products (i.e. essentially the process breaks the polymers that make up the plastics into smaller chemicals that can then be reused for a range of purposes).

The site is within the Hobsons Bay City Council local government area, is owned by Dow Chemical Australia. It was previously used as a chemical manufacturing site and is currently undergoing remedial works and decommissioning. Dow Chemical proposes to lease land to ARV at this site (ARV 2022).

The site is suitably zoned SUZ3 (Special Use Zone 3 - Petrochemical Complex Area) – a precinct specifically zoned for chemical manufacturing and other heavy industry (ARV 2022).

This human health risk assessment (HHRA) has been developed for the project by identifying and estimating the health impacts of the proposed project, as a result of emissions to air, on the health of the surrounding (local and regional) community. Consideration of potential impacts to community health based on noise emissions or water discharges from the site is also presented in this report.

Assessment Approach

The HHRA has been conducted as a desktop assessment in accordance with national guidelines available from the enHealth (enHealth 2012a, 2017) and guidance from EPA Victoria.

The assessment has focused on potential changes in community health from the emissions to air for this proposed facility. As a result, the HHRA has relied on the air modelling presented in the Air Quality Impact Assessment (Synergetics 2022).

The assessment presented relates to emissions to air from the proposed facility assuming:

- plant continuously emits at maximum stack concentrations as per European guidance for best practice waste to energy facilities as per guidance from by EPA Victoria – actual emissions and hence risks would be lower during normal operations.

The area surrounding the Project site largely comprises industrial areas. Residential and other sensitive land uses are present further from the Project site.

Detailed assessment of risks to human health for air emissions has considered acute and chronic inhalation exposures as well as multi-pathway exposures associated with the deposition of metals and dioxin-like compounds to the ground and the potential for direct contact with soil and dust (indoors) and uptake of these chemicals into homegrown produce (fruit and vegetables and eggs) and consumption of this produce. The assessment has also considered whether the deposition of metals and dioxin-like compounds would have the potential to adversely affect water quality in rainwater tanks, should these be present within the community and used for a range of non-potable purposes.

Consideration of impacts from noise or water discharges have been assessed using Australian guidance and details of the proposed facility.

Outcomes of the HHRA

Based on the available data and the conservative assumptions adopted in this assessment, the following has been concluded:

Air

- Inhalation exposures: Risks to human health associated with acute or chronic exposures are negligible. This includes risks to pollutants presents as gases, particulate matter and pollutants bound to particulates.
- Multiple pathway exposures: Risks to human health associated with chronic exposures to pollutants, bound to particulates, that may deposit to surfaces and be taken up into produce for home consumption relevant to surrounding areas where residential land use occurs are negligible.

Noise

- Based on the available information (i.e. noise from the site is not expected to be noticeable), the potential for noise from the site to result in adverse health impacts within the community is considered to be low/negligible.

Water

- The potential for adverse health impacts within the off-site community associated with use of water at the site is considered to be negligible.

Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Licella Holdings Ltd to undertake a Human Health Risk Assessment (HHRA) for an advanced plastics recycling facility at 541-583 Kororoit Creek Road, Altona, Victoria (the “site”) (refer to **Figure 2.4**). The project will be known as the Altona Advanced Recycling Facility and will use a catalytic hydrothermal reactor (i.e. Cat-HTR^{TM}). The operator of the project will be Advanced Recycling Victoria Pty Ltd (wholly owned subsidiary of Licella Holdings Ltd (ARV 2022).

The project proposes to take waste plastics (ones that cannot be mechanically recycled) and convert them into useable chemicals and hydrocarbon products (i.e. essentially the process breaks the polymers that make up the plastics into smaller chemicals that can then be reused for a range of purposes).

The site is within the Hobsons Bay City Council local government area, is owned by Dow Chemical Australia. It was previously used as a chemical manufacturing site and is currently undergoing remedial works and decommissioning. Dow Chemical proposes to lease land to ARV at this site (ARV 2022).

The site is suitably zoned SUZ3 (Special Use Zone 3 - Petrochemical Complex Area) – a precinct specifically zoned for chemical manufacturing and other heavy industry (ARV 2022).

A recent review by CSIRO noted that the Cat-HTR process had the following advantages over other advanced recycling processes:

- has efficient heat transfer and operates at a comparatively low temperature, 450°C, which is associated with producing lower char than other processes
- accepts PET (which can clog pipes and contaminate products in pyrolysis processes)
- is tolerant of contamination (e.g. paper, cardboard) and is, therefore, good for processing multilayer plastics packaging
- can process thermoset plastics
- is tolerant of some chlorine (from PVC), which washes out with water as a salt (ARV 2022).

The Cat-HTR process involves the following:

- The Cat-HTR technology uses superheated water to break down the carbon chains in plastics.
- Effectively, the very hot, dense supercritical water acts as an energy source and solvent and a chemical moderator which breaks down the long chain hydrocarbon polymers.
- Each Cat-HTR module will process 20,000 tonnes per year (tpy) of waste plastic. Production throughput can be increased by having more modules constructed.
- In the Cat-HTR Mass Balance, 1 tonne of feedstock waste plastic will produce 150 kg (15%) Process Gas, 720 kg (72%) Plasticrude and 130 kg (13%) Heavy Fraction bitumen.
- Advanced Recycling facilities using Cat-HTR technology are under planning or construction in the UK, Japan, Korea and Australia (ARV 2022).

1.2 Objectives

The objective of this HHRA is to assess potential impacts to community health in relation to the operation of a proposed Waste Plastic to Fuel plant at Altona in Victoria.

The risks due to emissions to air will be assessed quantitatively based on the results of air quality modelling undertaken by Synergetics. All other aspects of operation will be reviewed on a qualitative basis using information provided by Licella – the information being developed for inclusion in the Development Licence application.

1.3 Approach and scope of works

The HHRA has been undertaken in accordance with the following guidance (and associated references as relevant):

- enHealth, 2012. Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012a);
- enHealth, 2012. Australian Exposure Factor Guidance – Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012b); and
- Guidance and guidelines available from the National Environment Protection Council in relation to ambient air quality (NEPC 2016) and contaminated land (NEPC 1999 amended 2013a)
- Guidance and guidelines available from EPA Victoria (EPA Victoria 2022).

Where relevant, the HHRA has also considered impacts to community health as outlined in the following guidance documents:

- enHealth, 2017. Health Impact Assessment Guidelines (enHealth 2017);
- Harris, P., Harris-Roxas, B., Harris, E. & Kemp, L., Health Impact Assessment: A Practical Guide, Centre for Health Equity Training, Research and Evaluation (CHETRE). Part of the UNSW Research Centre for Primary Health Care and Equity. University of New South Wales, Sydney, 2007 (Harris 2007)

1.4 Definitions

For the conduct of the HHRA, the following definitions are relevant and should be considered when reading this report.

Health:

The World Health Organisation defines health as "*a (dynamic) state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity*".

Hence the assessment of health should include both the traditional/medical definition that focuses on illness and disease as well as the more broad social definition that includes the general health and wellbeing of a population.

Health Hazard:

These are aspects of a Project, or specific activities that present a hazard or source of negative risk to health or well-being.

In relation to the HHRA these hazards may be associated with specific aspects of the proposed development/construction or operational activities, incidents or circumstances that have the potential to directly affect health. In addition, some activities may have a flow-on effect that results in some effect on health. Hence health hazards may be identified on the basis of the potential for both direct and indirect effects on health.

Health Outcomes:

These are the effects of the activity on health. These outcomes can be negative (such as injury, disease or disadvantage), or positive (such as good quality of life, physical and mental wellbeing, reduction in injury, diseases or disadvantage).

It is noted that where health effects are considered these are also associated with a time or duration with some effects being experienced for a short period of time (acute) and other for a long period of time (chronic). The terminology relevant to acute and chronic effects is most often applied to the assessment of negative/adverse effects as these are typically the focus of technical evaluations of various aspects of the project.

Likelihood:

This refers to how likely it is that an effect or health outcome will be experienced. It is often referred to as the probability of an impact occurring.

Risk:

This is the chance of something happening that will have an impact on objectives. In relation to the proposed project and the conduct of the HHRA, the concept of risk more specifically relates to the chance that some aspect of the project will result in a reduction or improvement in the health and/or well-being of the local community.

The assessment of risk has been undertaken on a quantitative basis. This is in line with the methods and levels of evidence currently available to assess risk.

Equity:

Equity relates to the potential for the project to lead to impacts that are differentially distributed in the surrounding population. Population groups may be advantaged or disadvantaged based on age, gender, socioeconomic status, geographic location, cultural background, aboriginality, and current health status and existing disability.

1.5 Available information

In relation to the proposed project, this HHRA has been developed on the basis of information provided within the following reports:

Air quality assessment:

- Synergetics 2022, Altona Cat-HTR facility additional air emission modelling and impact assessment. Report prepared for Licella, dated 19 April 2022.

Other aspects of the project:

- ARV 2022, Best available techniques and technologies (BATT), Advanced Recycling Victoria. Dated May 2022.
- Attexo 2021, Development Licence Application Supporting Documentation, Altona Advanced Recycling Facility Using Cat-HTR™ Technology. Dated December 2021. (containing noise assessment used in **Section 6**).

Section 2. Project description

2.1 Process

CSIRO undertook a review of advanced recycling technologies for plastics in 2021. They defined advanced recycling as follows:

Advanced recycling of plastics is the conversion to monomer or production of new raw materials by changing the chemical structure of a material or substance through cracking, gasification or depolymerisation, excluding energy recovery and incineration. Advanced recycling is also referred to as chemical, molecular or feedstock recycling.

They summarise the various processes as shown in **Figure 2.1**.

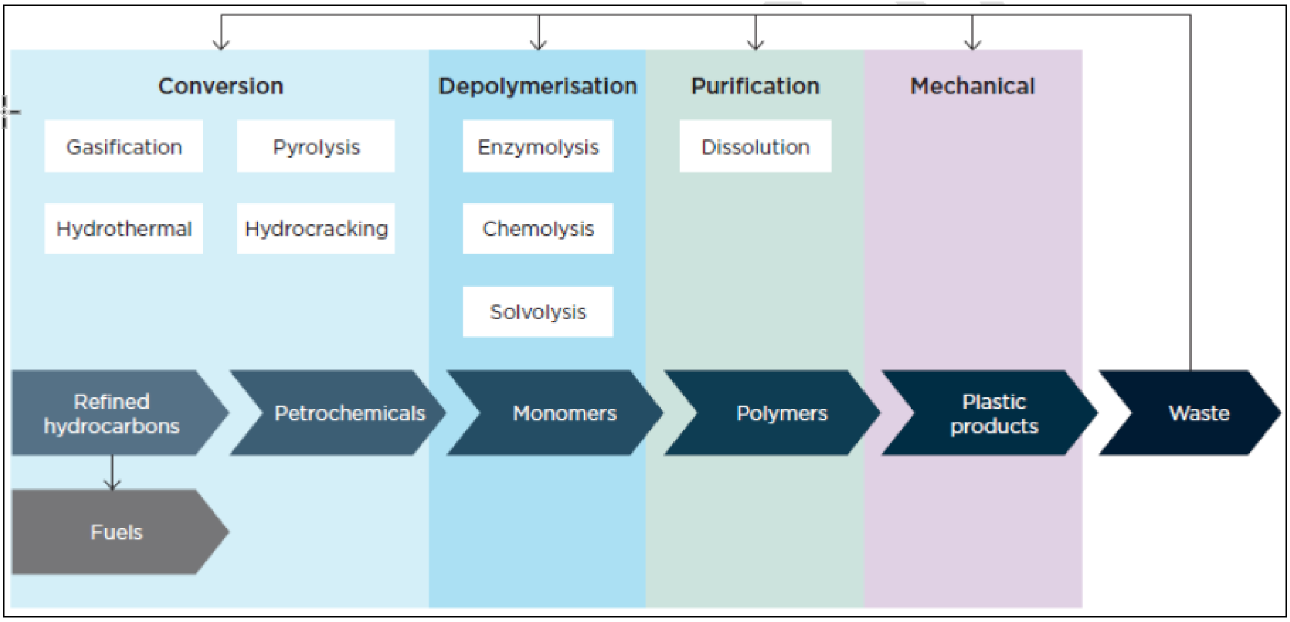
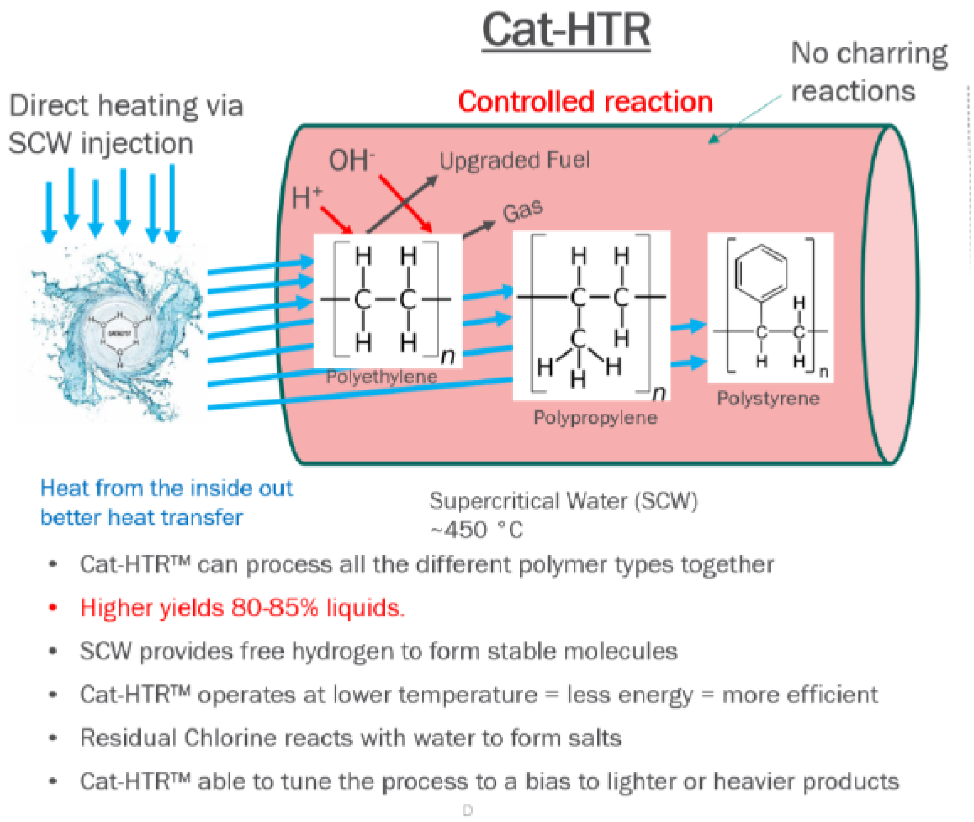


Figure 2.1 Advanced plastics recycling technologies (from CSIRO report as shown in (ARV 2022))

The Cat-HTR process is a hydrothermal process and involves the use of superheated water (under pressure) as the energy source and solvent to break apart the hydrocarbon chains present as the polymers in various plastics. The sorts of plastics targeted in this process are ones that are otherwise difficult to recycle and currently end up in landfill. **Figure 2.2** shows the process.

The outputs from the process are a synthetic crude oil type product that can be used as feedstock for the plastics industry, a process gas that can be used as a fuel for the boilers and a heavy fraction similar to bitumen.



- Cat-HTR™ can process all the different polymer types together
- Higher yields 80-85% liquids.
- SCW provides free hydrogen to form stable molecules
- Cat-HTR™ operates at lower temperature = less energy = more efficient
- Residual Chlorine reacts with water to form salts
- Cat-HTR™ able to tune the process to a bias to lighter or heavier products

Figure 2.2 Illustration of Cat-HTR process (ARV 2022)

The process flow chart is shown in **Figure 2.3**.

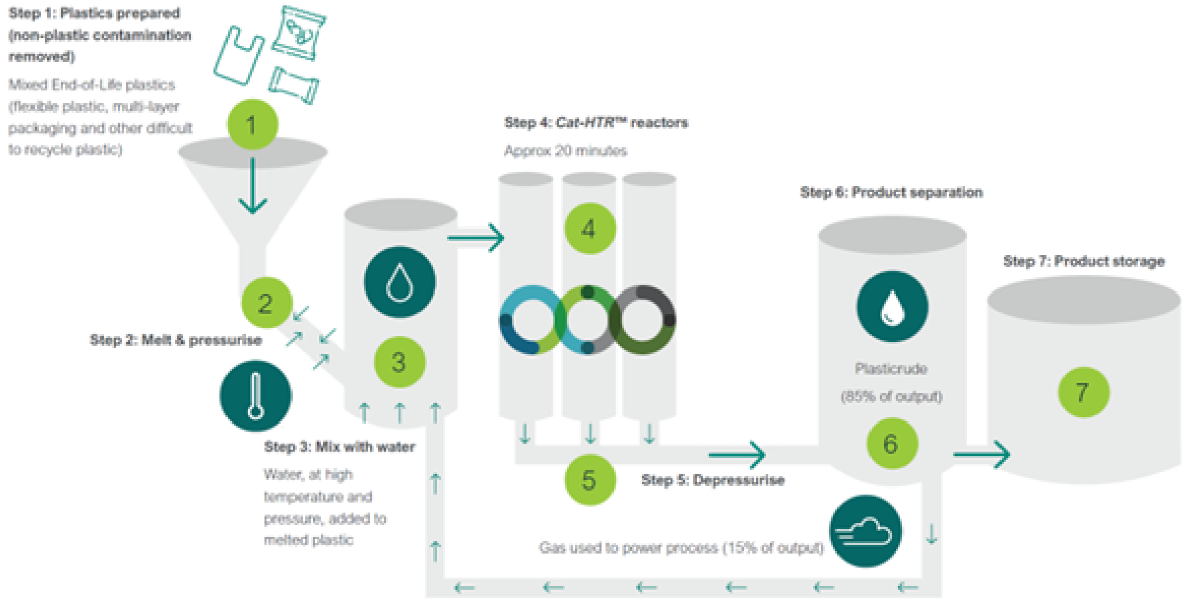


Figure 2.3: Process flow chart (ARV 2022)

The steps in the process can be summarised

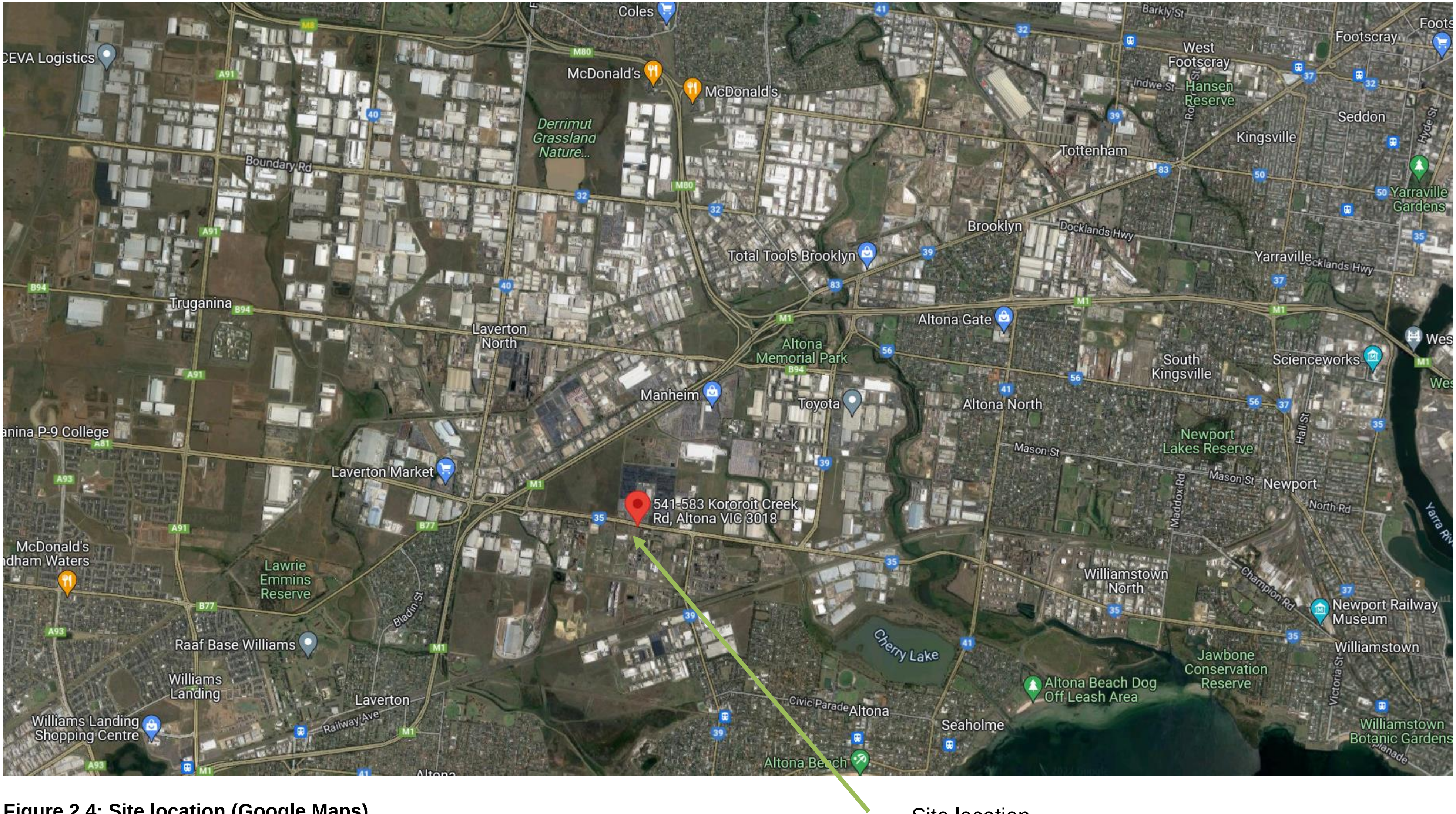
- Plastics obtained from companies already collecting waste plastics. These plastics will be transported and stored at the site in 40 ft shipping containers. This ensures appropriate litter management etc.
- The plastics will be prepared for the process by iQRenew (or equivalent) – preparation will involve shredding of the plastic, removal of contaminants (glass, metals, paper, wood), removal of plastics that can be mechanically recycled, removal of PVC and PVCD plastics and cleaning/storing remaining materials for transport to Altona site.
- Industrial recycled water from Greater Western Water will be used for the process.
- Water treatment plant will treat water prior to discharge to trade waste system operated by Greater Western Water. The treatment process will include dissolved air flotation and/or filtration through activated carbon. Any slops oil remaining in the water will be collected within the water treatment process and put back into the process to minimise any waste/loss. The treated water must comply with the Greater Western Water trade waste limits.
- Boilers are required to produce the superheated water and to produce steam for other purposes on the site (cleaning etc). The boilers will use natural gas during start up but once the process is operating, the gas produced in the process will be used to heat the boilers.
- The exhaust gas from the boilers will be scrubbed as appropriate prior to discharge using either a catalytic converter to reduce NOx levels or a packed bed wet scrubber. The choice of technology will be based on monitoring at the UK plant which is currently under construction and set to commence operations in later 2022.
- Plastics will be introduced into the process via an extruder to heat and pressurise.
- Approximately 60 tonnes of waste will be put through the process each day once the plant is operational for Stage 1.

2.2 Site

This plant is proposed to be constructed at the now decommissioned Dow Chemical site where a range of chemicals were previously manufactured. This site is in Altona in Victoria. The site has well established infrastructure including ready access to relevant road networks (Melbourne/Geelong freeway) for trucks and is accessed via an intersection controlled by traffic lights with a dedicated right turn lane (ARV 2022).

Existing tanks and bunding will be refurbished to ensure they are adequate for storage of outputs and feedstock (ARV 2022).

Figure 2.4 shows the site location. It is clear from the Figure that the site is within a large industrial precinct and well separated from any housing. The site is within an area zoned for the development of petrochemical facilities (SUZ3) and this precinct is surrounded by areas zoned as SUZ4 – special industrial and is designated for activities that would not be impacted by the location of petrochemical facilities in the SUZ3 area (ARV 2022).



Site location

Figure 2.4: Site location (Google Maps)

The proposed layout for the site is shown in **Figure 2.5**.

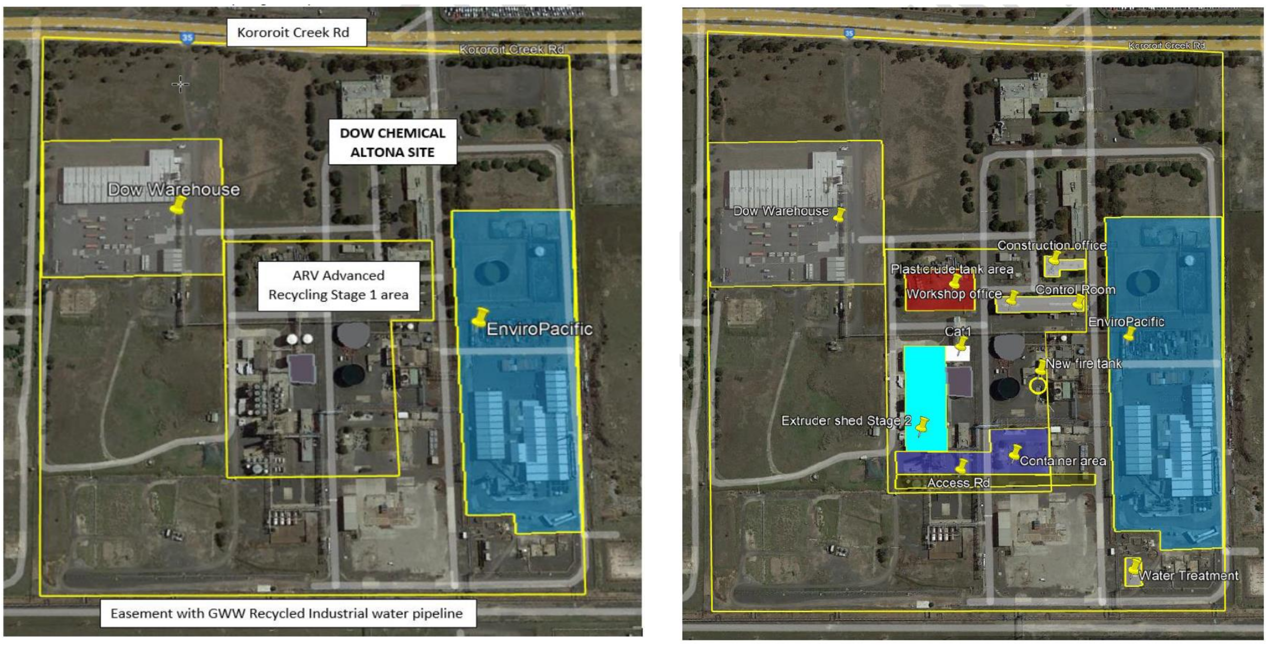


Figure 2.5: Site layout (proposed) (ARV 2022)

Section 3. Community profile

3.1 General

This section provides an overview of the community potentially impacted by the proposed project. It is noted that the key focus of this assessment is the local community surrounding the site.

3.2 Land uses

The site is located in Altona in an area zoned for special use for petrochemical plants and related heavy industry. This area is then surrounded by commercial/industrial areas with recreational and residential areas (particularly to the south, south east and south west) further away.

Modelling of air emissions from the plant has been undertaken across an area of 10 km x 10 km, with the plant located at the centre of this grid. The modelling has identified the maximum impacted location within the grid and outside the boundary of the proposed facility and also estimated air concentrations and deposition at 9 sensitive receptors (i.e. homes, schools, hospitals, childcare centres etc) in the vicinity. It is noted that the closest of these sensitive receptors is a residential area 1.4 km to the south east of the proposed facility. These sensitive receptors are listed in **Table 3.1** and shown on **Figure 3.1**.

Table 3.1: Receptor locations from air quality assessment

Receptor No.	Description	Distance from Site (km)	Direction from Site
1	Cherry Lake	2.35	SE
2	Altona College	1.65	SW
3	Residential property (Charles Rd)	1.37	SE
4	Residential property (Hibiscus Ct)	1.97	SW
5	St Martin de Porres Primary School	2.14	W
6	Residential property (Tyquin St)	1.95	W
7	Western Autistic School	2.05	W
8	Altona Memorial Park	2.47	NE
9	Emmanual College St Pauls Campus	3.8	NE

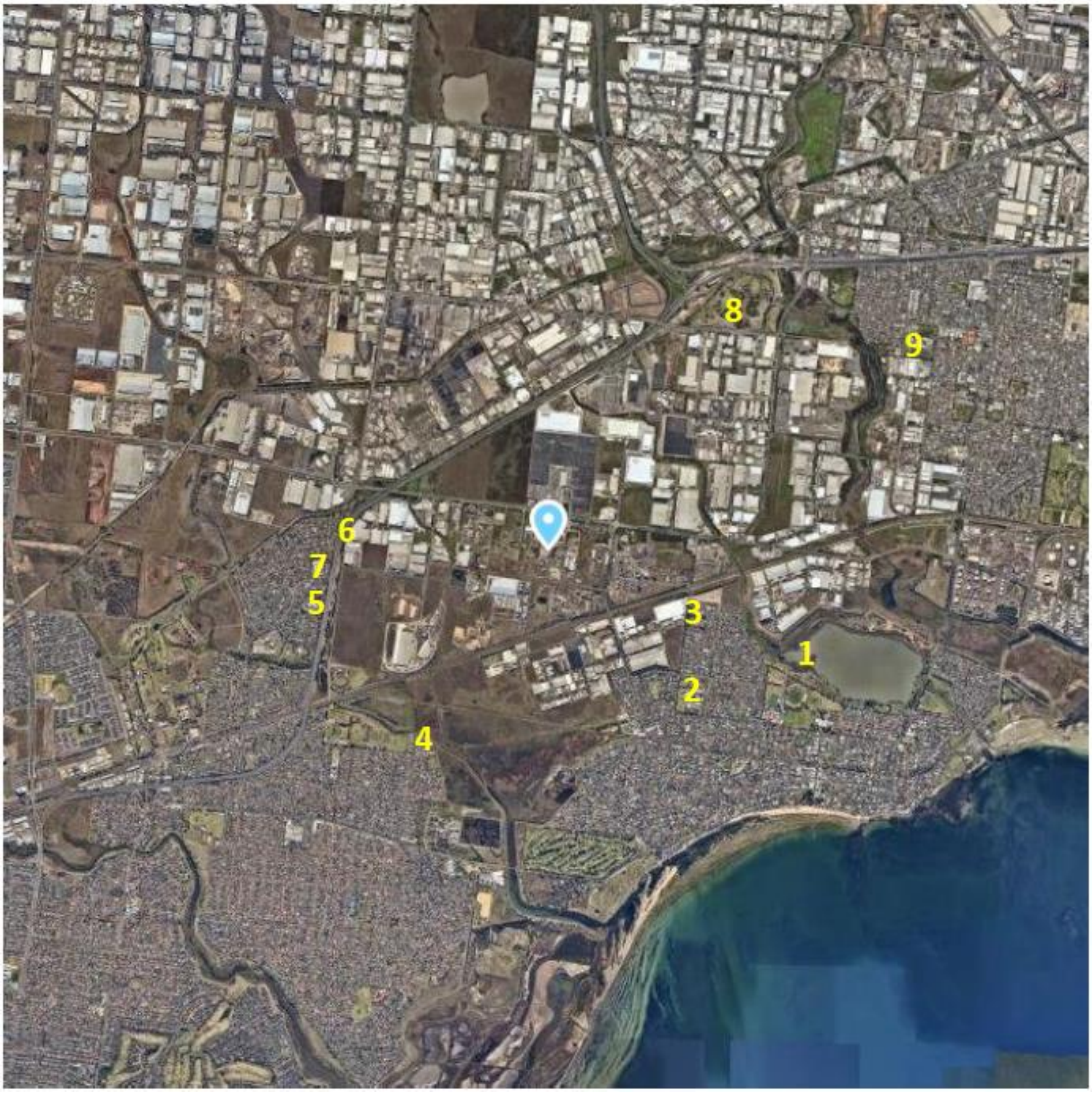


Figure 3.1: Subject site (indicated by blue marker), surrounding land uses and locations of sensitive receptors (indicated by yellow markers)

The closest residential properties are located around 1.4 km from the proposed facility. Such areas are assumed to be low-density residential land use which may include some home-grown fruit and/or vegetables and/or the keeping of chickens for eggs.

This assessment includes the evaluation of exposure via inhalation for workers within the immediate area surrounding the proposed facility and inhalation plus consumption of homegrown fruit and vegetables and eggs for community locations outside the industrial precinct.

3.3 Population

Table 3.2 presents a summary of the information relevant to the population in the Altona State Suburb (based on 2016 Census and 2016 Socio-Economic data from the Australian Bureau of Statistics) in comparison to Greater Melbourne and Australian populations.

Table 3.2: Summary of populations surrounding the proposed project site (ABS Census 2016)[1]

Indicator	**State Suburb**	**Local Government Area (LGA)**	**Greater Melbourne**	**Australia**
	Altona	**Hobsons Bay**		
Total population	10,762	88,778	4,485,211	23,401,886
Population 0 – 4 years	6.2% (668)	6.8% (6,062)	6.4% (287,178)	6.3% (1,464,779)
Population 5 – 19 years	15% (1,565)	17% (14,946)	17.9% (801,539)	18.5% (4,321,424)
Population 20 – 64 years	60% (6,459)	62% (54,650)	61.7% (2,767,015)	59.7% (13,938,913)
Population 65 years and over	19% (2,085)	15% (13,126)	14% (629,484)	15.7% (3,676,758)
Median age	42	38	36	38
Household size	2.3	2.6	2.7	3.2
Unemployment[1]	4%	4.9%	6%	6.9%
Tertiary education[2]	26%	26.1%	27.5%	22%
SEIFA IRSAD[3]	1,027	1,020	--	--
SEIFA rank	4	5	--	--
SEIFA IRSD[4]	1,030	1,015	--	--
SEIFA rank	4	4	--	--
Indigenous	0.5%	0.5%	0.54%	2.8%
Born overseas	35.4%	36.7%	40.2%	33.3%

Notes

Shading relates to comparison against Greater Melbourne: 🟧 more vulnerable; 🟦 less vulnerable

1 = rates (Sept 2021) as per labour market information portal (lmip.gov.au) small area labour markets data for local government areas and for statistical area 2 (https://www.nationalskillscommission.gov.au/topics/small-area-labour-markets#DecemberQuarter2021) (values used for Altona (Statistical area 2) and Hobsons Bay LGA)

2 = Bachelor degree and above

3 = SEIFA IRSAD = index of socioeconomic advantage and disadvantage, rank relates to rank in Australia that ranges from 1 = most disadvantaged to 5 = most advantaged (values listed for Altona (state suburb) and Hobsons Bay LGA)

4 = SEIFA IRSD = index of socioeconomic disadvantage, rank relates to rank in Australia that ranges from 1 = most disadvantaged to 5 = least disadvantaged (values listed for Altona (state suburb) and Hobsons Bay LGA)

Based on the population data available and presented in **Table 3.2**, the community of Altona and/or of the local government area of Hobsons Bay is quite similar to Greater Melbourne.

The indicators outlined in **Table 3.2** generally reflect the vulnerability of the population, its ability to adapt to environmental stresses, and are important to highlight from an equity point of view. The project will be implemented within a community which is not of great disadvantage.

3.4 Population health

The health of the community is influenced by a complex range of interactive factors including age, socio-economic status, social capital, behaviours, beliefs and lifestyle, life experiences, country of origin, genetic predisposition and access to health and social care. The health indicators available and reviewed in this report (**Table 3.3** and **Figures 3.2, 3.3**) generally reflect a wide range of these factors.

---

[1] https://www.abs.gov.au/census/find-census-data/search-by-area

Health data are more readily available on a local government area perspective. Suburb populations are relatively small and health data are not made available at that scale. It is assumed that the health of the local community is consistent with that reported for Hobsons Bay LGA.

The Victorian Public Health Survey health statistics are provided at https://www.health.vic.gov.au/population-health-systems/victorian-population-health-survey. These statistics are generally updated on a yearly basis but not all factors are updated yearly. For this assessment, the Victorian Population Health Survey from 2017 and from 2020 have been used as these provide the greatest coverage of factors and also provide infographics that are useful.

Figure 3.2 shows the infographics for general factors that may impact on health for the Hobsons Bay local government area from the 2017 survey. **Figure 3.3** shows the infographics for some of those factors from the 2020 survey.

Data have also been sought from the Social Health Atlas of Australia (most recently published in June 2019 (PHIDU 2019)). Chronic diseases[2] that are considered generally relevant to the conduct of a human health assessment for this project include heart disease, respiratory disease (including asthma), stroke, cancer, and mental health.

Table 3.3 presents a summary of the general population health considered relevant to the area. The table presents available information on indicators for the burden of disease within the community compared to Victoria.

---

[2] Many different illness and health conditions can be classified under the broad heading of chronic disease. Typically, chronic diseases are long-lasting, and have persistent effects. Chronic diseases can range from mild conditions, such as short-sightedness, dental decay, and minor hearing loss, to debilitating arthritis and low back pain, and to life-threatening heart disease and cancers. These conditions may never be cured completely, so there is generally a need for long term management. Once present, chronic diseases often persist throughout life, although they are not always the cause of death (refer to the Australian Government Department of Health for further details on chronic diseases).

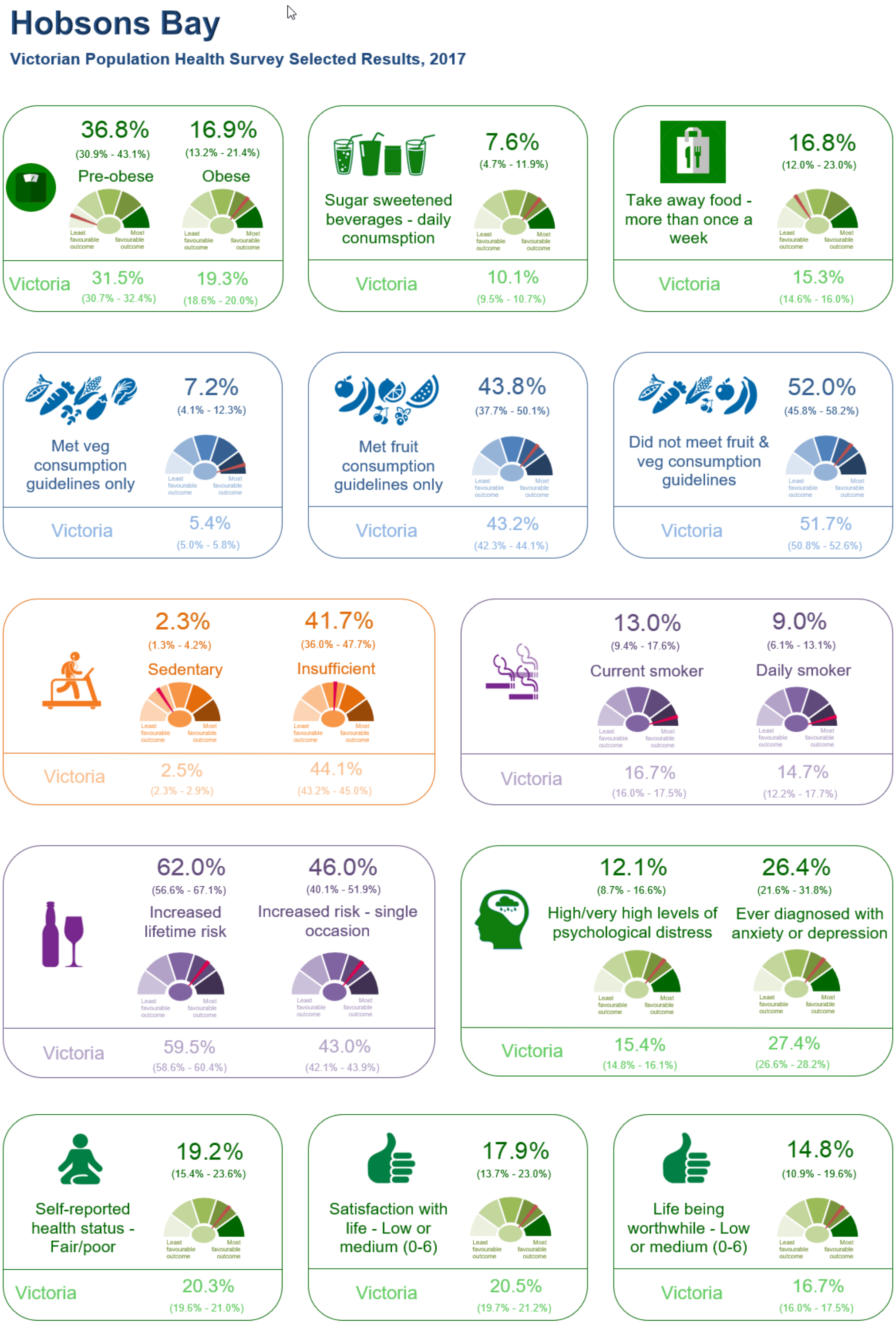


Figure 3.2: Infographic from Victorian Public Health Survey 2017 for Hobsons Bay LGA[3]

---

[3] https://www.health.vic.gov.au/population-health-systems/victorian-population-health-survey-2017

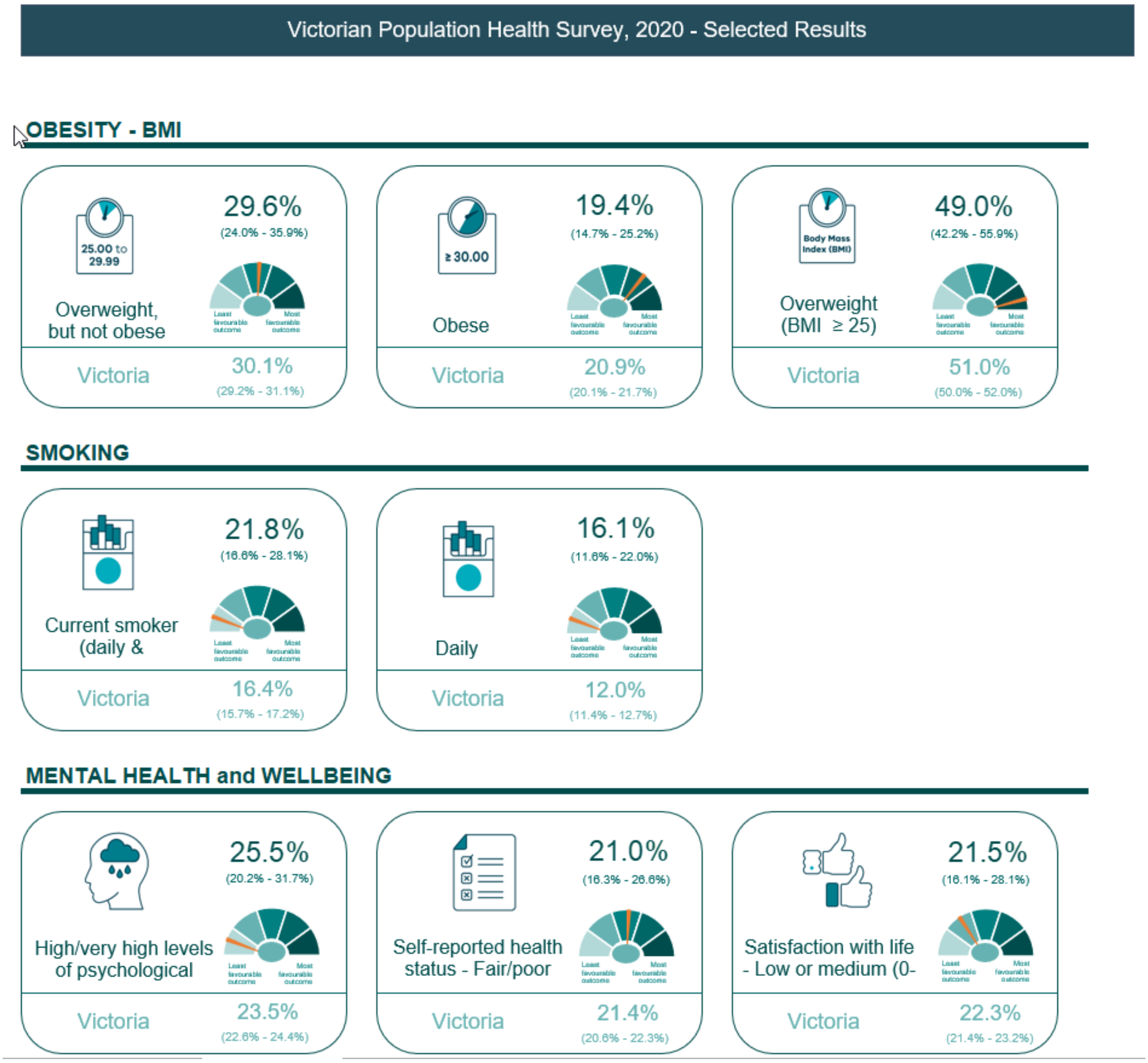


Figure 3.3: Infographic from Victorian Public Health Survey 2020 for Hobsons Bay LGA[4]

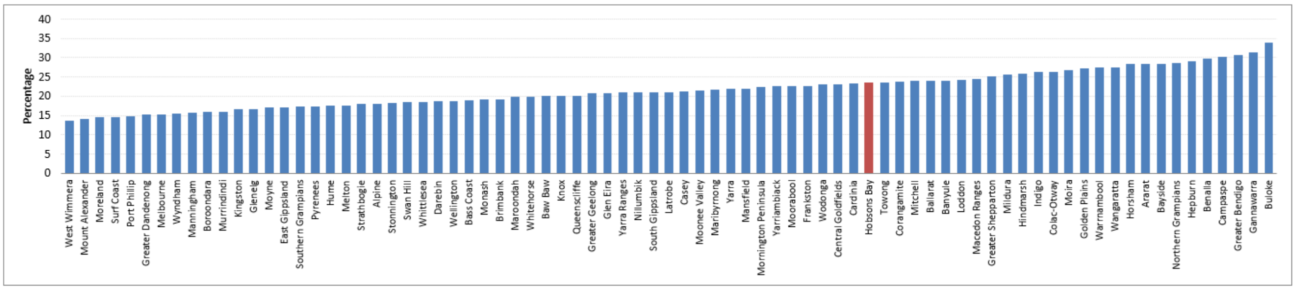
The results for 2017 indicate that Hobsons Bay LGA is similar to Victoria as a whole. None of these parameters showed a statistically different result for Hobsons Bay compared to Victoria as a whole.

The results for 2020 only cover a subset of factors. Only smoking, body weight and the mental health/wellbeing factors are repeated in both datasets. These show that smoking rates have slightly increased and are generally higher than Victoria as a whole. Rates of obesity have increased for both Hobsons Bay and Victoria as a whole since 2017. The rate of high levels of stress (i.e. psychological distress) have increased in both Hobsons Bay and Victoria since 2017 but this may be related to COVID-19 depending on when the survey was undertaken.

---

[4] https://www.health.vic.gov.au/population-health-systems/victorian-population-health-survey-2020

The rate of asthma (age standardised) in Hobsons Bay (red bar) (2017) is in the middle of the range for LGAs in Victoria as shown on **Figure 3.4**.



Source: Victorian Population Health Survey 2017, DHHS

Figure 3.4: Graph for rate of asthma for Hobsons Bay LGA compared to the rest of Victoria [5]

Table 3.3: Summary of health indicators/data

Health indicator/data	**Hobsons Bay LGA**	**Victoria**
Burden of disease (rate per 100,000 with LL95% to UP 95% in brackets where available)		
Mortality – all causes (2020)*2	480	500
Mortality – avoidable causes (persons 0-74 years) (2016 – 2020)*1	136.7 (124.3 – 149.1)	109.6 (108.4 – 110.8)
Mortality – cardiovascular (2016 – 2020)*1	47.6 (40.3 – 55)	32.4 (31.8 – 33.1)
Mortality – respiratory (2016 – 2020)*1	9.5 (6.1 – 12.8)	9.0 (8.6 – 9.3)
Morbidity – cardiovascular disease hospital admissions (2018/2019)*1	2,218	2,251
Morbidity – respiratory disease hospital admissions (2018/2019)*1	1,643	1,833
Morbidity – asthma hospital admissions (2018/2019)*1	146.3	144.1

Notes:

1 Data from the Social Health Atlas for Victoria http://phidu.torrens.edu.au/social-health-atlases/data#social-health-atlases-of-australia-local-government-areas

2 Data from the Australian Bureau of Statistics for Hobsons Bay LGA, expressed as rate per 100,000 population for all deaths reported in 2020 (i.e. value in ABS table for standardised death rate expressed as rate per 1,000 is adjusted to a rate per 100,000 by multiplying by 100) https://www.abs.gov.au/statistics/people/population/deaths-australia/latest-release

Shading relates to comparison against Victoria as a whole:

🟧 statistic/data suggestive of a potential higher vulnerability within the population to health stressors

🟦 statistic/data suggestive of a potential lower vulnerability within the population to health stressors

In general, the key indicators of health for the population in the Hobsons Bay LGA are relatively similar to those for Victoria as a whole.

---

[5] https://www.health.vic.gov.au/population-health-systems/victorian-population-health-survey-2020

Section 4. Screening level assessment of potential health impacts from air emissions

4.1 Approach

This section presents a review of impacts on health associated with predicted air emissions, relevant to the operation of the facility. The assessment presented has relied on the Synergetics (2020) air quality assessment.

The characterisation of risk follows the general principles outlined in the enHealth document Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012a).

This assessment has relied on the Air Quality Impact Assessment (AQIA) report prepared by Synergetics (2022).

4.2 Modelled air impacts

4.2.1 Air modelling

To be able to determine the concentration of pollutants that may be in the air, off-site within the community, from a proposed project (i.e. one that has not yet been built), an air dispersion model has to be used. The model uses a range of information such as:

- the concentration (or emission rate) of pollutant in the stack before discharge
- information about the stack itself such as height and width at the top, the discharge velocity and temperature as well as the presence of any tall buildings close to the stack
- information about the meteorological conditions
- information about the terrain in the surrounding areas.

All this information is used to estimate how the pollutants are mixed and transported in the air and the concentration that may be present at ground level at different locations.

Figures 4.1 and **4.2** illustrate the processes which govern how the emissions get mixed into the atmosphere.

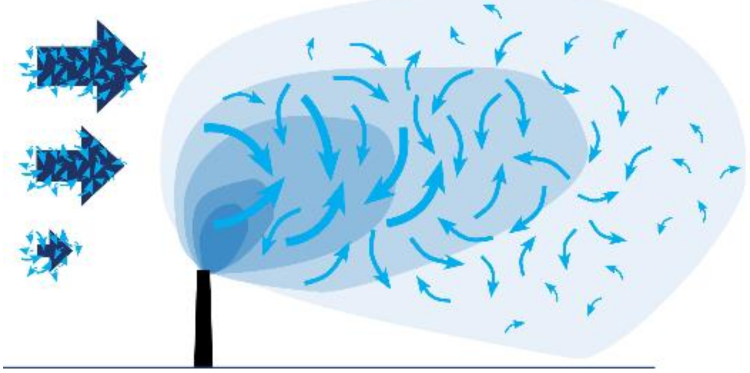


Figure 4.1: Turbulence in the air, how it mixes and dilutes pollutants emitted from a stack (NSW Chief Scientist 2018)

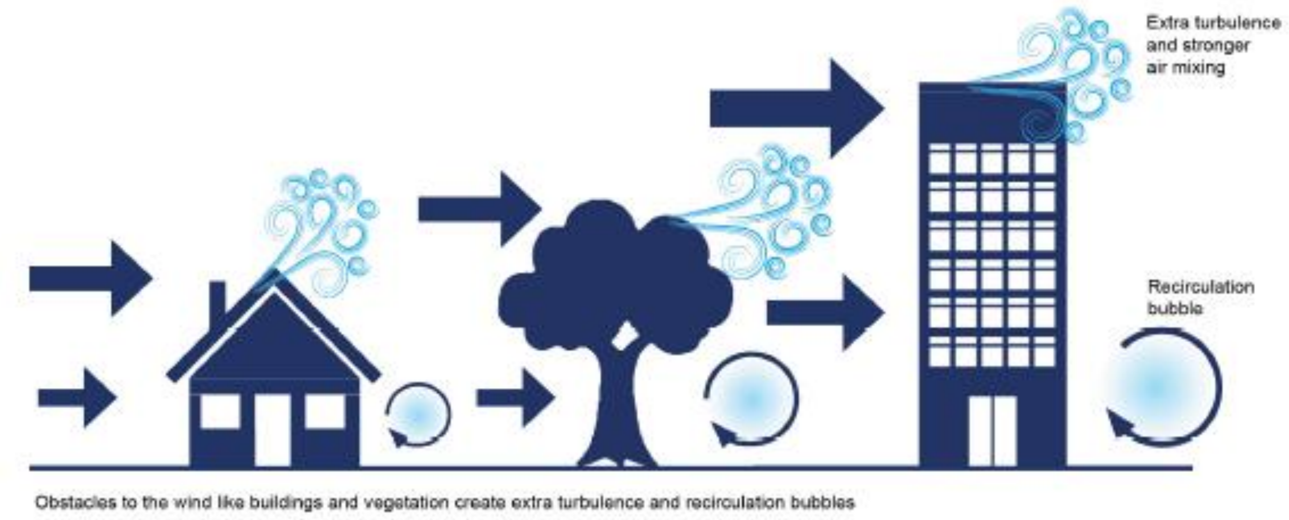


Figure 4.2: Turbulence in the air and how it is affected by buildings and vegetation (NSW Chief Scientist 2018)

Gases (and any fine particles that remain in the gas (unlikely for this facility)) are emitted at temperatures between 100^{o}C and 200^{o}C. These warm gases are pushed out of the stack using fans (i.e. at some speed) so these gases (and fine particles) rise or are pushed up significant distances above the top of the stack – because hot gases rise and because these gases are travelling at a faster speed than the air surrounding the stack. This can be seen in the figures above.

As the gases (and fine particles) cool and slow down they begin to interact with the wind above the stack. This mixes the gases (and fine particles) into the atmosphere decreasing the actual concentration present in any one particular place.

Figure 4.1 shows that most of the pollutants remain up in the atmosphere away from where people can be exposed. However, small amounts do eventually reach ground level. The air dispersion modelling determines what proportion of the amount in the stack could reach ground level at different locations. Such modelling looks at worst case weather characteristics (that can actually occur – based on real meteorological data) to ensure that the amount that could reach ground level in areas where people live or work neighbouring the proposed facility are not underestimated. It is these ground level concentrations that are then used to assess potential for health impacts.

Data from the modelling can also be used to estimate the rate at which particles in the emissions could fall out of the atmosphere (due to gravity) or get washed out of the atmosphere (due to rain). It is this deposition rate that is then used to estimate how much of chemicals attached to particles could get into soil around the facility.

4.2.2 Site specific details

Emissions to air for this facility result from the burning of natural gas or process gas to power the boilers.

Air quality modelling requires the following information types:

- the concentration (or emission rate) of pollutant in the stack before discharge
- information about the stack itself such as height and width at the top, the discharge velocity and temperature as well as the presence of any tall buildings close to the stack
- information about the meteorological conditions
- information about the terrain in the surrounding area.

Stack concentrations

While a number of plants using this technology are under construction or have been approved for construction, none are operational at this time.

In consultation with EPA Victoria, the air quality modelling for this project has assumed the stack concentrations specified in European guidance for best practice waste to energy facilities to assess potential emissions from burning process gas to heat the boilers on the site.

This means it is assumed that the emissions from this facility will be similar to a waste to energy facility.

There are a range of differences between this type of plant and a waste to energy facility which should mean emissions from this facility will be significantly lower than for a best practice waste to energy facility including:

- only the process gas is burned/combusted to generate heat for the boilers.
- combustion process does not include the burning of any solid materials.
- use of superheated water in the process means that the process gas (produced when the outputs from this process are cooled post reaction) is much cleaner than the gases produced when mixed solid waste is burned directly in a waste to energy facility.
- water soluble chemicals remain with the water and do not get carried through into the gas.
- large molecules that are not volatile remain in the synthetic oil or the heavy end bitumen and do not get carried through into the gas.
- process gas contains only the volatile chemicals produced when the large polymers are broken into small pieces.

It is, therefore, expected that the process gas will be cleaner (or at worst the same) than the emissions from a waste to energy facility and that the European standards for such plants are relevant (and likely conservative) for assessing this facility.

The pollutants that have been included (with notes included on how these pollutants have been considered in this assessment):

- particulates as total dust which has been assumed to comprise 100% $PM_{2.5}$
- oxides of nitrogen (NOx) which has been assumed to comprise 100% NO_2
- sulfur dioxide (SO_2) gas
- hydrogen chloride (HCl) gas
- hydrogen fluoride (HF) gas
- carbon monoxide (CO) gas
- ammonia gas (NH_3)

- metals and organics bound to particulates, which include:
    - mercury which is assumed to be present as elemental mercury in air and inorganic mercury depositing to soil
    - cadmium + thallium (as a sum) (assumed to be all cadmium)
    - dioxins and furans

It is noted that particles in the emissions from this facility will be negligible, given the washing of the gas as it forms post reaction and the fact that only the gas will be burnt, not solid material that is more likely to produce significant ash.

To be conservative, though, this assessment has assumed the particles will be present to the same extent as a waste to energy facility.

The assessment of short-term emissions has focused on acute inhalation exposures only while the assessment of ground level concentrations for longer term exposures has considered both long term inhalation exposures and deposition of particles to soil and potential for uptake into crops or livestock (where relevant).

Stack engineering

The stacks will be engineered to operate with the following characteristics:

- Temperature – 240-350˚C
- Oxygen concentration – 2.8-2.9%
- Flow rate – 0.3-0.6 Nm^3/s (@3% O_2)
- Stack height – 25 m above ground level
- Stack diameter – 0.2-0.3 m (each boiler has separate stacks)
- Stack velocity – 23-24 m/s.

It is noted that the flow through stacks at this facility is lower than for a waste to energy facility – around 1 cubic metre per second compared to >10 cubic metres per second for a waste to energy facility. This limits the amount (or load) of any particular pollutant that gets emitted into the atmosphere around this facility mixing into the atmosphere toward ground level, limiting the potential ground level concentrations to which people could be exposed.

Meteorological and terrain information

Meteorological information was sourced from the Bureau of Meteorology using the Laverton RAAF station and the Melbourne Airport station. The Laverton station is about 4 km from the site. Five calendar years of historical data (2015 to 2019) were used for this assessment. An assessment of these data indicates the following about the wind at the site:

- northerly winds are most common
- north easterly winds are the least common
- hourly average wind speeds below 10 km/hr account for 25% of all conditions
- hourly average wind speeds 40 km/hr and above account for approximately 0.75% of the assessed period.

Information about wind is of importance in air dispersion modelling as wind is the major driver of how the pollutants in the discharge from the plant are diluted prior to reaching ground level (as per **Figures 4.1** and **4.2**).

Information about the terrain in the area (i.e. presence of hills, valleys or relevant buildings) is sourced from topographical maps etc.

Model

Emissions to air were modelled by Synergetics (2022) using the AERMOD air dispersion model, which is an approved model specified by EPA Victoria (EPA Victoria 2013, 2022). This model uses air emissions estimates (shown in **Table 4.1**), engineering information (for example, stack location, dimensions, exit velocity) and local terrain & meteorological data to predict the ground level concentrations of pollutants at all locations across the grid within the defined study area (in this case, the grid was 10 km x 10 km domain with 50 m grid spacing). In addition to the grid locations, 9 specific receptors identified in **Section 3.2** and **Figure 3.1** have also been assessed. This means the modelling estimated ground level concentrations every 50 m across the entire grid and specifically at the 9 receptor locations.

Table 4.1: Stack concentrations used in modelling

Pollutant	EU Limits (mg/Nm^3 @11%O_2)	Values used for this assessment
Dust (Total suspended particles)	2-5 (24 hr average)	5 (as both $PM_{2.5}$ and PM_{10})
Mercury (Hg)	0.005-0.02 (24 hr average)	0.02
Cadmium + Thallium (Cd+Tl) (assessed as Cadmium in this assessment)	0.005-0.02 (24 hr average)	0.02
Carbon monoxide (CO)	10-50 (24 hr average)	50
Hydrogen fluoride (HF)	1 (24 hr average)	1
Hydrogen chloride (HCl)	2-6 (24 hr average)	6
Oxides of nitrogen (NOx)	50-120 (24 hr average)	120
Sulfur dioxide (SO_2)	5-30 (24 hr average)	30
Ammonia (NH_3)	2-10 (24 hr average)	10
Dioxin-like compounds (WHO TEQ)	1-8x10^{-8} (24 hr average)	8x10^{-8}

The maximum predicted impact at any grid location (i.e. anywhere in the 10 km x 10 km area regardless of existing land use) and the maximum impact at one of the specific receptors (that include the closest recreational and residential areas), from the air modelling as presented by Synergetics (2022) have been used in this HHRA.

Full details on the air model are presented in the AQIA (Synergetics 2022). This model is used to provide predicted air concentrations over the study area and at the 9 sensitive locations/receptors (as detailed in **Section 3.2** and **Figure 3.1**), with the results averaged over different time periods.

4.3 Screening assessment – human health

For the pollutants evaluated in the AQIA, **Table 4.2** presents the maximum air concentrations relevant for long term operations. These are the concentrations at ground level for the various averaging periods at the most affected location anywhere in the grid (i.e. grid maximum). These concentrations have been compared to guidelines from relevant government authorities – i.e.

Australian ambient air NEPM for criteria air pollutants and EPA Victoria for all other pollutants (EPA Victoria 2022; NEPC 2021).

Exceedance of screening criteria does not mean that there is an unacceptable risk to health, rather exceedance of these criteria means that a more detailed assessment of risks to human health is required to take account of relevant site specific information.

Table 4.2: Screening risk assessment

Pollutant relevant to Project	Averaging time	Maximum modelled concentration (µg/m^3) – facility only	Screening guideline – EPA Victoria or Ambient Air NEPM (µg/m^3)
PM$_{2.5}$	24-hour	0.15	25/20 (cumulative)
	annual	0.035	8/7 (cumulative)
PM$_{10}$	24-hour	0.15	50 (cumulative)
	annual	0.035	25 (cumulative)
Mercury	Annual	0.00014	1
Cadmium	1-hour	0.0012	18
	24-hour	0.0006	0.03
	annual	0.00014	0.005
Carbon monoxide	8-hour	2.5	10,300 (cumulative)
Hydrogen fluoride	24-hour	0.03	2.9
Hydrogen chloride	1-hour	0.37	2,100
	annual	0.042	20
Nitrogen oxides (NO$_2$)	1-hour	6.8	150 (cumulative)
	annual	0.8	28 (cumulative)
Ammonia	1-hour	0.61	3,200
	24-hour	0.3	1,184
	annual	0.07	70
Sulfur dioxide	1-hour	1.7	262/197 (cumulative)
	24-hour	0.8	52 (cumulative)
Dioxins and furans (as TCDD WHO-TEQs)	annual	$6x10^{-10}$	4×10^{-5}

Notes:

Guidelines from EPA Victoria are those from the most recent guidance published in 2022 (EPA Victoria 2022)

Guidelines from Ambient Air NEPM are those from the most recent guidance published in 2021 (NEPC 2021). For sulfur dioxide and PM$_{2.5}$, the values listed are those currently in place followed by the values that come into force in 2025.

All incremental ground level concentrations (i.e. facility only values) expected for this facility are well below the relevant guideline values.

To provide further support that risks are expected to be low and to allow appropriate consideration of cumulative risks (i.e. the incremental ground level concentrations plus the existing air quality), a more detailed assessment of risks to human health is presented in **Section 5**.

Section 5. Detailed assessment of potential health impacts from air emissions

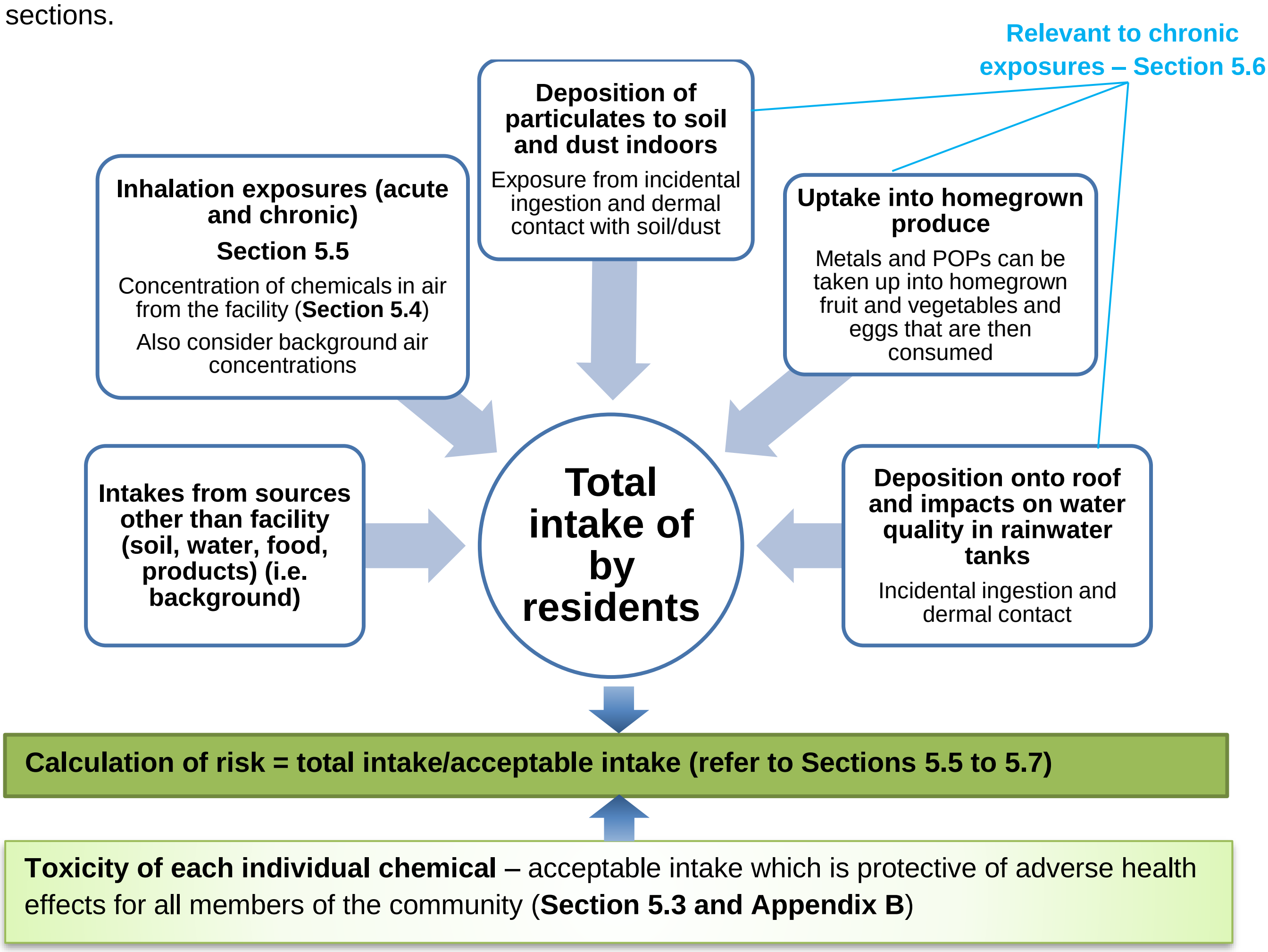
5.1 General

This section presents a detailed assessment of potential risks to human health as a result of emissions to air from the facility.

The assessment of risk has relied on air modelling presented in the AQIA (Synergetics 2022) and follows the general principles outlined in the enHealth document Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012a). This approach requires assessment of:

- how people may be exposed to the emissions to air over short-term (acute) and long-term (chronic) (i.e. exposure assessment)
- the hazards posed by (or toxicity of) the chemicals present in the emissions (i.e. hazard or toxicity assessment)
- calculation of potential risks to health or risk characterisation.

The following diagram presents an overview of the assessment approach detailed in the following sections.



5.2 Exposure assessment – conceptual site model

Understanding how a community member may come into contact with pollutants released in air emissions from the proposed facility is a vital step in assessing potential health risk from these emissions. A conceptual site model provides a holistic view of these exposures, outlining the ways a community member may come in contact with these pollutants.

There are two main ways a community member may be exposed to a chemical substance emitted from the plant:

- Inhalation of gases, vapour or fine particulate matter in air
- Ingestion and/or dermal absorption of chemicals present in dust where that dust deposits onto surfaces – such as the ground or buildings – and where it can be mixed into soil to which people may come into contact or be taken up into produce grown in that soil or be washed off roofs and accumulated in water collected in rainwater tanks.

For some of the pollutants emitted from the facility, inhalation is considered the only route of exposure. The properties of a pollutant make the other pathways inconsequential for chemicals that are only present as a gas. This group includes the gases nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), hydrogen chloride (HCl), ammonia (NH_3) and hydrogen fluoride (HF) as well as fine particulate matter (as particulates less than 2.5 micrometres ($PM_{2.5}$)). These particles are so small they remain suspended in air and so can be considered in this class of chemicals where inhalation only is the exposure pathway.

Other pollutants may be inhaled and also may be attached to dust which falls from the atmosphere and gets deposited onto the ground or other surfaces. The dust and the attached chemicals get mixed into the soil and can then be ingested either directly through incidental consumption of soil or indirectly through food grown or raised in the soil (fruit, vegetables and eggs). In addition, the dust may be deposited onto a roof where it may be washed into and affect water quality in rainwater tanks. Skin contact with the soil and water in rainwater tanks is also possible. Therefore, it is important that all three exposure pathways are considered in this assessment. The chemicals relevant to this type of assessment include metals and dioxin-like compounds. These groups are bound to the heavier particulate matter that may fall out and deposit onto the ground.

It is important to note that exposures related to settling of particles onto the ground for this facility will be a minor pathway. This is because this facility has a small volume of emissions and the levels of particles that will be present in the emissions will be very low due to the nature of the hydrothermal process to break down the polymers that make up the plastics.

This assessment is based on assuming the emissions will be similar to those from a waste to energy facility. Such facilities burn solid waste materials generating ash in the combustion process. This facility only burns the process gas which does not include particles from the plastics as these would remain in the water post reaction nor will it produce particles to any great extent during combustion of the gas as only small volatile chemicals will be present in the process gas. In addition, many of the chemicals that are attached to particles in waste to energy facilities are formed during the combustion process (i.e. dioxin-like compounds) or are present in the waste materials (i.e. metals). These chemicals (or the chemicals from which they form) are unlikely to be present when the process gas is burned due to the way it is produced and the materials from which it is generated.

This assessment has been undertaken in a conservative fashion and includes direct exposure via inhalation and indirect exposure to chemicals attached to particles and is likely to overestimate potential risks for this facility.

Table 5.1 lists the pollutants or chemicals evaluated in the emissions to air assumed to be discharged from this facility and the exposure pathway/s of potential concern.

Table 5.1: Substances and routes of exposure

Substance	Route of exposure
Nitrogen dioxide	**Inhalation only** as these are gases
Sulfur dioxide	
Hydrogen chloride	
Hydrogen fluoride[1]	
Carbon monoxide	
Ammonia	
PM_{10}	**Inhalation relevant for particulates based on particle size** as these particulates are very small and will remain suspended in air. It is noted that other exposure pathways have also been assessed for the individual chemical substances bound to these particles that may be deposited to the ground. These other pathways relate to the individual chemical substances, rather than the physical size of the particulates, however they do relate to the more coarse fractions of dust in PM_{10} (rather than $PM_{2.5}$) as some PM_{10} will deposit to the ground
$PM_{2.5}$	
Cadmium	**Inhalation** of these pollutants adhered to fine particulates **Ingestion and dermal contact** with these pollutants deposited to soil or deposited to a roof where they wash into and impact on water quality in rainwater tanks. It is recognised that the surrounding residential areas include rainwater tanks that are used for irrigation (in some cases as replacements for groundwater bores decommissioned due to the presence of groundwater contamination). **Ingestion** of produce grown in soil potentially impacted by these pollutants. For this assessment the surrounding urban residential areas may include homegrown fruit and vegetables and eggs. Metals and dioxins/furans can be taken up/bioaccumulated into plants and animal products that may be consumed.
Mercury (inorganic and organic)	
Dioxin-like compounds	

Figure 5.1 provides a diagrammatical representation of the community exposures to emissions from the facility (conceptual site model).

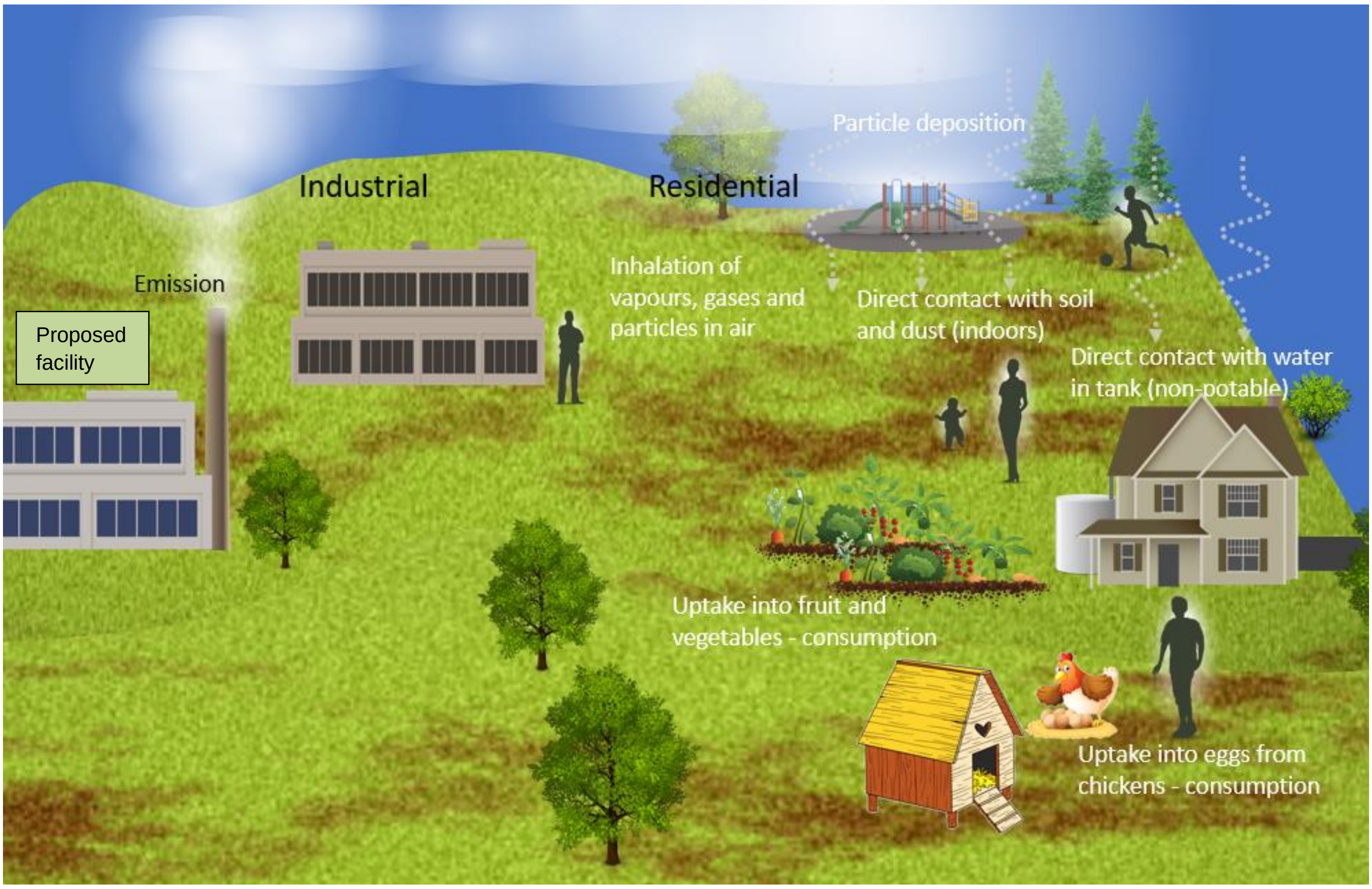


Figure 5.1: Conceptual site model (illustrative only, not to scale)

As discussed above, inhalation of gases and particles is likely to be the major pathway of exposure for this facility. However, the other pathways shown in this figure have also been evaluated to ensure that no potential exposures have been missed or underestimated.

For some of the pollutants evaluated, additional conservative assumptions have been built into the assessment for an individual pollutant or group of chemicals where the composition is less well defined. The following conservative assumptions have been adopted in this assessment:

- Dioxin-like compounds have been assessed assuming the group is characterised by the toxicity of the most potent compound, 2,3,7,8-TCDD, assuming that the emission limits relate to a WHO toxicity equivalent concentration (as WHO-TEQ) using the guidance from the World Health Organisation in 2005
- Inorganic mercury exposures have been assessed assuming that it is present in air as elemental mercury, and when deposited to the ground forms inorganic mercury

5.3 Hazard assessment

To quantify the potential for the chemicals to be of concern in relation to health risks, the hazards associated with these chemicals has been quantified for acute and chronic inhalation, and chronic oral and dermal exposures, using current and robust toxicity reference values (TRVs).

This assessment has addressed potential exposures to chemicals present in emissions to air via the stack from the facility. The chemicals evaluated, as listed in **Table 5.1**, include gases, particulates as well as metals and organics, in particular dioxin-like compounds, that are bound to the particulates. This assessment as addressed acute inhalation exposures, along with chronic inhalation and multi-pathway exposures.

Appendix B presents further discussion and detail relating to the TRVs adopted for the quantification of hazards for the chemicals evaluated in this assessment. Some additional discussion on hazards and the TRVs or health-based guidelines adopted is also presented in **Section 5.5**, with information specific to assessing particulate size, nitrogen dioxide, sulfur dioxide and carbon monoxide presented in relevant subsections.

5.4 Use of air modelling data

The air dispersion modelling has predicted ground level concentrations on the basis of the facility operating all of the time at the maximum (or upper limit) emission limits for waste to energy facilities operating using best practice technologies in Europe. This approach was adopted based on advice from EPA Victoria (Synergetics 2022).

The air dispersion modelling has estimated ground level concentrations. The concentrations have been predicted over each of the years of meteorological data considered (i.e. 2015-2019), with the maximum from these years evaluated for short-duration exposures (99.9th percentile) and the maximum annual average used for long term exposures.

The focus of this assessment relates to the evaluation of health impacts that may occur as a result of acute (i.e. short term) or chronic (i.e. longer term) exposures to emissions from the facility.

This requires the use of 1 hour average (for the assessment of acute exposures), 24 hour average data (for short-term exposures to particulates) and annual average (for the assessment of chronic exposures) data. All data required for use in this assessment have been provided by Synergetics (2022) and are from the same model as presented in the AQIA. No adjustments or post processing of the air modelling outputs have been made for use in this assessment.

In addition to assessing risks due to inhalation, this HHRA also assesses long term risk following dust deposition. This requires the use of a deposition rate.

Dust deposition was not specifically modelled by Synergetics (2022), however, guidance on the assessment of multi-pathway exposures from the US (OEHHA 2015) indicates that, for facilities where particulate matter control devices (such as baghouses) are implemented, a default deposition velocity of 0.02 m/s can be adopted. Where emissions are less well controlled, the default deposition velocity is 0.05 m/s (refer to **Appendix C3.1** for further detail on the use of this value).

A worst-case deposition velocity of 0.02 m/s (i.e. 2 cm/s) has been adopted in this assessment given the low volume of emissions and the low concentration of particles (i.e. well controlled). Pollutant specific deposition rates have then been calculated based on the annual average air concentration for each pollutant and the particle deposition velocity of 0.02 m/s.

The calculation is as follows:

Deposition rate (mg/m^2/s) = concentration (mg/m^3) x particle deposition velocity (m/s)

The deposition rate is then converted to mg/m^2/year for use in the risk calculations.

Risk calculations have been presented for the following locations within the community:

- **Maximum impacted location anywhere** within the study area (i.e. grid maximum) regardless of location and land use – this is a location on the site or on the site boundary. In this case, such a location will be within the industrial area surrounding this facility. It is unlikely that land use in the area adjacent to this site could change to a more sensitive land use (like residential), given the nature of businesses already present in the precinct and the information from zoning documents which indicates that only businesses that do not limit the nature of the heavy industry for this site and those immediately adjacent are permitted in the neighbouring zoning area. This indicates that this area is being protected to ensure these industries can be located in appropriate places. Inhalation exposures of workers (during work hours) is, therefore, the relevant exposure scenario for assessment of the ground level concentrations at the grid maximum.
- **Maximum impacted sensitive receptor** – this is the maximum impacted receptor from the individual sensitive or residential receptors shown on **Figure 3.1**. Exposures (inhalation and multi-pathway) are assumed to occur for 24 hours per day, every day at this location.

5.5 Inhalation exposures

5.5.1 General

For all the pollutants released to air from the proposed facility, whether present as a gas or as particulates, there is the potential for the community to be exposed via inhalation. Assessment of potential health impacts relevant to inhalation exposures for these pollutants is discussed further below.

5.5.2 Particulates (size)

The assessment of potential health impacts associated with exposure to particulate matter, based on the size of the particulate matter, rather than composition, has been undertaken and presented within the AQIA (Synergetics 2022).

The focus in this HHRA is on fine particulates, namely $PM_{2.5}$. These are particles which are small enough to reach deep into the lungs and have been linked with, and shown to be causal, for a wide range of health effects (USEPA 2012; WHO 2013b). Not only are they the most important from a health perspective, given the processes used in this plant, they are also likely to be the major form of particles produced at this facility.

National and state based guidelines are based on consideration of the relevant health effects and have been recently reviewed and updated (EPA Victoria 2022; NEPC 2016, 2021).

The air criteria relate to total exposures to $PM_{2.5}$. This includes background/existing levels that are found everywhere as well as the additional impact from the proposed facility. Background levels of

$PM_{2.5}$ relevant to the local area have been included in the modelling based on data from government monitoring stations and emissions modelling for the key licenced facilities in the local area.

Table 5.2 provides a summary of the contribution of the project to the total $PM_{2.5}$ concentrations, and the air criteria. The modelling has assumed that dust or TSP is all present as $PM_{2.5}$. This is because particles of this size and smaller can reach the depths of the lungs when inhaled so it is important not to underestimate potential exposure. However, assuming all particles are present as $PM_{2.5}$ is a conservative approach as some particles will be larger than these very small ones and they will be too large to reach the lungs when inhaled.

Table 5.2 shows that the worst-case $PM_{2.5}$ derived from the facility makes a very small contribution to existing concentrations of particles and the emissions only contribute a small fraction of the national air guideline for $PM_{2.5}$. It is noted that background concentrations of $PM_{2.5}$ are already elevated above state guidelines. Elevated background levels of $PM_{2.5}$ are the result of emissions from other regional sources that include road traffic, domestic wood burning, occasional controlled burns and bushfires.

Table 5.2: $PM_{2.5}$ impacts from the Project – maximum impacts (at any location)*

Parameter	**$PM_{2.5}$ – as 24-hour average (µg/m^3)**	**$PM_{2.5}$ – as annual average (µg/m^3)**
Air guideline relevant for Victoria (2022) (EPA Victoria 2022; NEPC 2016, 2021)	25	8
Air guideline relevant for Victoria (2025) (EPA Victoria 2022; NEPC 2016, 2021)	20	7
Licence limit scenario		
Contribution from Project (maximum)*	0.15	0.035
% contribution of project to air guideline	0.6%	0.4%
Background levels (government monitoring station data)	34	7.4
Total concentration (Project + background)	34	7.5

*Maximum predicted concentration at any location modelled in the study area

In addition to the analysis presented above, it is possible to also estimate the incremental individual risk associated with the estimated change in $PM_{2.5}$ that could occur due to the emissions from the facility. This calculation has been undertaken on the basis of the most significant health indicator, namely mortality, for which changes in $PM_{2.5}$ have been identified to have a causal relationship. The health indicator also captures a wide range of other health effects associated with $PM_{2.5}$.

The calculation has considered the baseline mortality rate in Whittlesea LGA (all ages and all causes – refer to **Table 3.3**), along with the exposure-response relationship relevant to assessing all-cause mortality. Further details and calculations are presented in **Appendix A**.

These calculations assume that someone is present at the location of maximum increase in $PM_{2.5}$ from the facility for 24 hours a day, every day of the year. Given that the facility is located in an industrial area where people do not live, this assumption ensures the assessment is appropriately conservative.

A maximum annual average increase of $PM_{2.5}$ of 0.035 µg/m^3 in the surrounding community (noting that assessing changes in regional and community air quality is not relevant for locations on the site boundary or in the industrial zone) results in a maximum individual risk of 9.7×10^{-7}. This risk level is considered to be low to negligible, as per guidance from enHealth and NEPC (enHealth 2012a; NEPC 1999 amended 2013a).

On the basis of the above, changes in $PM_{2.5}$ due to emissions from this facility are considered to have a negligible impact on the health of the off-site community.

5.5.3 Sulfur dioxide

Sulfur oxides are formed during combustion when chemicals present in fuels (such as coal, gas, petrol etc) and which containing sulfur react with oxygen to form sulfur oxides. Burning of coal in power stations in Europe resulted in acid rain affecting forests. The acid rain was primarily a result of the formation of sulfur oxides as the coal was burnt. Sulfur oxides are also released from volcanos. Wildfires and other types of fires are also sources to the atmosphere of these chemicals (USEPA 2018).

Sulfur dioxide (SO_2) is the main sulfur oxide that can have impacts on people. Exposure to elevated levels can result in irritation of the respiratory system and can make breathing difficult. The most affected by exposure to these chemicals are people with asthma (USEPA 2018).

National and state based guidelines are based on consideration of the relevant health effects and have been recently reviewed and updated (EPA Victoria 2022; NEPC 2016, 2021). These guidelines are based on protection from adverse health effects following both short-term (acute) and longer term (chronic) exposure for all members of the population including sensitive populations like asthmatics, children and the elderly.

Table 5.3 presents a comparison of modelled SO_2 levels and the relevant air guidelines.

Table 5.3: SO_2 impacts from the Project – maximum impacts (at any location)*

Parameter	**SO_2 (µg/m^3)**	
	1-hour average	**24-hour average**
Air guideline relevant for Victoria (2022) (EPA Victoria 2022; NEPC 2016, 2021)	262 (100 ppb)	52 (20 ppb)
Air guideline relevant for Victoria (2025) (EPA Victoria 2022; NEPC 2016, 2021)	197 (75 ppb)	NA
Licence limit scenario		
Contribution from Project (maximum)	2.8	0.9
% contribution of project to air guideline	1.1%	1.7%
Background levels (government monitoring station data)	160	49.5
Total concentration (Project + background)	162	50.5

*Maximum predicted concentration at any location modelled in the study area

Table 5.3 shows that emissions of SO_2 (incremental) from the Project are well below the relevant air guidelines that relate to the assessment of short and long-term exposures from specific projects. Concentrations at the off-site community (receptor) locations are even lower than presented in this table for the grid maximum.

On this basis, there are no risks to community health in relation to SO_2 emissions from the Project.

5.5.4 Nitrogen dioxide

Nitrogen oxides (NOx) refer to a collection of highly reactive gases containing nitrogen and oxygen, most of which are colourless and odourless. Nitrogen oxide gases form when fuel is burnt including when waste is used as fuel. Motor vehicles, along with industrial, commercial and residential (e.g., gas heating or cooking) combustion sources, are primary producers of nitrogen oxides.

In Sydney, the NSW Government estimated that for calendar year 2013 on-road vehicles accounted for about 53% of emissions of nitrogen oxides, industrial facilities accounted for 12%, other mobile sources accounted for about 26%, with the remainder from domestic/ commercial or natural sources (Ewald et al. 2020; NSW EPA 2019).

In terms of health effects, nitrogen dioxide is the only oxide of nitrogen that may be of concern (WHO 2000c). Nitrogen dioxide is a colourless and tasteless gas with a sharp odour. Nitrogen dioxide can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated levels of nitrogen dioxide has also been associated with increased mortality, particularly related to respiratory disease, and with increased hospital admissions for asthma and heart disease patients (WHO 2013a). Asthmatics, the elderly and people with existing cardiovascular and respiratory disease are particularly susceptible to the effects of elevated nitrogen dioxide (Morgan et al. 2013; NEPC 2010). The health effects associated with exposure to nitrogen dioxide depend on the duration of exposure as well as the concentration.

National and state based guidelines are based on consideration of the relevant health effects and have been recently reviewed and updated (EPA Victoria 2022; NEPC 2016, 2021). These guidelines are based on protection from adverse health effects following both short-term (acute) and longer term (chronic) exposure for all members of the population including sensitive populations like asthmatics, children and the elderly.

Table 5.4 presents a comparison of the maximum modelled NO_2 concentrations (anywhere) and the relevant air guidelines.

Table 5.4: NO_2 impacts from the Project – maximum impacts (at any location)*

Parameter	**NO_2 (µg/m^3)**	
	1-hour average	**Annual average**
Air guideline relevant for Victoria (2022) (EPA Victoria 2022; NEPC 2016, 2021)	150 (80 ppb)	28 (15 ppb)
Licence limit scenario		
Contribution from Project (maximum)	11	1
% contribution of project to air guideline	7.3%	3.6%
Background levels (government monitoring station data)	92	19
Total concentration (Project + background)	103	20

*Maximum predicted concentration at any location modelled in the study area

Table 5.4 shows that emissions of NO_2 from the Project are well below the relevant air guidelines that relate to the assessment of short and long-term exposures from specific projects. Concentrations at the off-site community (receptor) locations are even lower than presented in this table for the grid maximum. The maximum NO_2 concentrations for a 1 hour averaging period comprise around 7% of the relevant air guideline.

On this basis, there are no risks to community health in relation to NO_2 emissions from the Project.

5.5.5 Carbon monoxide

Motor vehicles are the dominant source of carbon monoxide in air (DECCW 2009). Carbon monoxide is produced during combustion when there is a limited supply of oxygen. This facility is designed to optimise the oxygen available in the combustion zone so the production of carbon monoxide should be very low.

It is well known that excess levels of carbon monoxide in enclosed spaces can cause significant impacts. This may occur when indoor gas or other types of heaters are not operating correctly and are left on overnight.

The sorts of effects that can be expected due to exposure to CO are those linked with carboxyhaemoglobin (COHb) in blood – i.e. where CO replaces oxygen in the blood preventing oxygen from being transported around the body. In addition, association between exposure to carbon monoxide and cardiovascular hospital admissions and mortality, especially in the elderly for cardiac failure, myocardial infarction and ischemic heart disease; and some birth outcomes (such as low birth weights) have been identified (NEPC 2010).

National and state based guidelines are based on consideration of the relevant health effects and have been recently reviewed and updated (EPA Victoria 2022; NEPC 2016, 2021). These guidelines are based on protection from adverse health effects following both short-term (acute) and longer term (chronic) exposure for all members of the population including sensitive populations like asthmatics, children and the elderly.

Table 5.5 presents a comparison of the maximum modelled CO concentrations (anywhere) and the air guidelines.

Table 5.5: CO impacts from the project – maximum impacts (at any location)*

Parameter	CO (µg/m^3)
	8-hour average
Air guideline relevant for Victoria (2022) (EPA Victoria 2022; NEPC 2016, 2021)	10,000 (9 ppm)
Licence limit scenario	
Contribution from Project (maximum)	2.7
% contribution of project to air guideline	0.03%
Background levels (government monitoring station data)	NA
Total concentration (Project + background)	NA

*Maximum predicted concentration at any location modelled in the study area

Table 5.5 shows that emissions of CO from the Project make only a very small contribution in relation to the relevant air guideline. Concentrations at the off-site community (receptor) locations are even lower than presented in this table for the grid maximum.

On this basis, there are no risks to community health in relation to CO emissions from the Project.

5.5.6 All other pollutants

For all other pollutants, inhalation exposures have considered both short-term/acute exposures as well as chronic exposures.

Acute exposures (i.e. short-term exposures)

The assessment of acute exposures is based on comparing the maximum predicted 1-hour average exposure concentration with health-based criteria relevant to an acute or short-term exposure, also based on a 1-hour average exposure time. The ratio of the maximum predicted concentration to the acute guideline is termed a hazard (or risk) index (HI/RI) and is calculated as follows:

$$\text{HI or RI} = \frac{\text{Exposure concentration (maximum modelled 1-hour average)}}{\text{(Acute TRV)}}$$

$$\text{Total HI or RI} = \sum \text{HI or RI (individual pollutants)}$$

Where:
Exposure concentration = calculated from the concentration in air derived from the air modelling (mg/m^3)
Acute TRV = health based toxicity reference value (TRV) or guideline that is protective of short-duration exposures for all members of the community including sensitive individuals, as per **Appendix B** (mg/m^3)

Consistent with guidance provided by enHealth (enHealth 2012a), risks associated with acute exposures are considered to be acceptable where the individual and total HI/RI's are less than or equal to 1.

For this assessment, the maximum predicted 1-hour average concentrations relevant to all locations, and all sensitive/residential receptors have been provided. The modelled air concentrations relate to impacts derived from the Project. The chemicals evaluated in this section comprise hydrogen chloride, hydrogen fluoride, ammonia, cadmium, mercury. Potential impacts for dioxin-like compounds are not relevant and there are no short term guidelines for this group of chemicals.

The acute health-based guidelines, or acute toxicity reference values (TRVs), adopted in this assessment have been selected on the basis of the approach detailed in **Appendix B**. It is noted that for the assessment of exposure to dioxin-like compounds as well as some metals, there are no health-based guidelines for short-term exposure available as the key issues for these chemicals relate to chronic exposures or long-term body burdens. The acute assessment has, therefore, focused on the chemicals where acute health effects are relevant.

Table 5.6 present the relevant health-based guideline and the predicted maximum 1-hour average concentrations (100th percentile) at the maximum impacted location (grid maximum) and the maximum concentration at any of the sensitive receptors. These values have then been used to calculate the HI/RI for each chemical. An acceptable HI/RI adopted for this project is <1 for individual chemicals and <1 for the sum of all chemicals.

Exposures at all other locations, including the other sensitive receptors will be lower than presented in **Table 5.6**.

Table 5.6: Review of acute exposures and risks

Pollutants	Acute air guideline (1-hour average) (mg/m^3)	1-hour average concentration (mg/m^3)		Calculated HI/RI	
		Maximum anywhere*	Maximum sensitive receptors (facility only)	Maximum anywhere*	Maximum sensitive receptors (facility only)
Hydrogen chloride (HCl)	0.66[1]	0.0006	0.0001	0.0009	0.0002
Hydrogen fluoride (HF)	0.06[1]	0.00009	0.00002	0.002	0.0003
Ammonia	0.59[1]	0.0009	0.0002	0.002	0.0003
Cadmium	0.0054[1]	0.000002	0.0000004	0.0004	0.00007
Mercury (as elemental)	0.0006[2]	0.000002	0.0000004	0.003	0.0007

Total HI/RI	**0.008**	**0.002**
Acceptable HI/RI	**<1**	**<1**

* Maximum anywhere is the maximum concentration (and calculated HI) at any of the modelled locations within the whole study area, regardless of land use. Maximum impact occurs in industrial setting. This is different to the sensitive receptors which is where there are existing residential, or other sensitive uses

References for health-based acute air guidelines (1-hour average):

1 = Guideline available from the Texas Commission on Environmental Quality (TCEQ), https://www.tceq.texas.gov/toxicology/dsd/final.html

2 = Guideline available from California Office of Environmental Health Hazard Assessment (OEHHA) https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary

Review of **Table 5.6** indicates that all maximum predicted short-term concentrations of chemicals in air from emissions at the proposed facility are below the health-based criteria protective for acute effects (at least 100 times lower overall).

On this basis, there are no risk issues in relation to short-term inhalation exposures to emissions from the Project.

Chronic exposures (i.e. longer term exposures)

For the assessment of chronic exposures, all the chemicals evaluated have a threshold guideline value that enables the predicted annual average concentration to be compared with a health based, or acceptable, guideline. For the assessment of chronic effects, the assessment has also considered potential intakes of these chemical substances from other sources, i.e. background intakes. As a result, the individual HI/RI is calculated as follows (enHealth 2012a):

$$\text{HI or RI} = \frac{\text{Exposure concentration}}{\text{TRV x (100\% - Background)}}$$

$$\text{Total HI} = \sum \text{HI or RI (individual pollutants)}$$

Where:

Exposure concentration = concentration in air relevant to the exposure period – annual average (mg/m^3)

TRV = health-based toxicity reference value based on a threshold that is protective of all health effects for all members of the community (mg/m^3) (refer to **Appendix B**)

Background = proportion of the TTV that may be derived from other sources/exposures such as water, soil or products (%) (refer to **Appendix B**)

Consistent with guidance provided by enHealth (enHealth 2012a), risks associated with chronic exposures are considered to be acceptable where the individual and total HI/RI's are less than or equal to 1.

This assessment has included consideration of background intakes or exposure concentrations (refer to **Appendix B**). Hence an acceptable HI/RI adopted for this project is <1 for individual chemicals and <1 for the sum of all chemicals.

When quantifying inhalation exposures, the following has been assumed:

- Maximum concentration reported occurs on the site boundary (or close to the boundary) in the industrial area, where inhalation exposures are assumed to occur at this maximum impacted location for 8 hours per day, 240 days of the year.
- Maximum concentrations at sensitive receptors are assumed to be at a residential location where a resident spends 24 hours per day at home (or working), every day of the year.

Appendix B presents the relevant health-based TRVs adopted in these calculations, along with assumptions adopted for the assessment of background intakes and the quantification of inhalation exposures for the calculation of the HI/RI. **Appendix D** presents the calculations undertaken for residential and industrial inhalation exposures.

It is noted that for the purposes of assessing potential impacts due to indirect exposure to metals and dioxin-like compounds via their attachment to dust particles, it is assumed that the concentrations predicted relate to PM_{10}. It is noted that if the particles are $PM_{2.5}$ (which is more likely for this facility and for a waste to energy facility then the particles are likely to stay suspended in the air and not settle to the ground.

Also, if the emissions are primarily $PM_{2.5}$, then the majority will be small enough to be inhaled deep into the lungs. For the purposes of this assessment, it has been assumed that 100% of particles will reach deep into the lungs. It is common to assume only 37.5% of such particles are small enough to reach deep into the lungs (consistent with guidance on assessing dust inhalation exposures), so assuming 100% for this assessment is an additional conservative step (NEPC 1999 amended 2013b, 1999 amended 2013a).

Table 5.7 presents the calculated individual HI/RI relevant to the assessment of chronic inhalation exposures for workers at the grid maximum location and for residents at the maximum concentration relevant to all sensitive receptors.

For the chemicals listed (i.e. cadmium, mercury, dioxin-like compounds), consideration of other exposures to these chemicals (i.e. background) has been included (where relevant) in the risk calculations shown in **Appendix D** (i.e. acceptable/reference concentration has been corrected based on assuming people are already exposed to a proportion of that concentration, so the facility being assessed can only contribute a proportion of what is left).

Table 5.7: Calculated chronic risks*

Pollutant	Maximum anywhere – inhalation exposures for workers in industrial area		Maximum for sensitive receptors – inhalation exposures for residents	
	Concentration in air (mg/m^3)	Calculated HI/RI	Concentration in air (mg/m^3) – facility only	Calculated HI/RI – facility only
Hydrogen chloride (HCl)	0.00004	0.0003	0.000001	0.00005
Hydrogen fluoride (HF)	0.000007	0.00005	0.0000002	0.000007
Ammonia	0.00007	0.00005	0.000002	0.000007
Cadmium	0.0000001	0.008	0.000000004	0.001
Mercury	0.0000001	0.0002	0.000000004	0.00002
Dioxin-like compounds	6×10^{-13}	0.00003	2×10^{-14}	0.000005
Total HI/RI		**0.008**	**Total HI/RI**	**0.001**
Negligible risk		**≤ 1**	**Negligible risk**	**≤ 1**

* Refer to **Appendix D** for detailed calculations of the risk and HI/RI, and **Appendix B** for the toxicity reference values adopted in the calculations

Based on the assessment presented in **Table 5.7**, all the individual and total risks (threshold and non-threshold) are less than the value recommended by national health authorities as indicating negligible risk. The emissions from this proposed facility have been considered in the context of overall background exposures to these chemicals and the potential additional exposures due to emissions from this facility (should it proceed) are negligible.

It is noted that the margin of safety (MOS) relevant to inhalation exposures from all the chemicals combined ranges from 100 to 1,000 for the total HI/RI[6], with the margin even higher for the individual pollutants (i.e. ranging from 200 to 200,000).

The size of these margins is more than sufficient to address any likely changes in guidelines that may be applicable to these pollutants over time.

It should also be noted that the calculated risks should be considered as worst-case, as actual emissions to air during plant operations would be lower than those quantified in this assessment for the following reasons:

- these emissions to air are based on the worst case (i.e. always operating at maximum emission limits) for a well operated modern waste to energy facility.
- emissions from burning the process gas in the boilers at this plastics recycling facility will be lower, given that the gas is essentially washed in the hydrothermal process and contains only the volatile chemicals that separate into the gas when the pressure is released at the end of the reaction phase.

On this basis, there are no risk issues in relation to long term inhalation exposures from this proposed facility.

---

[6] The MOS is calculated as the ratio of the target/acceptable HI: calculated total HI. Hence for the assessment of exposures at the maximum impacted location anywhere the MOS is calculated to be 1/0.008 = 125. For the assessment of exposures at the maximum impacted sensitive receptor the MOS is calculated as 1/0.001 = 1,000.

5.6 Multiple pathway exposures

5.6.1 General

Where pollutants may be bound to particulates (as PM_{10}), are persistent in the environment and have the potential to bioaccumulate in plants or animals, it is relevant to also assess potential exposures that may occur as a result of particulates depositing to the environment where a range of other exposures may then occur.

These include:

- Deposition to water (refer to **Section 5.7**):
    - Rainwater tanks, where water may be used as for irrigation, backyard use including the filling of backyard pools where incidental ingestion and dermal contact may occur.
- Deposition to soil (this section (**Section 5.6**))
    - Incidental ingestion and dermal contact with soil (and dust indoors that is derived from outdoor soil or deposited particulates)
    - Ingestion of homegrown fruit and vegetables where chemicals may deposit onto the plants and is also present in the soil where the plants are grown, and where chemicals are taken up into these plants
    - Ingestion of eggs where chemicals may deposit onto pasture and be present in soil (which the soil present where backyard chickens are kept and ingested during feeding), and the chemicals are taken up into the eggs.

This proposed facility is located in an urban environment and is in a precinct designated for industrial purposes. It is not expected that farms, where uptake into livestock or crops could occur, are present nearby. This assessment has focused on multiple exposure pathways that could occur in residential backyards such as exposure via uptake into fruits, vegetables or eggs and direct contact with soil. The above exposures are chronic or long-term exposures.

5.6.2 Assessment approach

In relation to these exposures, such exposures will only occur on residential properties where people live and where produce may be grown and regularly consumed by the people living at the property. The maximum impacts predicted from the facility are located on the site, or on the site boundary, within an industrial precinct where residential type exposures cannot occur. Hence risks associated with multiple pathway exposures are only relevant to the assessment of impacts at the off-site sensitive receptors. This assessment has focused on the maximum impacted sensitive receptor. Risks relevant to all other sensitive receptors (i.e. other houses etc) would be lower than for the maximum impacted location.

An assessment of multiple pathway exposures for workers who may be exposed via inhalation and via direct contact with soil where deposition may have occurred has also been undertaken.

The calculation of risks posed by multiple pathway exposures only relates to pollutants that are bound to particles. The calculations undertaken have utilised a deposition rate, which is derived from the air modelling results and as detailed in **Section 5.4** (and **Appendix C3.1**).

Appendix C includes the equations and assumptions adopted for the assessment of potential exposures via these exposure pathways, with the calculation of risk for each of these exposure pathways presented in **Appendix D**.

5.6.3 Calculated risks – residential (i.e. maximum sensitive receptor location)

Risks have been calculated on the basis of the maximum predicted deposition rate for all of the sensitive receptors in the surrounding community and provides a conservative estimation of risks relevant to other urban residential areas. The table presents the total HI/RI for each exposure pathway, calculated as the sum over all the pollutants evaluated. The table also includes the calculated HI/RI associated with inhalation exposures (from **Section 5.5.6**), as these exposures are additive to the other exposure pathways for residential properties. This gives an overall understanding of total risks.

Depending on the use of a property, the types of exposures that may occur are likely to vary. For this assessment, a number of scenarios have been considered where a range of different exposures may occur. The sums of risks associated with each of these multiple exposures are presented in **Table 5.8**.

Table 5.8: Summary of risks for multiple pathway exposures (maximum sensitive receptor)*

	Calculated HI/RI	
Exposure pathway	**Young children**	**Adults**
Individual exposure pathways		
Inhalation (I)	0.001	0.001
Soil ingestion (SI)	0.0005	0.00006
Soil dermal contact (SD)	0.00007	0.00004
Ingestion of homegrown fruit and vegetables (F&V)	0.0003	0.0001
Ingestion of homegrown eggs (E)	0.00002	0.000009
Multiple pathways (i.e. combined exposure pathways)		
I + SI + SD	0.002	0.001
I + SI + SD + F&V	0.002	0.001
I + SI + SD + E	0.002	0.001
I + SI + SD + F&V + E	0.002	0.001
Negligible risk	**< 1**	**< 1**

* Refer to **Appendix D** for detailed risk calculations for each exposure pathway

Review of **Table 5.8** indicates that all calculated risks associated with each individual exposure pathway as well as a combination of multiple exposure pathways, remain below the target risk levels considered representative of negligible risks.

The margin (MOS) relevant to the calculated multi-pathway risks for threshold chemicals is at least 500 fold for the maximum impacted sensitive receptor[7].

---

[7] The MOS is calculated as the ratio of the target/acceptable HI: calculated total HI. Hence for the assessment of exposures at the maximum impacted sensitive receptor the MOS is calculated as 1/0.002 = 500 for the chemicals that act via threshold mechanisms.

The size of the overall margin is more than sufficient to address any likely changes in guidelines that may be applicable to these pollutants over time. It should also be noted that the calculated risks should be considered as worst-case, as actual emissions to air during plant operations would be lower than those quantified in this assessment as already discussed.

On the basis of this assessment, there are no chronic risk issues that may be relevant to the off-site community in relation to multiple pathway exposures to pollutants that may be emitted to air from this proposed facility.

5.6.4 Calculated risks – workers (i.e. grid maximum location)

Risks have also been calculated on the basis of the maximum predicted deposition rate at the grid maximum and provides a conservative estimation of risks relevant to the industrial areas immediately outside the boundary of the proposed site.

Table 5.9 presents the total HI/RIs for each exposure pathway, calculated as the sum over all the pollutants evaluated. The table also includes the calculated HI/RI associated with inhalation exposures (from **Section 5.5.6**), as these exposures are additive to the other exposure pathways for residential properties. This gives an overall understanding of total risks.

For this assessment, exposure via inhalation and via direct contact with soil have been considered.

Table 5.9: Summary of risks for multiple pathway exposures (grid maximum)*

Exposure pathway	Calculated HI/RI
	Adults
Individual exposure pathways	
Inhalation (I)	0.02
Soil ingestion (SI)	0.0006
Soil dermal contact (SD)	0.0005
Multiple pathways (i.e. combined exposure pathways)	
I + SI + SD	0.02
Negligible risk	**< 1**

* Refer to **Appendix D** for detailed risk calculations for each exposure pathway

Review of **Tables 5.9** indicates that all calculated risks associated with each individual exposure pathway as well as a combination of multiple exposure pathways, remain below the target risk levels considered representative of negligible risks.

The MOS relevant to the calculated multi-pathway risks for threshold chemicals is at least 50 fold for the maximum impacted sensitive receptor[8].

The size of these margins is more than sufficient to address any likely changes in guidelines that may be applicable to these pollutants over time. It should also be noted that the calculated risks

---

[8] The MOS is calculated as the ratio of the target/acceptable HI: calculated total HI. Hence for the assessment of exposures at the maximum impacted sensitive receptor the MOS is calculated as 1/0.02 = 50 for the chemicals that act via threshold mechanisms.

should be considered as worst-case, as actual emissions to air during plant operations would be lower than those quantified in this assessment as previously discussed.

On the basis of this assessment, there are no chronic risk issues of concern in relation to multiple pathway exposures to pollutants that may be emitted from this proposed facility that may be relevant for workers in the areas immediately outside the boundary of the proposed facility.

5.7 Residential and recreational exposures to water

Where there may be deposition of particles to which chemicals that are persistent may be attached in urban environments it is important to consider the potential for exposures via the use of rainwater collected in tanks from roof runoff etc. Such water may be used for irrigation, backyard play and/or swimming pool use. Consequently, there is the potential for chemicals attached to such particles to accumulate which may then impact on water quality in such tanks. It is noted that rainwater from such tanks is not likely to be used as potable water in Melbourne as there is a mains potable supply.

The deposition of chemicals to a roof, and accumulation in rainwater, has been estimated for the maximum impacted receptor location, assuming:

- the average rainfall for Laverton RAAF meteorological station from the Bureau of Meteorology
- a roof that is consistent with a 4 bedroom Australian home
- use of a first-flush device (noting that outcomes do not change if this device is not included).

Using this approach allows the concentrations of chemicals in the water as suspended sediment and in dissolved form to be calculated. Rainwater tanks are designed such that suspended sediment deposits or settles to the bottom of the tank and is not consumed. For the purpose of this assessment, it is assumed that both suspended sediment and dissolved phase concentrations may be present in the water used every day.

Predicted concentrations in rainwater tanks have then been compared with drinking water guidelines, which are protective of all exposures relevant to potable water use including ingestion, dermal contact, bathing and irrigation of crops that may be consumed. These guidelines are also protective of the health of pets who may consume water from rainwater tanks. Recreational water guidelines have also been considered as these are more relevant to the assessment of exposures in swimming pools.

Table 5.10 presents the maximum predicted concentrations in rainwater tanks with comparison against drinking water and recreational water guidelines. It is noted that most recreational water guidelines adopted are 10 times higher than drinking water guidelines, consistent with guidance provided by NHMRC (NHMRC 2008) and the WHO (WHO 2006b) in relation to recreational exposures.

Appendix C presents detail on the modelling undertaken and assumptions adopted, and **Appendix D** presents the calculated water concentrations.

Table 5.10: Summary and review of exposures to chemicals in water (maximum receptor)

Relevant pollutants	Calculated maximum concentration in rainwater tanks (mg/L)		Adopted water guideline (mg/L)	
	Dissolved – most relevant to exposure	Total (particulate and dissolved) – highly conservative (assumes sediment is stirred up in tank)	Drinking water	Recreational water ^{X}
Licence limit scenario				
Cadmium	0.00000002	0.0000007	0.002 ^{A}	0.02
Mercury	0.00000003	0.0000007	0.001 ^{A}	0.01
Dioxin-like compounds	$9x10^{-17}$	$3x10^{-12}$	$1.6x10^{-8\ A}$	$1.6x10^{-7}$

Refer to **Appendix C and D** for the calculation of water concentrations

A = Australian Drinking Water Guidelines (NHMRC 2011 updated 2021), with the exception of dioxin-like compounds where the drinking water guideline in the recycled water guidelines has been adopted (NRMMC 2008)

U = Residential tap water guideline from USEPA Regional Screening Levels

X = Recreational water guideline based on 10 x drinking water guidelines (NHMRC 2008, 2011 updated 2021)

Review of **Table 5.10** indicates that the predicted water concentrations in rainwater tanks are all well below the adopted water guidelines (ranging from 1,000 fold lower to 5,000 fold lower for total concentrations compared to the drinking water guidelines).

This is particularly conservative, given that it is more likely that people would be exposed to the maximum dissolved phase concentration rather than the total concentration. The total concentrations only reflect a peak situation where water is taken from the tank as sediment is disturbed (unlikely to occur unless disturbed during cleaning).

The calculations also demonstrate that the contribution of Project emissions to water quality in rainwater tanks are negligible as all the listed concentrations are below relevant limits of reporting for laboratory analyses. Such changes in water quality would, therefore, not be measurable (i.e. no actual change). Hence the intakes and exposures (from using water from rainwater tanks) have not been calculated in detail.

Based on the assessment undertaken, there are no risk issues of concern in relation to potential exposures to persistent and bioaccumulative chemicals that may be present in rainwater tanks surrounding the site.

5.8 Uncertainties and additional considerations

5.8.1 General

The characterisation of potential health risks related to exposures to emissions to air from the proposed facility has utilised data from the air quality modelling as well as a number of assumptions. The following presents further discussion on these data and parameters, the level of uncertainty in these values and whether changes in these values will change the outcome of the assessment presented.

The quantification of human health risks has relied on the modelling of emissions to air and prediction of worst-case or maximum impacts in the off-site community. Hazards associated with potential exposure to the chemicals evaluated is based on current toxicological information relevant to the chemicals evaluated. Quantification of risk has utilised a number of assumptions that are expected to overestimate actual exposure to chemicals derived from the proposed facility.

Some key assumptions adopted on how individual chemicals have been assessed are detailed in **Section 5.2**. These assumptions would result in overestimation of risk relevant to these individual chemicals.

In addition, the following should be noted:

- The calculated soil concentrations assume that deposition occurs throughout a 70 year period with all impacts accumulating in surface soil and indoor dust. It is also assumed that there is no cleaning of indoor dust or use of any other topsoil/mulch/soil conditioner or fertiliser is used that would reduce concentrations in surface soil or indoor dust.
- Concentrations calculated on aboveground plants that may be consumed assumes that all dust settled on these parts of the plant are ingested, and that the produce are not washed prior to consumption.

Further review of some aspects of the HHRA has been undertaken as detailed below.

5.8.2 Air modelling – normal operations

The modelling of air emissions has been undertaken by Synergetics (2022) using a regulatory approved model, utilising meteorological and terrain data relevant for the local area. The stack concentrations used in the assessment were those detailed in European guidance for best practice waste to energy facilities as the maximum concentrations that are permitted to be in those emissions.

These calculated risks are worst-case, as actual emissions to air during plant operations for this facility would be lower for the following reasons:

- these emissions to air are based on the worst case (i.e. always operating at maximum emission limits) for a well operated modern waste to energy facility – such facilities do not operate continuously at their licence limits – they operate somewhat below those levels so they can demonstrate compliance to the regulator
- emissions from burning the process gas in the boilers at this plastics recycling facility will be lower, given that the gas is essentially washed in the hydrothermal process and contains only the volatile chemicals that separate into the gas when the pressure is released at the end of the reaction phase.

Hence the emissions data are considered appropriate for the proposed facility and the predicted air concentrations arising from the modelling are considered appropriate for use in the HHRA.

5.8.3 Inhalation exposures

The risk calculations for the residential scenario assumes that residents are home 24 hours per day, every day of the year for as long as they live at their home. This is overly conservative as most people attend childcare, school, work or other activities and have holidays away from the home.

Also, for the assessment of exposures in workplace and recreational areas, it is assumed people are present at the same workplace for 8 hours per day, 240 days per year for a working lifetime.

In addition to the above, it is assumed that indoor air concentrations are equal to concentrations outdoors at all times.

As a result, the potential for exposure via inhalation is, therefore, expected to be an overestimate.

5.8.4 Multi-pathway exposures

These have been calculated on the basis of an assumed dust deposition rate of 0.02 m/s. Experience on other projects indicates that this default deposition rate is conservative for waste to energy facilities with pollution control equipment (as discussed in **Appendix C**). This is also likely to be extremely conservative for this facility as only gases are combusted to heat the boilers (i.e. similar to burning natural gas) and those gases are formed after the plastics have been subjected to hydrothermal treatment and following release of pressure within the system. The release of pressure will allow chemicals that are gases at the relevant temperature to separate from the treated solution but not other chemicals/materials which could be more likely to form particles when combusted to fire the boilers.

The quantification of potential intakes via ingestion of soil, fruits, vegetables and eggs and dermal contact with soil, has adopted a number of assumptions relating to how the dust mixes in with soil, how much accumulates in edible produce, and how people may be exposed. These assumptions have used conservative models and uptake factors that are likely to overestimate the accumulation of pollutants in soil and edible produce. In particular, the soil concentrations are estimated for 70 years deposition of dust to the soil from the facility. In addition, default exposure parameters have been adopted assuming exposures occur all day every day, which is also likely to overestimate exposure and, therefore, risks.

5.8.5 Future changes in guidelines

Consistent with enHealth guidance (enHealth 2012a) this assessment has considered guidelines and toxicity reference values that are based on current science. However, it should be noted that should guidelines and toxicity values change in the future, there is a significant margin of safety between the calculated risks and the thresholds/values adopted as representative of where risks are considered to be unacceptable.

It is unlikely that changes in guidelines and criteria for any individual contaminant would be more than 2-5 fold as the chemicals evaluated are those where there are already a large number of studies and a significant information available. The margin of safety ranges from 50 to 1,000 which is more than sufficient to address any such changes in guidance or toxicity, should these changes result in more conservative criteria.

Should future changes in guidance and toxicity result in less conservative criteria then the margin of safety would become larger. In addition, the contribution emissions to air from the proposed facility to $PM_{2.5}$ and PM_{10} concentration will be negligible, hence any change in these guidelines in the future would not significantly change this outcome.

5.8.6 Overall

Overall, the approach taken will have overestimated actual exposures and, therefore, risks. Changes in the assumptions to those more representative of actual exposures will result in lower levels of risk, rather than higher levels of risk.

5.9 Outcomes of health impact assessment: air

Table 5.11 presents a summary of the outcomes of the assessment undertaken in relation to the impacts of emissions to air, associated with the proposed project, on community health.

Table 5.11: Summary of health impacts – air

Health impacts associated with air emissions	
Benefits	There are no benefits to the off-site community in relation to air emissions
Impacts	Based on the a conservative approach to modelling air emissions from this facility (based on EPA Victoria guidance), the potential for adverse health impacts within the off-site community associated with emissions to air from this proposed facility has been assessed as negligible.
Mitigation	No additional mitigation measures other than those already included in the modelling (i.e. height of stack, velocity/temperature of emissions etc) are required.

Section 6. Health impacts: Noise

6.1 Approach

This section presents a review and further assessment of impacts on health associated with noise, relevant to the operation of the facility. The assessment presented has relied on the information provided in the Noise Impact Assessment Report (Wood 2021).

6.2 Health impacts associated with noise

Environmental noise has been identified (I-INCE 2011; WHO 2011) as a growing concern in urban areas because it has negative effects on quality of life and well-being and it has the potential for causing harmful physiological health effects. With increasingly urbanised societies, impacts of noise on communities have the potential to increase over time.

Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Unlike chemical pollution, noise energy does not accumulate either in the body or in the environment, but it can have both short-term and long-term adverse effects on people. These health effects include (WHO 1999, 2011):

- sleep disturbance (sleep fragmentation that can affect psychomotor performance, memory consolidation, creativity, risk-taking behaviour and risk of accidents)
- annoyance
- hearing impairment
- interference with speech and other daily activities
- impacts on children’s school performance (through effects on memory and concentration)
- impacts on cardiovascular health.

Other effects for which evidence of health impacts exists, but for which the evidence is weaker, include:

- effects on mental health (usually in the form of exacerbation of existing issues for vulnerable populations rather than direct effects)
- tinnitus (which can also result in sleep disturbance, anxiety, depression, communication and listening problems, frustration, irritability, inability to work, reduced efficiency and a restricted participation in social life)
- cognitive impairment in children (including deficits in long term memory and reading comprehension)
- some evidence of indirect effects such as impacts on the immune system.

Within a community, the severity of the health effects of exposure to noise and the number of people who may be affected are schematically illustrated in **Figure 6.1**.

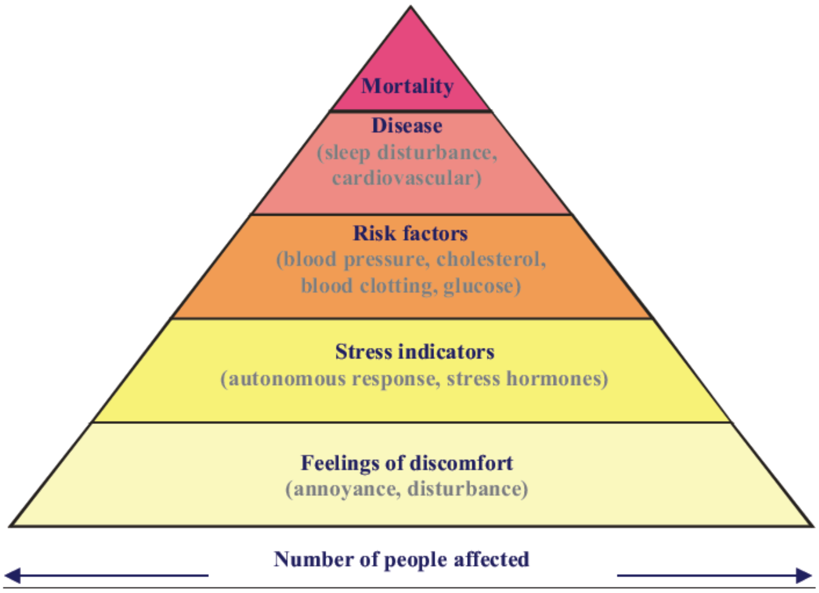


Figure 6.1: Schematic of severity of health effects of exposure to noise and the number of people affected (WHO 2011)

Often, annoyance is the major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects, and it affects the greatest number of people in the population.

There are many possible reasons for noise annoyance in different situations. Noise can interfere with communication or other desired activities. Noise can contribute to sleep disturbance, which can obviously be very annoying and has the potential to lead to long-term health effects. Sometimes noise is just perceived as being inappropriate in a particular setting without there being any objectively measurable effect at all. In this respect, the context in which sound becomes noise can be more important than the sound level itself.

Different individuals have different sensitivities to types of noise and this reflects differences in expectations and attitudes more than it reflects any differences in underlying auditory physiology. A noise level that is perceived as reasonable by one person in one context (for example in their kitchen when preparing a meal) may be considered completely unacceptable by that same person in another context (for example in their bedroom when they are trying to sleep). In this case, the annoyance relates, in part, to potential for intrusion from the noise. Similarly, a noise level, which is considered to be completely unacceptable by one person, may be of little consequence to another even if they are in essentially the same room. In this case, the annoyance depends almost entirely on the personal preferences, lifestyles and attitudes of the listeners concerned.

6.3 Summary of noise assessment

6.3.1 General

The noise assessment was based on the *Noise Limit and Assessment Protocol (Noise Protocol)* (EPA Victoria 2021). This guideline provides a process for calculating the recommended maximum noise levels for an industrial site in urban areas in Victoria.

6.3.2 Site noise assessment

Project noise limits

The Noise Protocol provides guidance about establishing noise limits for an industrial project in an urban area in Victoria. The Protocol provides guidance for establishing limits for daytime, evening and night time. In this case, the limits have been developed for night time, in particular, as this part of the day (i.e. night) is likely to have the most impact on people should noise levels be high.

Noise limits have been developed for each of the 5 sensitive locations in the surrounding area which have been used in the other parts of this assessment of noise. These locations are shown in **Figure 6.2** and are listed in **Table 6.1**.

Table 6.1: Noise receptor locations

Noise sensitive receptor ID	Address
NSR1	32 Charles Road Altona
NSR2	14 Fenfield Street Altona
NSR3	9 Morrow Street Altona
NSR4	5 Victoria Street Altona Meadows
NSR5	41 Tyquin Street Laverton

Figure 6.2: Noise receptor locations (yellow area is proposed site and blue pins are the receptor locations) (Wood 2021)

The noise limits developed by Wood (2021) for this project in line with the Noise Protocol from EPA Victoria are listed in **Table 6.2**.

Table 6.2: Project noise limits

Receptor ID	Night time zoning level (dB(A))	Night time noise limit (dB(A))
NSR1	50	50
NSR2	39	46
NSR3	51	51
NSR4	42	55
NSR5	46	54

Modelling

Noise impact from the project was estimated by estimating noise from operational activities proposed for the site including:

- Feedstock receival and storage
- Material preparation
- Plastic pumping system
- Water boiler
- Distillation
- Water treatment
- Emergency flare
- Transport of products to off-site users.

These activities generate noise because they involve truck movements or movements of equipment like forklifts or because pumps or boilers or other equipment needs to operate continuously.

The assessment was based on the process as shown in the flow diagram in **Figure 6.3**.

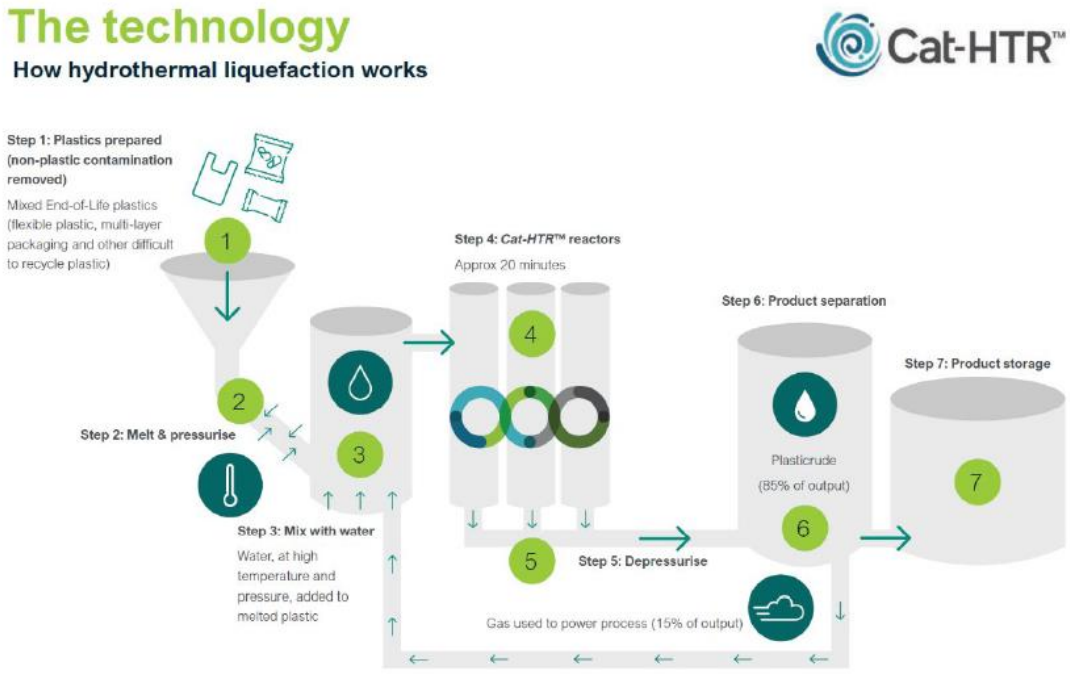


Figure 6.3: Process diagram

Noise modelling was undertaken using the acoustic software package SoundPLAN (version 8.2). The modelling considered one night time operating scenario under steady state conditions. This is likely to be the most sensitive time period. The modelling used adverse meteorological conditions (such as during a temperature inversion) relevant to the night period to ensure potential noise impacts were not underestimated.

Noise generation from the various equipment to be used on the site was estimated from a noise database of common plant equipment for use in this modelling. All equipment was assumed to be operating continuously and simultaneously for the night periods. The locations of these equipment on the site, including within buildings were considered. Standard noise mitigation measures were considered in the assessment (such as whether the equipment is only operated within a building or a sound enclosure).

The model also requires topographical information regarding the land form and the land uses in the surrounding environment which may block or not block noise from moving toward sensitive receptor locations.

Monitoring

Background noise was monitored at the receptor locations (i.e. NSR1-5) in August 2021 for 1 evening using attended monitoring equipment. The monitoring was in accordance with the short method for determining background outlined in the Noise Protocol (Wood 2021).

Attended monitoring allows observations to be made about the sources of noise during the monitoring which helps gain a good understanding of the existing situation at those locations.

The results of this monitoring are provided in **Table 6.3** from Wood (2021).

Table 6.3: Attended noise monitoring results

Receptor ID	Background noise level (dB(A))	Observations
NSR1	46	Constant noise from Altona Industrial Area (refinery noise). Occasional noise from train, insects and bird calls.
NSR2	43	Constant noise from Altona Industrial Area (refinery noise) and traffic. Occasional noise from reverse alarms, impact noise, train noise (shunting), level crossings, bat calls and dogs barking.
NSR3	46	Constant noise from Altona Industrial Area (refinery noise) and traffic. Occasional noise from reverse alarms, impact noise, train noise (rail and shunting noise), level crossings.
NSR4	52	Constant traffic noise from M1 Highway, and insects / frogs in background. Occasional noise from crane / crate stacker (engine revving) and trains (rail and shunting noise).
NSR5	51	Constant traffic noise from M1 Highway.

Assessment

The final step in the assessment is to compare the modelled/predicted noise levels due to the project at each of the receptor locations with the project noise limits. This comparison is shown in **Table 6.4**.

Table 6.4: Predicted noise levels

Receptor ID	Night time noise limit (dB(A))	Predicted noise level for the project (dB(A))
NSR1	50	29
NSR2	46	27
NSR3	51	30
NSR4	55	22
NSR5	54	26

All predicted noise levels at the relevant sensitive receptors due only to the equipment being used at the proposed facility are well below the limit for noise levels developed in accordance with EPA Victoria guidance. These predicted levels were modelled using worst case meteorological conditions so, in practice, noise levels will be lower than these values.

These predicted levels are also well below the background noise levels measured at the sensitive receptor locations (as listed in **Table 6.3**). This means noise from the facility is unlikely to be noticeable/audible compared to the existing situation – i.e. no change will be noticed.

Based on the available information (i.e. noise from the site will not be noticeable), the potential for noise from the site to result in adverse health impacts within the community is considered to be low/negligible.

6.4 Outcomes of health impact assessment: noise

Table 6.5 presents a summary of the outcomes of the assessment undertaken in relation to the impacts of changes in noise, associated with the proposed project, on community health.

Table 6.5: Summary of health impacts – noise

Health impacts associated with noise emissions	
Benefits	There are no benefits to the off-site community in relation to noise emissions
Impacts	Based on the predicted noise levels, the potential for adverse health impacts within the off-site community associated with noise generated from the operation of the facility is considered to be negligible.
Mitigation	No additional mitigation measures other than those already included in the modelling (such as equipment being operated within buildings) are required.

Section 7. Health impacts: Water

7.1 Approach

This section presents a review and further assessment of impacts on health associated with the management of water, relevant to the operation of the facility. The assessment presented has relied on the information provided in the BATT Report (ARV 2022).

7.2 Summary of management of water for the site

7.2.1 Background

Water at the site involves process water (i.e. water used in the process of breaking down the plastics) and stormwater (i.e. rain water that falls on the site) (ARV 2022).

Process water will be treated on-site by a water treatment plant prior to being discharged as trade waste into the Greater Western Water (GWW) sewerage system for additional treatment and potential reuse as recycled water. In addition to the process water, water from within the bunded areas on-site will also be treated via this plant. Water within the bunded areas could arise due to rain or due to washdown of equipment or vehicles (ARV 2022).

Rain that falls in other areas of the site will be handled by normal stormwater systems as these areas are not impacted by the plastics recycling process. Stormwater in these areas will be of similar quality to water falling on homes, roads, parks or commercial buildings. Such water is collected and directed into Council operated systems. No further assessment of potential for health impacts from this water is required (ARV 2022).

Water from kitchen, toilets and showers at the site will be handled by the normal sewerage services. No further assessment of potential for health impacts from this water is required (ARV 2022).

7.2.2 Site water uses

Process water will be used on the site in the boilers. The supercritical boiler will produce steam at high temperature (and under pressure) for use in the hydrothermal process. The standard boiler will produce steam for activities such as heating tanks and cleaning equipment (ARV 2022).

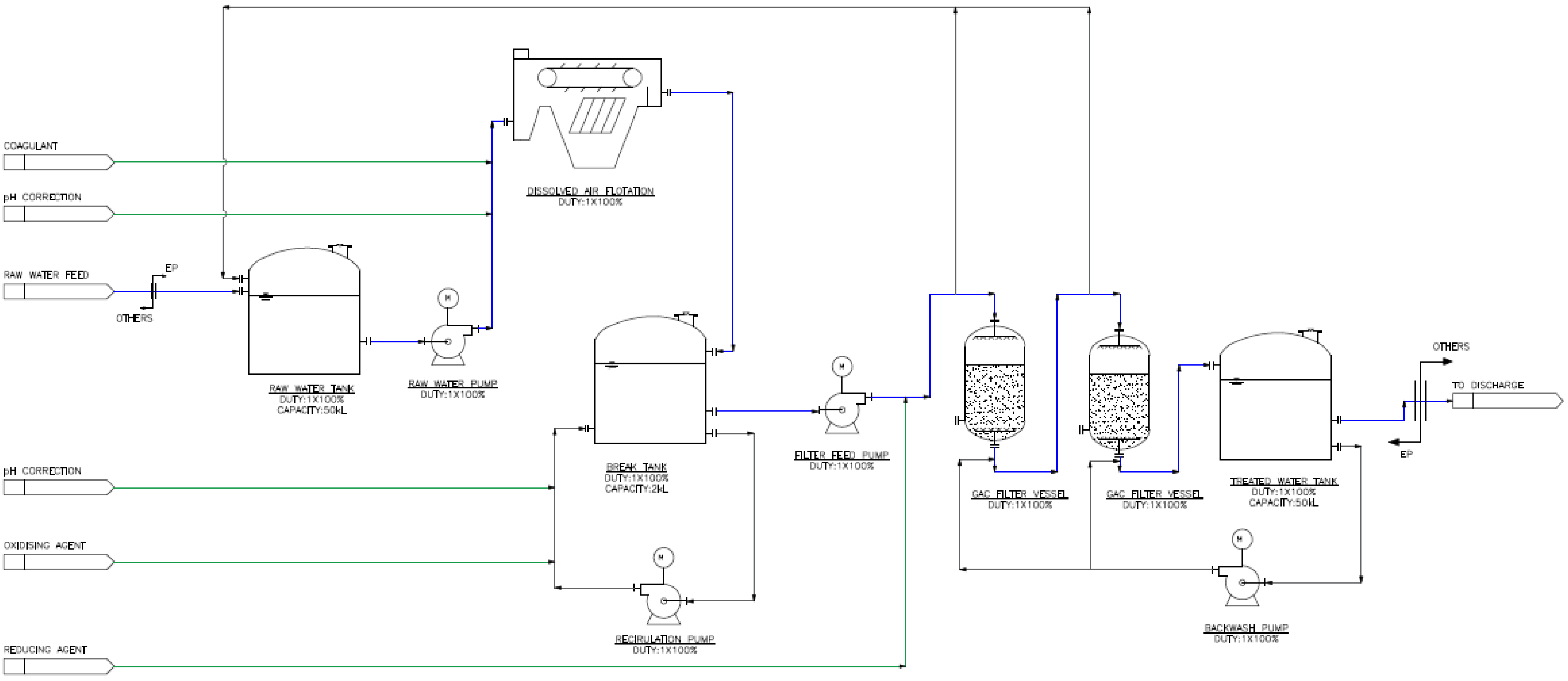
7.2.3 Water treatment

The water treatment plant will include dissolved air flotation and filtration through activated carbon (ARV 2022).

- Dissolved air flotation causes any particles or separate phase material (i.e. oil) to float to the top of the water in a tank to allow it to be collected and skimmed off.
- Filtration through activated carbon adsorbs organic compounds (like large polymer molecules from plastics should they remain or any of the component parts of those molecules that have remained in the water phase when the pressure was released and the synthetic crude split from the water at the end of hydrothermal treatment).

These are commonly used robust treatment technologies and are relevant to the types of chemicals that may remain in the water phase post treatment. An outline of the proposed treatment plant is shown in **Figure 7.1**.

Figure 7.1 Design flow diagram for a site water treatment plant



Once process water (and other potentially impacted water) has been treated on the site, it then will be discharged into the trade waste line operated by GWW. Water in this line is taken to the Altona water treatment plant for reuse as recycled water for industrial use. The Altona water treatment plant includes a range of advanced treatment technologies including ultrafiltration and reverse osmosis[9]. The water from the plant is used for watering parks and golf courses as well as being used for industrial process water. The Altona plant treats around 13 million litres of wastewater per day, most of which is reused.

GWW requires that all water that is discharged into their system complies with relevant acceptance criteria. This means the water from the water treatment plant on this site must be of sufficient quality to be permitted to be discharged into the GWW system. Compliance with the acceptance criteria will need to be demonstrated to the satisfaction of GWW either by initial and regular monitoring for a continuous discharge or by batch by batch testing if the discharge is to be intermittent.

7.2.4 Potential exposure

Workers on the site may be exposed to process water as supplied by GWW. The quality of that water has already been demonstrated to be of appropriate quality, given that the Altona water treatment plant has been operational for a number of years and supplies water for similar purposes to a range of other industrial facilities.

Workers on the site may also be exposed to process water post hydrothermal reaction and prior to the on-site water treatment plant or during maintenance activities at the on-site water treatment plant. The water from the hydrothermal reactor will be transferred to the on-site water treatment plant via a pipeline. This means people can only be exposed should there be a break in that pipeline or if maintenance is required. This is also the case for water from the water treatment plant which will be transferred to the GWW line using a pipeline.

People in off-site areas cannot be exposed to untreated process water from this site as all process water leaving the site will have been treated to ensure it complies with the GWW acceptance criteria and because the GWW line keeps such wastewater contained and directed back to the Altona water treatment plant without coming into contact with the general public.

The acceptance criteria for trade waste issued by GWW are listed in **Table 7.1**. Recreational water quality guidelines are available in Australia from NHMRC(NHMRC 2008, 2011 updated 2021). These guidelines are based on the drinking water guidelines (which assume a person drinks 2 L of water every day of the year). The recreational water guidelines are the drinking water guidelines multiplied by 10 – i.e. assumes a person drinks 200 mL of water every day of the year during swimming, surfing etc.

In this case, assuming a person could drink 200 mL of the treated process water in the GWW pipeline if the pipeline should break at some point in time. Incidental ingestion during maintenance is normally assumed to involve consumption of 1-20 mL of water during plumbing work, irrigation or

---

[9] https://www.grupocobra.com/en/proyecto/altona-wastewater-treatment-and-recycled-water-plant/ and https://www.citywestwater.com.au/about_us/general_projects/atp_diffuser_tank_project

fire fighting based on guidance in the Australian guidelines for water recycling (NRMMC 2006). Adjusting the drinking water guidelines for use in this assessment based on occasional consumption (every 2nd or 3rd day of the year – i.e. 150 days per year) of 20 mL of treated water requires the drinking water guideline to be multiplied by 200 (i.e. 100x for adjustment from ingestion of 2 L to 20 mL and 2x for adjustment for the number of days per year). The relevant adjusted guidelines are listed in **Table 7.1** for comparison.

Table 7.1: GWW acceptance criteria

Parameter	Acceptance criteria (mg/L)	Adjusted water guideline[1] (mg/L)
Arsenic	1	2
Barium	150	400
Beryllium	30	12
Boron	25	800
Cadmium	2	0.4
Chromium	10	10
Cobalt	10	NG
Copper	10	400
Iron	100	No health based guideline
Lead	10	2
Manganese	10	100
Mercury	1	0.2
Molybdenum	10	10
Nickel	10	4
Selenium	10	2
Silver	5	20
Thallium	20	NG
Tin	10	NG
Uranium	30	3.4
Zinc	10	No health based guideline
Benzene	1	0.2
Toluene	2	160
Ethylbenzene	2	60
Xylenes (total)	2	120
Naphthalene	1.3	1.2[U]
Total petroleum hydrocarbons C5 to C9 fraction	1	200[N]/3,000[W]

Notes:

1 = guidelines based on NHMRC Australian drinking water guidelines unless otherwise specified (NHMRC 2011 updated 2021)
[N] = NEPM Schedule B1 – (HSL A&B for 2-4 m in sand for low/high density residential land use) (NEPC 1999 amended 2013c) (this guideline is based on protection for vapour intrusion due to this volatile group of chemicals)
[W] = WHO Drinking water Guidelines. Range presented for TRH reflects range relevant for aromatic and aliphatic fractions.(WHO 2017)
[U] = USEPA RSLs for tapwater (USEPA 2021)
NG = no guideline provided by NHMRC
No health based guideline = NHMRC provide a guideline based on aesthetic matters (stains on washing, corrosion in pipes or pumps, taste or odour) which are not relevant for this situation

For the chemicals that are more likely to be present in the treated process water, the acceptance criteria are similar to or less than guidelines based on protecting human health for occasional contact. It is noted that these adjusted guidelines still assume a person comes into contact with the treated process water in the pipeline 150 days per year which is highly unlikely. If a person could be exposed 15 days per year instead of 150 days per year, then these guidelines could be 10 times higher. This would mean all of the acceptance criteria will be lower than the relevant health based guideline. This means even if people could come into contact on occasion with the treated process water as it travels to Altona water treatment plant there would not be any expected impacts on health.

7.3 Outcomes of health impact assessment: water

Table 7.2 presents a summary of the outcomes of the assessment undertaken in relation to the impacts of water management, associated with the proposed project, on community health.

Table 7.2: Summary of health impacts – water

Health impacts associated with noise emissions	
Benefits	There are no benefits to the off-site community in relation to water management
Impacts	The potential for adverse health impacts within the off-site community associated with use of water at the site is considered to be negligible
Mitigation	The plant is designed to move water around the site and into the off-site area via pipelines. This limits the potential for the community to be exposed to any water used in the process. If people cannot be exposed to the water then the potential for health impacts is negligible. In addition, all process water used at the site will be subject to treatment prior to moving it off-site to ensure it is in compliance with the acceptance criteria required by GWW for the Altona water treatment plant. This ensures that the water moving off-site is of an appropriate quality for movement via pipeline through the industrial zoned areas to reach the Altona water treatment plant located to the south of the site.

Section 8. Conclusions

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Licella Holdings Ltd to undertake a Human Health Risk Assessment (HHRA) for an advanced plastics recycling facility at 541-583 Kororoit Creek Road, Altona, Victoria (the “site”) (refer to **Figure 1.1**). The project will be known as the Altona Advanced Recycling Facility and will use a catalytic hydrothermal reactor (i.e. Cat-HTR^{TM}). The operator of the project will be Advanced Recycling Victoria Pty Ltd (wholly owned subsidiary of Licella Holdings Ltd (ARV 2022).

The project proposes to take waste plastics (ones that cannot be mechanically recycled) and convert them into useable chemicals and hydrocarbon products (i.e. essentially the process breaks the polymers that make up the plastics into smaller chemicals that can then be reused for a range of purposes).

The site is within the Hobsons Bay City Council local government area, is owned by Dow Chemical Australia. It was previously used as a chemical manufacturing site and is currently undergoing remedial works and decommissioning. Dow Chemical proposes to lease land to ARV at this site (ARV 2022).

The site is suitably zoned SUZ3 (Special Use Zone 3 - Petrochemical Complex Area) – a precinct specifically zoned for chemical manufacturing and other heavy industry (ARV 2022).

This human health risk assessment (HHRA) has been developed for the project by identifying and estimating the health impacts of the proposed project, as a result of emissions to air, on the health of the surrounding (local and regional) community. Consideration of potential impacts to community health based on noise emissions or water discharges from the site is also presented in this report.

Detailed assessment of risks to human health for air emissions has considered acute and chronic inhalation exposures as well as multi-pathway exposures associated with the deposition of metals and dioxin-like compounds to the ground and the potential for direct contact with soil and dust (indoors) and uptake of these chemicals into homegrown produce (fruit and vegetables and eggs) and consumption of this produce. The assessment has also considered whether the deposition of metals and dioxin-like compounds would have the potential to adversely affect water quality in rainwater tanks, should these be present within the community and used for a range of non-potable purposes.

Consideration of impacts from noise or water discharges have been assessed using Australian guidance and details of the proposed facility.

Based on the available data and the conservative assumptions adopted in this assessment, the following has been concluded:

Air

- Inhalation exposures: Risks to human health associated with acute or chronic exposures are negligible. This includes risks to pollutants presents as gases, particulate matter and pollutants bound to particulates.

- Multiple pathway exposures: Risks to human health associated with chronic exposures to pollutants, bound to particulates, that may deposit to surfaces and be taken up into produce for home consumption relevant to surrounding areas where residential land use occurs are negligible.

Noise

- Based on the available information (i.e. noise from the site is not expected to be noticeable), the potential for noise from the site to result in adverse health impacts within the community is considered to be low/negligible.

Water

- The potential for adverse health impacts within the off-site community associated with use of water at the site is considered to be negligible.

Section 9. References

CRC CARE 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC for Contamination Assessment and Remediation of the Environment, CRC CARE Technical Report no. 10, Adelaide. <http://www.crccare.com/products-and-services/health-screening-levels>.

DEH 2005, *National Dioxins Program, Technical Report No. 12, Human Health Risk Assessment of Dioxins in Australia*, Office of Chemical Safety, Australian Government Department of the Environment and Heritage.

enHealth 2010, *Guidance on use of rainwater tanks*, Commonwealth of Australia. <https://www1.health.gov.au/internet/main/publishing.nsf/Content/0D71DB86E9DA7CF1CA257BF0001CBF2F/$File/enhealth-raintank.pdf>.

enHealth 2012a, *Environmental Health Risk Assessment, Guidelines for assessing human health risks from environmental hazards*, Commonwealth of Australia, Canberra. <https://www1.health.gov.au/internet/main/publishing.nsf/Content/A12B57E41EC9F326CA257BF0001F9E7D/$File/Environmental-health-Risk-Assessment.pdf>.

enHealth 2012b, *Australian Exposure Factors Guide*, Commonwealth of Australia, Canberra. <http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-publicat-environ.htm>.

enHealth 2017, *Health Impact Assessment Guidelines*, enHealth.

EPA Victoria 2013, *Guidance notes for using the regulatory air pollution model AERMOD in Victoria*, EPA Victoria. <https://www.epa.vic.gov.au/~/media/Publications/1551.pdf>.

EPA Victoria 2021, *Noise limit and assessment protocol for the control of noise from commercial, industrial and trade premises and entertainment venues. EPA Publication 1826.4*, EPA Victoria. <https://www.epa.vic.gov.au/about-epa/publications/1826-4>.

EPA Victoria 2022, *Guideline for assessing and minimising air pollution in Victoria (for air pollution managers and specialists), Publication Number 1961*, EPA Victoria. <https://www.epa.vic.gov.au/about-epa/publications/1961>.

EPHC 2005, *National Dioxins Program - National Action Plan for Addressing Dioxins in Australia*, Environment Protection and Heritage Council. <http://www.nepc.gov.au/system/files/resources/74b7657d-04ce-b214-d5d7-51dcbce2a231/files/cmgt-rev-national-dioxins-program-national-action-plan-addressing-dioxins-australia-200510.pdf>.

EPHC 2010, *Expansion of the multi-city mortality and morbidity study, Final Report*, Environment Protection and Heritage Council.

Ewald, B, Knibbs, LD, Campbell, R & Marks, GB 2020, 'Public health opportunities in the Australian air quality standards review', *Australian and New Zealand Journal of Public Health,* vol. n/a, no. n/a.

FAO/WHO 2018, *Joint FAO/WHO Food Standards Programme. Codex Committee on Contaminants in Foods. 12th Session, Utrecht, 12–16 March 2018. Proposed draft revision of the Code of Practice for the Prevention and Reduction of Dioxins and Dioxin-like PCBs in Food and Feed*, Food and Agriculture Organzation and World Health Organization. <http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FMeetings%252FCX-735-12%252FWD%252Fcf12_08e.pdf>.

FSANZ 2017, *Supporting Document 2 Assessment of potential dietary exposure to perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS) occurring in foods sampled from contaminated sites*, Food Standards Australia and New Zealand, Commonwealth Department of Health. <http://www.health.gov.au/internet/main/publishing.nsf/Content/ohp-pfas-hbgv.htm>.

Harris, P, Harris-Roxas, B., Harris, E. & Kemp, L. 2007, *Health Impact Assessment: A Practical Guide*, Centre for Health Equity Training, Research and Evaluation (CHETRE). Part of the UNSW Research Centre for Primary Health Care and Equity. University of New South Wales.

I-INCE 2011, *Guidelines for Community Noise Impact Assessment and Mitigation, I-INCE Publication Number: 11-1*, International Institute of Noise Control Engineering (I-INCE) Technical Study Group on Community Noise: Environmental Noise Impact Assessment and Mitigation.

Jalaudin, B & Cowie, C 2012, *Health Risk Assessment - Preliminary Work to Identify Concentration-Response Functions for Selected Ambient Air Pollutants*, Woolcock Institute of Medical Research. <http://www.nepc.gov.au/system/files/pages/18ae5913-2e17-4746-a5d6-ffa972cf4fdb/files/health-report.pdf>.

Krewski, D, Jerrett, M, Burnett, RT, Ma, R, Hughes, E, Shi, Y, Turner, MC, Pope, CA, 3rd, Thurston, G, Calle, EE, Thun, MJ, Beckerman, B, DeLuca, P, Finkelstein, N, Ito, K, Moore, DK, Newbold, KB, Ramsay, T, Ross, Z, Shin, H & Tempalski, B 2009, 'Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality', *Research report*, no. 140, May, pp. 5-114; discussion 115-136.

Kus, B, Kandasamy, J, Vigneswaran, S & Shon, HK 2010, 'Analysis of first flush to improve the water quality in rainwater tanks', *Water Sci Technol,* vol. 61, no. 2, pp. 421-428.

Lizárraga-Mendiola, L, Vázquez-Rodríguez, G, Blanco-Piñón, A, Rangel-Martínez, Y & González-Sandoval, M 2015, 'Estimating the Rainwater Potential per Household in an Urban Area: Case Study in Central Mexico', *Water,* vol. 7, no. 9, pp. 4622-4637.

Lowe, JA, Dietrich, W & Alberts, MT 1991, 'Health Risk Assessment for Waste-To-Energy Projects in California', in HA Hattemer-Frey & C Travis (eds), *Health Effects of Municipal Waste Incineration*, CRC Press, pp. 163-200.

Mariraj Mohan, S 2016, 'An overview of particulate dry deposition: measuring methods, deposition velocity and controlling factors', *International Journal of Environmental Science and Technology,* vol. 13, no. 1, 2016/01/01, pp. 387-402.

Martinson, B & Thomas, T 2009, *Quantifying the first-flush phenomenon: effects of first-flush on water yield and quality*, In: 14th International Rainwater Catchment Systems Conference, Kuala Lumpur.

Morgan, G, Broom, R & Jalaludin, B 2013, *Summary for Policy Makers of the Health Risk Assessment on Air Pollution in Australia*, Prepared for National Environment Protection Council by the University Centre for Rural Health, North Coast, Education Research Workforce, A collaboration between The University of Sydney, Southern Cross University, The University of Western Sydney, The University of Wollongong, Canberra.

NEPC 1999 amended 2013a, *Schedule B4, Guideline on Site-Specific Health Risk Assessment Methodology, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

NEPC 1999 amended 2013b, *Schedule B7, Guideline on Derivation of Health-Based Investigation Levels, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

NEPC 1999 amended 2013c, *Schedule B1, Guideline on Investigation Levels For Soil and Groundwater, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

NEPC 2004, *National Environment Protection (Air Toxics) Measure*, National Environment Protection Council. <http://scew.gov.au/nepms/air-toxics>.

NEPC 2010, *Review of the National Environment Protection (Ambient Air Quality) Measure, Discussion Paper, Air Quality Standards*, National Environmental Protection Council.

NEPC 2016, *National Environment Protection (Ambient Air Quality) Measure*, Federal Register of Legislative Instruments F2016C00215.

NEPC 2021, *National Environment Protection (Ambient Air Quality) Measure*, Australian Government. <https://www.legislation.gov.au/Details/F2021C00475>.

NHMRC 1999, *Toxicity Assessment for Carcinogenic Soil Contaminants*, National Health and Medical Research Council.

NHMRC 2002, *Dioxins: Recommendation for a Tolerable Monthly Intake for Australians*, National Health and Medical Research Council and Therapeutic Goods Administration.

NHMRC 2008, *Guidelines for Managing Risks in Recreational Water*, National Health and Medical Research Council, Canberra.

NHMRC 2011 updated 2021, *Australian Drinking Water Guidelines 6, Version 3.6 Updated March 2021, National Water Quality Management Strategy*, National Health and Medical Research Council, National Resource Management Ministerial Council, Canberra.

NRMMC 2006, *National Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)*, Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers Conference. <http://waterquality.gov.au/guidelines/recycled-water>.

NRMMC 2008, *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies*, Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and National Health and Medical Research Council. <http://waterquality.gov.au/guidelines/recycled-water>.

NSW Chief Scientist 2018, *Advisory Committee on Tunnel Air Quality - Technical Paper 5: Road Tunnel Stack Emissions*, Advisory Committee on Tunnel Air Quality, NSW Chief Scientist and Engineer. <https://chiefscientist.nsw.gov.au/reports/advisory-committee-on-tunnel-air-quality>.

NSW EPA 2019, *Air Emissions Inventory for the Greater Metropolitan Region in New South Wales 2013 Calendar Year Consolidated Natural and Human-Made Emissions: Results*, NSW Environment Protection Authority, NSW Government. <https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/air/19p1917-air-emissions-inventory-2013.pdf?la=en&hash=9217ADF2C8D5647147FF00F447258319D00BB75D>.

OEHHA 2012, *Air Toxics Hot Spots Program, Risk Assessment Guidelines, Technical Support Document, Exposure Assessment and Stochastic Analysis*, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

OEHHA 2015, *Air Toxics Hot Spots Program, Risk Assessment Guidelines, Guidance Manual for Preparation of Health Risk Assessments*, Air, Community, and Environmental Research Branch, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Ostro, B, Broadwin, R, Green, S, Feng, WY & Lipsett, M 2006, 'Fine particulate air pollution and mortality in nine California counties: results from CALFINE', *Environmental health perspectives,* vol. 114, no. 1, Jan, pp. 29-33.

PHIDU 2019, *Social Health Atlases of Australia: Local Government Areas, Victoria*, Public Health Information Development Unit, Torrens University Australia, <https://phidu.torrens.edu.au/social-health-atlases/data#social-health-atlases-of-australia-local-government-areas>.

Pope, IC, Burnett, RT, Thun, MJ & et al. 2002, 'Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution', *JAMA,* vol. 287, no. 9, pp. 1132-1141.

RAIS *The Risk Assessment Information System*, Department of Energy's (DOE's) Oak Ridge Operations Office (ORO).

Saylor, RD, Baker, BD, Lee, P, Tong, D, Pan, L & Hicks, BB 2019, 'The particle dry deposition component of total deposition from air quality models: right, wrong or uncertain?', *Tellus B: Chemical and Physical Meteorology,* vol. 71, no. 1, 2019/01/01, p. 1550324.

Sehmel, GA & Hodgson, WH 1978, *Model for predicting dry deposition of particles and gases to environmental surfaces, PNL-SA-6721*, Battelle Pacific Northwest Laboratories.

Stevens, B 1991, '2,3,7,8-Tetrachlorobenzo-p-Dioxin in the Agricultural Food Chain: Potential Impact of MSW Incineration on Human Health', in HA Hattemer-Frey & T Curtis (eds), *Health Effects of Municipal Waste Incineration*, CRC Press.

TCEQ 2014, *Development Support Document, Ammonia*, Texas Commission on Environmental Quality.

TCEQ 2015a, *Hydrogen Chloride, Development Support Document*, Texas Commission on Environmental Quality.

TCEQ 2015b, *Hydrogen Fluoride and Other Soluble Inorganic Fluorides*, Texas Commission on Environmental Quality.

Tesche, TW, Honrath, RA, Kaphai, R & Deitrich, RW 1978, *Improved Dry Deposition Estimates for Air Toxics Risk Assessments, presented at 80th Ann. Meeting of the Air Pollution Control Assoc*, New York.

UK EA 2009, *Supplementary information for the derivation of SGV for mercury*, Environment Agency, Bristol, UK.

USEPA 1989, *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A)*, Office of Emergency and Remedial Response, United States Environmental Protection Agency, Washington.

USEPA 2004, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, (Part E, Supplemental Guidance for Dermal Risk Assessment)*, United States Environmental Protection Agency, Washington, D.C.

USEPA 2005, *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities*, Office of Solid Waste and Emergency Response, US Environmental Protection Agency. <https://archive.epa.gov/epawaste/hazard/tsd/td/web/html/risk.html>.

USEPA 2009, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, (Part F, Supplemental Guidance for Inhalation Risk Assessment)*, United States Environmental Protection Agency, Washington, D.C.

USEPA 2012, *Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure*, National Center for Environmental Assessment RTP Division, Office of Research and Development, U.S. Environmental Protection Agency.

USEPA 2018, *Risk and Exposure Assessment for the Review of thePrimary National Ambient Air Quality Standard for Sulfur Oxides*, U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Health and Environmental Impacts Division Research Triangle Park, NC. <https://www.epa.gov/sites/production/files/2018-05/documents/primary_so2_naaqs_-_final_rea_-_may_2018.pdf>.

USEPA 2021, *Regional Screening Levels (RSLs), November 2021*, United States Environmental Protection Agency. <https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables>.

WHO 1999, *Guidelines for Community Noise*, World Health Organisation, Geneva.

WHO 2000a, *Air Quality Guidelines for Europe, Second Edition*, Copenhagen. <http://www.euro.who.int/en/publications/abstracts/air-quality-guidelines-for-europe>.

WHO 2000b, *Guidelines for Air Quality*, World Health Organisation, Geneva.

WHO 2000c, *WHO air quality guidelines for Europe, 2nd edition, 2000 (CD ROM version)*, World Health Organisation.

WHO 2003, *Elemental Mercury and Inorganic Mercury Compounds: Human Health Aspects*, World Health Organization, Geneva.

WHO 2006a, *Health risks or particulate matter from long-range transboundary air pollution*, World Health Organisation Regional Office for Europe.

WHO 2006b, *Guidelines for safe recreational water environments, Volume 2: Swimming pools and similar environments*, World Health Organization.

WHO 2010, *WHO Guidelines for Indoor Air Quality, Selected Pollutants*, WHO Regional Office for Europe.

WHO 2011, *Burden of disease from environmental noise, Quantification of healthy life years lost in Europe*, World Health Organisation and JRC European Commission.

WHO 2013a, *Review of evidence on health aspects of air pollution - REVIHAAP Project, Technical Report*, World Health Organization, Regional Office for Europe.

WHO 2013b, *Health Effects of Particulate Matter, Policy implications for countries in eastern Europe, Caucasus and central Asia*, WHO Regional Office for Europe.

WHO 2017, *Guidelines for Drinking Water Quality, Fourth Edition incorporating the First Addendum*, World Health Organisation. <http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/>.

WHO 2019, *Exposure to Dioxins and Dioxin-like Substances: A Major Public Health Concern*, World Health Organization.

Appendix A Calculation of risks from $PM_{2.5}$

Calculation of risk: $PM_{2.5}$

A quantitative assessment of risk for these endpoints uses a mathematical relationship between an exposure concentration (i.e. concentration in air) and a response (namely a health effect). This relationship is termed an exposure-response relationship and is relevant to the range of health effects (or endpoints) identified as relevant (to the nature of the emissions assessed) and robust (as identified in the main document). An exposure-response relationship can have a threshold, where there is a safe level of exposure, below which there are no adverse effects; or the relationship can have no threshold (and is regarded as linear) where there is some potential for adverse effects at any level of exposure.

In relation to the health effects associated with exposure to particulate matter, no threshold has been identified. Non-threshold exposure-response relationships have been identified for the health endpoints considered in this assessment.

Risk calculations relevant to exposures to $PM_{2.5}$ by the community have been undertaken utilising concentration-response functions relevant to the most significant health effect associated with exposure to $PM_{2.5}$, namely mortality (all cause).

The assessment of potential risks associated with exposure to particulate matter involves the calculation of a relative risk (RR). For the purpose of this assessment the shape of the exposure-response function used to calculate the relative risk is assumed to be linear[10]. The calculation of a relative risk based on the change in relative risk exposure concentration from baseline/existing (ie based on incremental impacts from the project) can be calculated on the basis of the following equation (Ostro 2004):

Equation 1 $$RR = \exp[\beta(X-X0)]$$

Where:

X-X0 = the change in particulate matter concentration to which the population is exposed (µg/m³)

β = regression/slope coefficient, or the slope of the exposure-response function which can also be expressed as the per cent change in response per 1 µg/m³ increase in particulate matter exposure.

Based on this equation, where the published studies have derived relative risk values that are associated with a 10 micrograms per cubic metre increase in exposure, the β coefficient can be calculated using the following equation:

---

[10] Some reviews have identified that a log-linear exposure-response function may be more relevant for some of the health endpoints considered in this assessment. Review of outcomes where a log-linear exposure-response function has been adopted (Ostro 2004) for $PM_{2.5}$ identified that the log-linear relationship calculated slightly higher relative risks compared with the linear relationship within the range 10–30 micrograms per cubic metre,(relevant for evaluating potential impacts associated with air quality goals or guidelines) but lower relative risks below and above this range. For this assessment (where impacts from a particular project are being evaluated) the impacts assessed relate to concentrations of $PM_{2.5}$ that are well below 10 micrograms per cubic metre and hence use of the linear relationship is expected to provide a more conservative estimate of relative risk.

Equation 2

$$\beta = \frac{\ln(RR)}{10}$$

Where:
RR = relative risk for the relevant health endpoint as published (µg/m^3)
10 = increase in particulate matter concentration associated with the RR (where the RR is associated with a 10 µg/m^3 increase in concentration).

The assessment of health impacts for a particular population associated with exposure to particulate matter has been undertaken utilising the methodology presented by the WHO (Ostro 2004)[11] where the exposure-response relationships identified have been directly considered on the basis of the approach outlined below.

An additional risk can be calculated as:

Equation 3 $$\text{Risk} = \beta \times \Delta X \times B$$

Where:
β = slope coefficient relevant to the per cent change in response to a 1 µg/m^3 change in exposure
ΔX = change (increment) in exposure concentration in µg/m^3 relevant to the project at the point of exposure
B = baseline incidence of a given health effect per person (eg annual mortality rate)

The calculation of the incremental individual risk for relevant health endpoints associated with exposure to particulate matter as outlined by the WHO (Ostro 2004) has considered the following four elements:

- Estimates of the changes in particulate matter exposure levels (ie incremental impacts) due to the project for the relevant modelled scenarios – these have been modelled for the proposed project, with the maximum change from all community receptors (where regional air quality is of most relevance) adopted in this calculation. For this assessment, the change in $PM_{2.5}$ relates to the change in annual average air concentrations and the value considered in this assessment is 0.035 µg/m^3.
- Baseline incidence of the key health endpoints that are relevant to the population exposed – the assessment undertaken has considered the baseline mortality data relevant to the suburbs of Hobsons Bay LGA, with the most recent data indicating a rate of 480 per 100,000 as an age standardised rate which has been adopted in this assessment (**Table 3.3**).

---

[11] For regional guidance, such as that provided for Europe by the WHO (WHO 2006a) regional background incidence data for relevant health endpoints are combined with exposure-response functions to present an impact function, which is expressed as the number/change in incidence/new cases per 100,000 population exposed per microgram per cubic metre change in particulate matter exposure. These impact functions are simpler to use than the approach adopted in this assessment, however in utilising this approach it is assumed that the baseline incidence of the health effects is consistent throughout the whole population (as used in the studies) and is specifically applicable to the sub-population group being evaluated. For the assessment of exposures in the areas evaluated surrounding the project it is more relevant to utilise local data in relation to baseline incidence rather than assume that the population is similar to that in Europe (where these relationships are derived).

- Exposure-response relationships expressed as a percentage change in health endpoint per microgram per cubic metre change in particulate matter exposure, where a relative risk (RR) is determined (refer to Equation 1). The concentration response function used in this report is that recommended in a NEPC published report (Jalaudin & Cowie 2012). It was derived from a study in the United States which examined the health outcomes of hundreds of thousands of people living in cities all over the United States. These people were exposed to all different concentrations of $PM_{2.5}$ (Pope et al. 2002). The study found a relative risk (RR) of all-cause mortality of 1.06 per 10 µg/m^3 change in $PM_{2.5}$, and that this risk relationship was in the form of an exponential function. Based on a RR of 1.06 per 10 µg/m^3 change in $PM_{2.5}$, this results in a $\beta = 0.0058$. It is noted that the exposure response relationship established in this study was re-affirmed in a follow-up study (that included approximately 500,000 participants in the US) (Krewski et al. 2009) and is consistent with findings from California (Ostro et al. 2006). The relationship is also more conservative than a study undertaken in Australia and New Zealand (EPHC 2010).

The above approach (while presented slightly differently) is consistent with that presented in Australia (Burgers & Walsh 2002), US (OEHHA 2002; USEPA 2005b, 2010) and Europe (Martuzzi et al. 2002; Sjoberg et al. 2009).

Based on the calculations undertaken the calculated incremental individual risk (rounded to 1 significant figure):

$$\text{Risk} = \beta \times \Delta X \times B$$

$$= 0.035 \times 0.00480 \times 0.0058$$

$$= 9.7 \times 10^{-7}$$

Appendix B Toxicity of key chemicals evaluated

B1 Approach to the identification of toxicity reference values

The quantitative assessment of potential risks to human health for any substance requires the consideration of the health end-points and where carcinogenicity is identified; the mechanism of action needs to be understood. This will determine whether the chemical substance is considered a threshold or non-threshold chemical substance. A threshold chemical has a concentration below which health effects are not considered to occur. A non-threshold chemical substance is believed to theoretically cause health effects at any concentration, and it is the level of health risk posed by the concentration of the chemical substance that is assessed. The following paragraphs provide further context around these concepts.

For chemical substances that are not carcinogenic, a threshold exists below which there are no adverse effects (for all relevant end-points). The threshold typically adopted in risk calculations (a tolerable daily intake [TDI] or tolerable concentration [TC]) is based on the lowest no observed adverse effect level (NOAEL), typically from animal or human (e.g. occupational) studies, and the application of a number of safety or uncertainty factors. Intakes/exposures lower than the TDI/TC is considered safe, or not associated with an adverse health risk (NHMRC 1999).

Where the chemical substance has the potential for carcinogenic effects the mechanism of action needs to be understood as this defines the way that the dose-response is assessed. Carcinogenic effects are associated with multi-step and multi-mechanism processes that may include genetic damage, altering gene expression and stimulating proliferation of transformed cells. Some carcinogens have the potential to result in genetic (DNA) damage (gene mutation, gene amplification, chromosomal rearrangement) and are termed genotoxic carcinogens. For these carcinogens it is assumed that any exposure may result in one mutation or one DNA damage event that is considered sufficient to initiate the process for the development of cancer sometime during a lifetime (NHMRC 1999). Hence no safe-dose or threshold is assumed and assessment of exposure is based on a linear non-threshold approach using slope factors or unit risk values.

For other (non-genotoxic) carcinogens, while some form of genetic damage (or altered cell growth) is still necessary for cancer to develop, it is not the primary mode of action for these chemical substances. For these chemical substances carcinogenic effects are associated with indirect mechanisms (that do not directly interact with genetic material) where a threshold is believed to exist.

In the case of particulate matter (PM_{10} or $PM_{2.5}$), current health evidence has not been able to find a concentration below which health impacts do not exist. Thus, the quantification of risk for $PM_{2.5}$ follows a non-threshold approach as described in **Appendix A**.

B2 Values adopted for the assessment of acute exposures

The assessment of potential acute exposures relates to inhalation exposures only. The assessment is based on the maximum predicted 1-hour average air concentration. Hence the selection of relevant and appropriate acute toxicity reference values (TRVs) has focused on guidelines that relate to a peak 1-hour exposure. There are other guidelines available that can be termed acute or short-term, however these relate to exposure periods longer than 1-hour, e.g. an 8-hour average or averaging periods up to 14 days (as is adopted by ATSDR). Guidelines for averaging periods longer than 1-hour are not preferred as the assessment would not then be comparing exposure concentrations and guidelines on the same basis.

The acute TRVs are protective of all adverse health effects for all members of the community including sensitive groups, such as children and the elderly.

For this assessment the acute TRVs have been selected on the basis of the following approach:

- Acute guidelines relevant to a 1-hour average exposure period are preferred
- The TRVs have been selected on the basis of the following hierarchy:
    1. Texas Commission on Environmental Quality (TCEQ) Acute Reference Value (Acute ReV), which is based on a target HI of 1, consistent with the target HI adopted in the derivation of guidelines in Australia (enHealth 2012a; NEPC 1999 amended 2013b, 2004) by the WHO (WHO 2000b, 2000a, 2010). These are used as the primary source of acute guidelines as they specifically relate to and consider studies relevant to a 1-hour exposure and they have undergone the most recent detailed review process.
    2. California Office of Environmental Health Hazard Assessment (OEHHA) acute Reference Exposure Level (REL), which are all based on a target HI of 1 with RELs relevant to 1-hour average exposures adopted.

Based on the above, the following acute TRVs have been adopted in this assessment:

Table B1: Acute TRVs adopted in this assessment

Chemicals	Acute air guideline (1-hour average) (mg/m^3)
Hydrogen chloride (HCl)	0.66[1]
Hydrogen fluoride (HF)	0.06[1]
Ammonia	0.59[1]
Cadmium	0.0054[1]
Mercury (as elemental)	0.0006[2]

References for health-based acute air guidelines (1-hour average):
1 = Guideline available from the Texas Commission on Environmental Quality (TCEQ), https://www.tceq.texas.gov/toxicology/dsd/final.html
2 = Guideline available from California Office of Environmental Health Hazard Assessment (OEHHA) https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary

B3 Values adopted for the assessment of chronic exposures

Chronic toxicity reference values (TRVs) associated with inhalation, ingestion and dermal exposures have been adopted from credible peer-reviewed sources as detailed in the ASC NEPM (NEPC 1999 amended 2013a) and enHealth (enHealth 2012a). The identification of the most appropriate and robust TRVs has followed guidance from Australia (enHealth 2012a), as noted above.

For carcinogens, this guidance requires consideration of the mechanism of action for the development of cancer. Some cancers are caused by a threshold mechanism, where there needs to be sufficient exposures to trigger the damage that results in or promotes the development of cancer. Other carcinogens are genotoxic/mutagenic and act in a way such that and any level of exposure is assumed to result in damage that may increase the lifetime risk of cancer. Not all carcinogenic (and not all mutagenic) pollutants cause cancer in the same way and hence the mechanism of action has been considered in the identification of appropriate TRVs for use in this assessment.

For the gaseous chemicals considered in this assessment, only inhalation TRVs have been adopted. For inorganics as well as dioxin-like compounds, TRVs relevant to all exposure pathways have been adopted. Background intakes of these chemicals have been estimated on the basis of existing available information as noted.

Table B2 presents the TRVs adopted for the assessment of chronic health effects associated with exposure to the chemicals considered in this assessment.

Table B2: Summary of chronic TRVs adopted for chemicals – threshold effects

Chemical	Inhalation TRV (mg/m^3)	Oral/dermal TRV (mg/kg/day)	GI absorption factor*	Dermal absorption*	Background intakes (as percentage of TRV)	
					Oral/dermal**	Inhalation**
Hydrogen chloride (HCl)	0.026 [T]	NA (gaseous chemical)			0%	0%
Hydrogen fluoride (HF)	0.029 [T]	NA (gaseous chemical)			0%	0%
Ammonia	0.32 [T]	NA (gaseous chemical)			0%	0%
Cadmium	0.000005 [W]	0.0008 [W]	100%	0	60%	20%
Mercury	0.0002 [W]	0.0006 [W]	7%	0.001	40%	10%
Dioxins and furans assumed to be WHO_{05} TEQs	8.05E-09 [R]	2.3E-09 [NH]	100%	0.03	54%	54%

Notes for Table B2

* GI factor and dermal absorption values adopted from RAIS (accessed in 2021) (RAIS)

** Background intakes relate to intakes from inhalation, drinking water and food products. The values adopted based on information provided in the ASC-NEPM (NEPC 1999 amended 2013b) and relevant sources as noted for the TRVs. Gaseous chemical background intakes are not known and hence for this assessment they have been assumed to be negligible

R = No inhalation-specific TRV available, hence inhalation exposures assessed on the basis of route-extrapolation from the oral TRV, as per USEPA guidance (USEPA 2009)

NH = Dioxin value (and background intakes, which includes natural soil) adopted from NHMRC (NHMRC 2002) and Environment Australia (DEH 2005; EPHC 2005), and other values consistent with that adopted by NHMRC to assess intakes in drinking water (NHMRC 2011 updated 2021)

T = TRV available from TCEQ, relevant to chronic inhalation exposures (and HI=1) (TCEQ 2014, 2015a, 2015b)

W = TRV available from the WHO, relevant to chronic inhalation exposures (WHO 2000a, 2017), noting inhalation value adopted for mercury is for elemental mercury (WHO 2003)

For this assessment the following pollutants have been classified as class 1 carcinogens by the International Agency for Research on Cancer (IARC), and a review has been undertaken on the mechanism of action relevant to the way in which they cause cancer as follows:

- Cadmium – the available data suggests only weak evidence of genotoxicity and review by NEPC (NEPC 1999 amended 2013b) indicates that a threshold mode of action is relevant for the assessment of cancer. Hence the threshold TRV adopted is protective of all health effects including carcinogenicity.
- Dioxins and furans, as 2,3,7,8-TCDD – review of carcinogenicity by NHMRC (NHMRC 2002) and the WHO (FAO/WHO 2018; WHO 2019) indicates that TCDD is not genotoxic and hence a threshold approach is considered appropriate. Hence the threshold TRV adopted is protective of all health effects including carcinogenicity.

All chronic TRVs adopted for the assessment of chronic exposures are protective of all adverse health effects for all members of the community including sensitive groups such as children and the elderly.

Appendix C Methodology and assumptions

C1 Introduction

This appendix presents the methodology and assumptions adopted in the calculation of risk related to the assessment of chronic risks via inhalation or other pathways that may occur following deposition of chemical substances that are persistent.

C2 Quantification of inhalation exposure

Intakes via inhalation has been assessed on the basis of the inhalation guidance available from the USEPA and recommended for use in the ASC NEPM and enHealth (enHealth 2012a; NEPC 1999 amended 2013b; USEPA 2009).

This guidance requires the calculation of an exposure concentration which is based on the concentration in air and the time/duration spent in the area of impact. It is not dependent on age or body weight. The following equation outlines the calculation of an inhalation exposure concentration, and **Table C1** provides details on the assumptions adopted in this assessment:

$$\text{Exposure Concentration} = C_a \bullet \frac{ET \bullet EF \bullet ED}{AT} \quad (\text{mg/m}^3)$$

Table C1: Inhalation exposure assumptions

Parameter		Value adopted	Basis
Ca	Concentration of chemical substance in air (mg/m^3)	Maximum from all receptors modelled	Calculations undertaken on the basis of the maximum predicted impacts
FI	Fraction inhaled from site	100%	All exposures occur at the same location
RF	Dust lung retention factor (unitless)	Gases = 1 Particulate bound chemicals = 1	100% of gases reach the lungs. For particulates, these are assumed to be as PM$_{2.5}$, where 100% of the particulates may reach the lungs as per enHealth (2012a) guidance
ET	Exposure time (dependent on activity) (hours/day)	Residents = 24 hours/day Workers = 8 hours/day	Residents: Assume someone is exposed at the maximum location all day, every day of the year. Workers: Working 8 hours per day, 5 days per week for 48 weeks of the year (enHealth 2012a)
EF	Exposure frequency (days/year)	Residents = 365 days Workers = 240 days	
ED	Exposure duration (years)	Residents = 35 years (6 as child, 29 as adult) Workers = 30 years	Duration of residency or time at the same workplace as per enHealth (enHealth 2012a)
AT	Averaging time (hours)	Threshold = ED x 365 days/year x 24 hours/day Non-threshold = 70 years x 365 days/year x 24 hours/day	As per enHealth (enHealth 2012a) guidance

C3 Multiple pathway exposures

C3.1 Particle deposition modelling

The assessment of multi-pathway exposures has utilised the default deposition velocity from OEHHA (OEHHA 2015). This means the deposition rate is calculated from the predicted/ modelled air concentration and a deposition velocity. The following is an extract from Lowe et al 1991 (Lowe et al. 1991) and it provides additional information on the use of this approach.

Deposition of particles onto the ground is used to evaluate exposures through the food chain. Pollutant deposition is assumed to be proportional to concentration of pollutants in air. Hence, deposition is estimated using a proportionality constant referred to as a deposition velocity. The deposition velocity is expressed in units of centimetres per second. The methods for evaluating deposition are critical and greatly influence the results of a risk assessment. The assumptions used and the values selected for deposition velocities tend to over predict the magnitude of particle deposition from WTE facilities.

Deposition of particles emitted from WTE facilities is a function of particle size, density, meteorological conditions, and terrain. Deposition is not constant over time and changes with variations in wind speed, stability, and vegetative canopy. All of these factors are considered in estimating the rate of deposition of facility-emitted pollutants.

Existing techniques for estimating the rate of deposition are not adequate to provide a realistic simulation. The most commonly used dispersion models were not specifically designed to simulate dispersion of fine particulate matter. USEPA-preferred dispersion models typically have a deposition algorithm in which the user specifies a settling velocity computed from Stokes' law and a reflection (or resuspension) coefficient dependent on settling velocity.

This type of deposition model, however, is not recommended for particles with a diameter of less than 20 µm for two reasons:

- *the dominant mechanism of deposition for particles with diameters less than 20 µm is not gravity but diffusion and*
- *the reflection coefficient for particles with a settling velocity of 3 to 5 cm/s (i.e., particles that are 10 to 20 µm in diameter) is essentially 100%.*

Hence, the dispersion model used in many regulatory applications assumes 100% reflection, which means that particles do not deposit onto environmental surfaces. It essentially treats emitted particles as gases. The main problem with this approach is that it is not mass conservative, because the model does not subtract mass from the plume. Thus, particles emitted from a WTE facility are assumed to both deposit from the plume (which is estimated by using a deposition velocity) and are also assumed to stay suspended in the air where people can inhale them (and they are allowed to disperse throughout the airshed). This approach also neglects the influence of meteorology and variations on particle size and terrain in estimating deposition.

However, modern WTE facilities equipped with a dry scrubber and baghouse filter emit a very small fraction of particles in the 20 to 50 µm size range; most emitted particles are less than 20 µm in diameter. In the absence of approved models and techniques, several alternative models have been *developed for simulating particle deposition. The most common method for simulating dispersion and deposition of particulate matter involves multiplying the modelled concentration in air by a chemical-specific deposition velocity, typically 1 to 2 cm/s. This approach is used in screening analyses but is considered conservative, since it tends to overestimate deposition and ground-level air concentrations.*

A more realistic approach utilizes the work of Sehmel and Hodgson (Sehmel & Hodgson 1978) to estimate a deposition velocity that is dependent on particle size, meteorological conditions, and surface roughness (terrain effects). They also developed (Sehmel & Hodgson 1978) a series of nomographs that relate particle diameter and density to wind speed, stability, and surface roughness. These nomographs have been incorporated into a computer model that was developed by ARB. This model uses hourly meteorological data and a size distribution of the emitted particles to obtain an hourly, size-dependent estimate of deposition velocity. These values are then used to compute deposition fluxes on an hourly basis, which are averaged over 1 year to determine annual average deposition rates. This method is also not mass conservative (i.e. assumes particles are in air and that they deposit onto the ground), but it does provide deposition velocities that are more realistic and better reflect changing weather conditions. For a typical WTE facility equipped with a baghouse, the deposition velocity for emitted pollutants can range from 0.05 to approximately 1 cm/s, depending on the particle size distribution used in the model.

Another approach to deposition modelling is currently under development (Tesche et al. 1978). In this approach, Sehmel and Hodgson 's nomographs are used to calculate a deposition rate, but a site-specific reflection coefficient is specified by the user. The difficulty of this approach is selection of a justifiable reflection coefficient, as this task involves an extensive research effort that is not feasible for health risk assessments prepared to support regulatory permitting. To date, this method has not been used or proposed for use in California.

Facility emissions in the Milliken WTE health risk assessment were modelled using the Industrial Source Complex-Short Term (ISCST) dispersion model. Deposition of pollutants onto environmental surfaces was modelled using a modified version of ISCST developed by the Radian Corporation[5] *(based on Sehmel and Hodgson 1978), in which deposition is calculated as a function of particle size and meteorological conditions. Particle size distributions were estimated from tests conducted at the WTE facility in Wurzburg, West Germany. Two size distributions were used in the modelling to account for the effects of fine particulate enrichment of organic compounds. Metals were assumed to be an integral part of the fly ash and to be evenly distributed on a mass basis. Semi-volatile organics were assumed to adsorb to the surface of particles during cooling of the flue gas and, thus, would distribute according to surface area. The surface area-weighted distribution (Table 4 below) indicates that over 99% of the total available surface area is in the 0 to 2 µm range. As a result of the different weighting schemes, metals had an estimated deposition rate of 0.6 cm/s, while the semi-volatile organics had an estimated rate of 0.06 cm/s.*

Estimated health risks were developed for two exposure scenarios. These scenarios describe the best estimate of upper-bound risk to the maximally exposed individual. These results represent the bounds of estimated risks, given the ranges of values for the data inputs. A deposition velocity of 1 cm/s, recommended by the California Air Resources Board, provides an upper-bound estimate of particle deposition. The lower bound estimates (0.6 cm/s for trace metals and 0.06 cm/s for semi-

volatile organic compounds) account for the distribution of organic emissions onto particle surface areas.

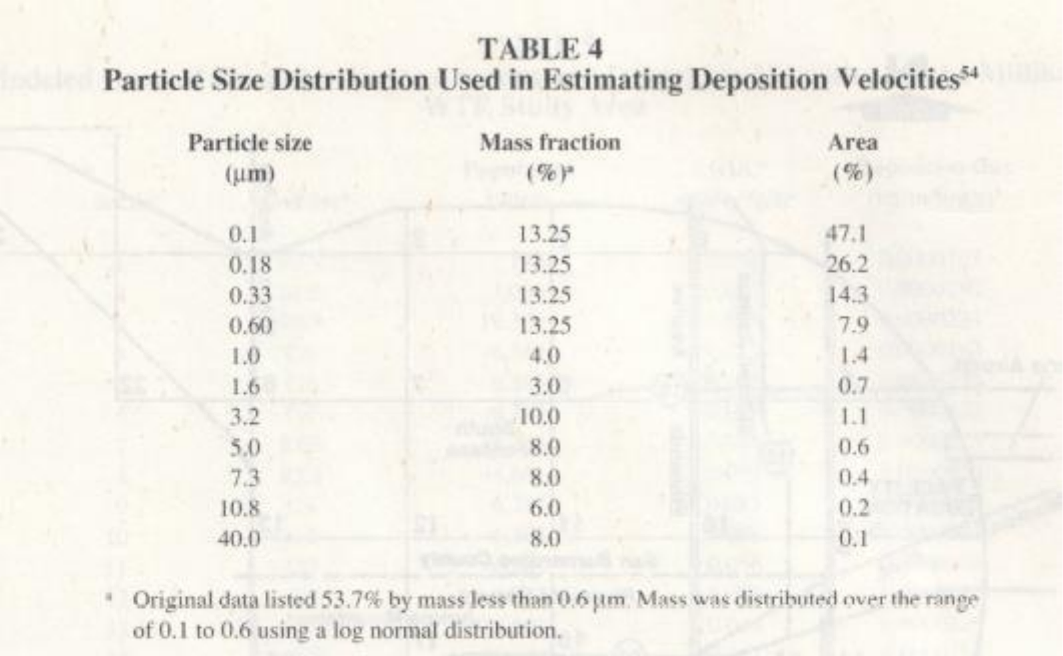


TABLE 4
Particle Size Distribution Used in Estimating Deposition Velocities[54]

Particle size (µm)	Mass fraction (%)[a]	Area (%)
0.1	13.25	47.1
0.18	13.25	26.2
0.33	13.25	14.3
0.60	13.25	7.9
1.0	4.0	1.4
1.6	3.0	0.7
3.2	10.0	1.1
5.0	8.0	0.6
7.3	8.0	0.4
10.8	6.0	0.2
40.0	8.0	0.1

[a] Original data listed 53.7% by mass less than 0.6 µm. Mass was distributed over the range of 0.1 to 0.6 using a log normal distribution.

End of extract.

Additional comments in relation to deposition velocity

The current default deposition velocities adopted by OEHHA (2015), which come from a review by ARM in 1989 are 5 cm/s for uncontrolled facilities and 2 cm/s for facilities with verifiable particulate matter control devices or facilities that only emit $PM_{2.5}$ (e.g. internal combustion engines) (OEHHA 2015).

A more recent review of deposition velocity which includes the Sehmel–Hodgson model discussed above in the extract from Lowe et al. 1991 (Mariraj Mohan 2016), further outlines the complexities in modelling deposition of fine particulates. Deposition velocities listed in this paper from literature for particulates that are predominantly PM_{10} are in the range 0.19 to 8.17 cm/s.

Similarly review by Saylor et al (Saylor et al. 2019) also outlines the complexities. The paper indicates that modelled and measured deposition velocities for PM_{10} typically sit in the range of 1 to 10 cm/s with some variability depending on the method used.

The value adopted for this assessment (2 cm/s or 0.02 m/s) is considered conservative especially where applied to modelled PM_{10} air concentrations and, even more so for $PM_{2.5}$ concentrations. A more realistic high end value is expected to be around 0.6 cm/s.

C3.2 Ingestion and dermal absorption

Chemical substances that are deposited on the ground have the potential to be ingested either directly through accidental consumption of dirt or indirectly through food grown or raised in the soil (fruit and vegetables, eggs, beef and milk) that is subsequently consumed.

The assessment of the potential ingestion of chemical substances has been undertaken using the approach presented by enHealth and the USEPA (enHealth 2012a; USEPA 1989). This approach is presented in the following equation, and parameters adopted in this assessment are presented in **Table C2**:

$$\text{Daily Chemical Intake}_{\text{Ingestion}} = C_M \bullet \frac{IR_M \bullet FI \bullet B \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

Chemical substances that are deposited on the ground have the potential to be absorbed through the skin when skin comes in contact with soil or dust.

The assessment of the potential dermal absorption of chemical substances has been generally undertaken using the approach presented by the USEPA (USEPA 1989, 2004). The USEPA define a simple approach to the evaluation of dermal absorption associated with soil contact. This is presented in the following equation and parameters adopted in this assessment are presented in **Table C2**:

$$\text{Daily Chemical Intake}_{\text{Dermal}} = C_M \bullet \frac{SA \bullet AF \bullet ABSd \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

Table C2: Ingestion and dermal exposure assumptions

Parameter		**Value adopted**		**Basis**
		Young children	**Adults**	
C_M	Concentration of chemical substance in media or relevance (soil [C_S], fruit and vegetables [C_P and C_{RP}], eggs [C_E])(mg/kg)	Modelled based on deposition of particulates to soil (refer to **Section C3.1**), adopting the maximum from all sensitive receptors		Calculations undertaken on the basis of the maximum predicted impacts relevant to areas where multi-pathway exposures may occur
IR_M	Ingestion rate of media			
	Soil (mg/day)	100 mg/day	50 mg/day	Ingestion rate of outdoor soil and dust (tracked or deposited indoors) as per enHealth (enHealth 2012b)
	Fruit and vegetables (kg/day)	0.28 kg/day 85% from aboveground crops 16% from root crops	0.4 kg/day 73% from aboveground crops 27% from root crops	Total fruit and vegetable intakes per day as per ASC NEPM (NEPC 1999 amended 2013b)
	Eggs (kg/day)	0.006 kg/day	0.014 kg/day	Ingestion rate of eggs per day as per enHealth (enHealth 2012b), also consistent with P90 intakes from FSANZ (FSANZ 2017)
FI	Fraction of media ingested derived from impacted media, or fraction of produce consumed each day derived from the property			

Parameter		Value adopted		Basis
		Young children	Adults	
	Soil	100%	100%	Assume all soil contact occurs on the one property
	Fruit and vegetables	10%	10%	Rate assumed for urban areas as per enHealth (enHealth 2012b)
	Eggs	100%	100%	Assume all eggs consumed from the home
B	Bioavailability or absorption of chemical substance via ingestion	100%	100%	Conservative assumption
SA	Surface area of body exposed to soil per day (cm^2/day)	2700	6300	Exposed skin surface area relevant to adults as per ASC NEPM (NEPC 1999 amended 2013b)
AF	Adherence factor, amount of soil that adheres to the skin per unit area which depends on soil properties and area of body (mg/cm^2 per event)	0.5	0.5	Default (conservative) value from ASC NEPM (NEPC 1999 amended 2013b)
ABSd	Dermal absorption fraction (unitless)	Chemical specific		Refer to **Table B2** in **Appendix B**
CF	Conversion factor			
	Soil	$1x10^{-6}$ to convert mg to kg		Conversion of units relevant to soil ingestion and dermal contact
	Produce	1		No units conversion required for these calculations
BW	Body weight	15	70	As per enHealth (enHealth 2012b) and ASC NEPM (NEPC 1999 amended 2013b)
EF	Exposure frequency (days/year)	365	365	Assume residents exposed every day
ED	Exposure duration (years)	6 years	29	Duration of residency as per enHealth (enHealth 2012b) and split between young children and adults as per ASC NEPM (NEPC 1999 amended 2013b)
AT	Averaging time (days)	Threshold = ED x 365 days/year Non-threshold = 70 years x 365 days/year		As per enHealth (enHealth 2012a) guidance

C3.3 Calculation of concentrations in various media

Potential Concentrations in Soil

The potential accumulation of persistent and bioaccumulative chemical substances in soil, which may be the result of deposition from a number of air emissions source, can be estimated using a soil accumulation model (OEHHA 2015; Stevens 1991).

The concentration in soil, which may be the result of deposition following emission of persistent chemical substances, can be calculated using the following equation from Stevens (1991), with assumptions adopted in this assessment presented in **Table C3**.

$$C_s = \frac{DR \cdot [1-e^{-k \cdot t}]}{d \cdot \rho \cdot k} \cdot 1000 \qquad \text{(mg/kg)}$$

Table C3: Assumptions adopted to estimate soil concentrations

Parameter		Value adopted		Basis
		Surface soil*	Agricultural soil*	
DR	Particle deposition rate for accidental release (mg/m^2/year)	Modelled for the facility. Adopted maximum deposition rate for discrete receptors = C_A x DV x 86400 x 365		Relevant to areas where multi-pathway exposures may occur
C_A	Concentration in air (mg/m^3)	As modelled for total dust or PM_{10} (based on an annual average)		
DV	Particle deposition velocity (m/s)	0.02 m/s		Default for the deposition of fine particulates (OEHHA 2015), refer to **Section C3.1**
86400	Conversion from seconds to days	Default conversion of units		
365	Conversion from days to year	Default conversion of units		
k	Chemical-specific soil-loss constant (1/year) = ln(2)/$T^{0.5}$	Calculated	Calculated	
$T^{0.5}$	Chemical half-life in soil (years)	Chemical specific	Chemical specific	Default values adopted for pollutants as per OEHHA (2015)
t	Accumulation time (years)	70 years	70 years	Default value (OEHHA 2015)
d	Soil mixing depth (m)	0.01 m	0.15 m	Default values (OEHHA 2015)
ρ	Soil bulk-density (g/m^3)	1,600,000	1,600,000	Default for fill material (CRC CARE 2011)
1000	Conversion from g to kg	Default conversion of units		

* Surface soil values adopted for the assessment of direct contact exposures. All other exposures including produce intakes utilise soil concentrations calculated for agricultural intakes (OEHHA 2015)

Homegrown fruit and vegetables

Plants may become contaminated with persistent chemical substances where particles with those chemicals attached deposit directly onto the plant outer surface or onto the soil in which the plants are grown and where the chemical can then be taken up via the root system. Both mechanisms have been assessed.

The potential concentration of persistent chemical substances that may be present within the plant following atmospheric deposition can be estimated using the following equation (Stevens 1991), with the parameters and assumptions adopted outlined in **Table C4**:

$$C_p = \frac{DR \cdot F \cdot [1-e^{-k \cdot t}]}{Y \cdot k} \qquad \text{(mg/kg plant – wet weight)}$$

The potential uptake of persistent chemical substances into edible crops via the roots can be estimated using the following equation (OEHHA 2015; USEPA 2005), with the parameters and assumptions adopted outlined in **Table C4:**

$$C_{rp} = C_s \cdot RUF \qquad \text{(mg/kg plant – wet weight)}$$

Table C4: Assumptions adopted to estimate concentration in fruit and vegetables

Parameter		Value adopted	Basis
DR	Particle deposition rate for accidental release (mg/m^2/day)	Modelled for the facility. Adopted maximum deposition rate for discrete receptors	Relevant to areas where multi-pathway exposures may occur
F	Fraction for the surface area of plant (unitless)	0.051	Relevant to aboveground exposed crops as per Stevens (1991) and OEHHA (OEHHA 2012)
k	Chemical-specific loss constant for particles on plants (1/days) = ln(2)/$T^{0.5}$	calculated	
$T^{0.5}$	Chemical half-life on plant (day)	14 days	Weathering of particulates on plant surfaces does occur and in the absence of measured data, it is generally assumed that organics deposited onto the outer portion of plant surfaces have a weathering half life of 14 days (Stevens, 1991)
t	Deposition time or length of growing season (days)	70 days	Relevant to aboveground crops based on the value relevant to tomatoes, consistent with the value adopted by Stevens (1991)
Y	Crop yield (kg/m^2)	2 kg/m^2	Value for aboveground crops (OEHHA 2015)
Cs	Concentration of pollutant in soil (mg/kg)	Calculated value for agricultural soil	Calculated as described above and assumptions in **Table B6**
RUF	Root uptake factor (unitless)	Chemical specific value adopted	Root uptake factors from RAIS (RAIS) (soil to wet weight of plant), with the exception of the values adopted for mercury, where the higher (most conservative) value from the UK EA evaluation has been adopted for inorganic and methylmercury (UK EA 2009)

Eggs

The concentration of bioaccumulative pollutants in animal products is calculated on the basis of the intakes of these pollutants by the animal (chicken or cow) and the transfer of these pollutants to the edible produce. The approach adopted in this assessment has involved calculation of intakes from pasture, assumed to be grown on the property, and soil.

The concentration (C_P) calculated in eggs is calculated using the following equation (OEHHA 2015), with parameters and assumptions adopted presented in **Table C5**:

$$C_P = (FI \times IR_C \times C + IR_S \times C_s \times B) \times TF_P$$

Where P = E for eggs

Table C5: Assumptions adopted to estimate concentration in eggs

Parameter		Value adopted	Basis
FI	Fraction of grain/crop ingested by animals each day derived from the property (unitless)	100%	Assume all pasture/crops ingested by chickens are grown on the property
IR_C	Ingestion rate of pasture/crops by animal (kg/day)		
	Chickens	0.12 kg/day	Ingestion rate from OEHHA (2015)
C	Concentration of pollutant in crops consumed by animals (mg/kg)	Assume equal to that calculated in aboveground produce	Calculated as described above with assumptions in **Table C3**
IR_S	Ingestion rate of soil by animals each day (kg/day)		
	Chickens	0.01 kg/day	As per OEHHA (2015) and advice from Ag Vic
C_S	Concentration of pollutant in soil (mg/kg)	Calculated value for agricultural soil	Calculated as described above and assumptions in **Table C2**
B	Bioavailability of soil ingested (unitless)	100%	Conservative assumption
TF_P	Transfer factor for the produce of interest		
	Eggs	Chemical specific	Transfer factors adopted from OEHHA (2015)

Rainwater tanks

The concentration in rainwater tanks depends on the deposition rate of dust, the size of the roof, the volume of rainfall each year and how much of the rain that falls onto the roof is captured in the tank. When dust is deposited onto a roof, some will be remobilised into air (wind) and blown off the roof before it can be washed into the tank. This mechanism which may reduce the amount of dust present on a roof that could wash into the tank has not been considered in this assessment.

In addition, health authorities[12] recommends the use of first flush devices to minimise the movement of accumulated dust, bird droppings and organic matter into the tank. These can affect water quality (contamination and bacterial load). The use of a first-flush device has not been considered in this assessment as it is unknown if there are relevant tanks in the area or if they use such a device. For rainwater tanks used for drinking water purposes, it is expected that these tanks would be maintained appropriately, in line with guidance from health authorities (enHealth 2010). Such maintenance includes the regular cleaning to remove accumulated sediments, maintaining roof materials, gutters and tank inlet, use of first-flush devices and disinfection. The proper maintenance of rainwater tanks (specifically the cleaning out of sediments) would further reduce concentrations below those estimated in this assessment.

Based on mass balance modelling undertaken on rainwater tanks with first flush devices (Martinson & Thomas 2009) and measurements conducted in Australia (Kus et al. 2010), first-flush devices can reduce concentrations of contaminants from dust washing into a rainwater tank by 90% or more.

---

[12] https://www.health.nsw.gov.au/environment/water/Documents/rainwater_tanks.pdf;
https://www.health.qld.gov.au/__data/assets/pdf_file/0025/444427/factsheet-rainwater.pdf;
https://www.health.qld.gov.au/__data/assets/pdf_file/0020/444323/rainwatertanks.pdf
https://www.health.vic.gov.au/water/rainwater

The concentrations in a rainwater tank (used for household purposes) in this assessment have been calculated as follows, where the parameters adopted for this assessment are detailed in **Table C6**:

$$C_W = \frac{DM}{VR \times Kd \times \rho}$$

$$VR = \frac{R \times Area \times Rc \times 1000}{1000}$$

Table C6: Assumptions adopted to estimate concentration in rainwater tanks

Parameter		Value adopted	Basis
DM	Mass of dust deposited on the roof each year that would enter the tank (mg)	DR x Area x 1 year	
DR	Particle deposition rate (mg/m^2/year)	Calculated for the maximum receptor	Relevant to areas where multi-pathway exposures may occur
Area	Area of the roof (m^2)	200	Based on the average roof size for a 4 bedroom house in Australia (refer to Footnote 1)
VR	Volume of water collected from the roof each year (L)	calculated	Equation as above
R	Rainfall each year (mm)	533.6	Average rainfall at Laverton RAAF Met Station for all years of records (1941 – 2022). No first flush device is considered; hence all rainfall is considered
Rc	Runoff coefficient	0.7	Assumes 30% loss in capture of water into the tank (Lizárraga-Mendiola et al. 2015)
1000	Conversion from m^3 to L Conversion from mm to m		
Kd	Soil-water partition coefficient (cm^3/g)	Chemical-specific	All values from RAIS (RAIS)
ρ	Soil bulk density (g/cm^3)	0.5	Assumed for loose deposited dust on roof (upper end measured for powders)

1 - https://www.nedlands.wa.gov.au/sites/default/files/Rainwater%20tank%20factsheet.pdf

All calculations relevant to the estimation of pollutant concentrations in water, soil, fruit and vegetables as well as animal products (eggs) are presented in **Appendix D**.

Appendix D Risk calculations

Maximum sensitive receptor

Inhalation exposures

Inhalation - gases and particulates - Residential (i.e. maximum sensitive receptor location)

$$InhalationExposureConc_V = C_a \bullet \frac{ET \bullet FI \bullet EF \bullet ED}{AT} \qquad (mg/m^3)$$

Parameters Relevant to Quantification of Community Exposures - Residents		
Exposure Time at Home (ET, hr/day)	24	Assume residents at home or on property 24 hours per day
Fraction Inhaled from Source (FI, unitless)	1	Assume resident at the same property
Exposure Frequency - normal conditions (EF, days/yr)	365	Days at home (normal conditions), as per NEPM (1999 amended 2013)
Exposure Duration (ED, years)	35	As per NEPM (1999 amended 2013)
Averaging Time - NonThreshold (Atc, hours)	613200	US EPA 2009
Averaging Time - Threshold (Atn, hours)	306600	US EPA 2009

Key Chemical	Toxicity Data				Concentration	Daily Exposure		Calculated Risk			
	Inhalation Unit Risk $(mg/m^3)^{-1}$	**Chronic TC Air** (mg/m^3)	**Background Intake (% Chronic TC)**	**Chronic TC Allowable for Assessment (TC-Background)** (mg/m^3)	**Estimated Concentration in Air - Maximum anywhere (Ca)** (mg/m^3)	**Inhalation Exposure Concentration -** NonThreshold (mg/m^3)	**Inhalation Exposure Concentration -** Threshold (mg/m^3)	**Non-Threshold Risk** (unitless)	**% Total Risk**	**Chronic Hazard Quotient** (unitless)	**% Total HI**
Hydrogen chloride (HCl)		2.6E-02	0%	2.6E-02	1.2E-06	6.0E-07	1.2E-06	--		0.0000462	4%
Hydrogen fluoride (HF)		2.9E-02	0%	2.9E-02	2.1E-07	1.1E-07	2.1E-07	--		0.00000724	1%
Ammonia		3.2E-01	0%	3.2E-01	2.1E-06	1.1E-06	2.1E-06	--		0.00000656	1%
Cadmium (and thallium)		5.0E-06	20%	4.0E-06	3.9E-09	2.0E-09	3.9E-09	--		0.000975	92%
Mercury (as inorganic and elemental)		2.0E-04	10%	1.8E-04	3.9E-09	2.0E-09	3.9E-09	--		0.0000217	2%
Dioxin-like compounds		8.1E-09	54%	3.7E-09	1.7E-14	8.5E-15	1.7E-14	--		0.00000459	0%
							TOTAL	**0.0E+00**		**0.00106**	

Multi-pathway exposures for maximum sensitive receptor

Soil exposures

Calculation of Concentrations in Soil

$$C_s = \frac{DR \bullet \left[1 - e^{-k \bullet t}\right]}{d \bullet \rho \bullet k} \bullet 1000$$ **(mg/kg)** ref: Stevens B. (1991)

where:

DR= Particle deposition rate (mg/m^2/year)
K = Chemical-specific soil-loss constant (1/year) = ln(2)/T0.5
T0.5 = Chemical half-life in soil (years)
t = Accumulation time (years)
d = Soil mixing depth (m)
ρ = Soil bulk-density (g/m^3)
1000 = Conversion from g to kg

General Parameters		**Surface (for direct contact)**	**Depth (for agricultural pathways)**	
Soil bulk density (p)	g/m^3	1600000	1600000	Default for fill materials
General mixing depth (d)	m	0.01	0.15	As per OEHHA (2015) guidance
Duration of deposition (T)	years	70	70	As per OEHHA (2015) guidance

Chemical-specific Inputs and calculations - maximum receptors

Chemical	**Half-life in soil**	**Loss constant (K)**	**Deposition Rate (DR)**	**Surface Concentration in Soil**	**Agricultural Concentration in Soil**
	years	**per year**	**mg/m^2/year**	**mg/kg**	**mg/kg**
Cadmium (and thallium)	273973	2.5E-06	2.5E-03	1.1E-02	7.2E-04
Mercury (as inorganic and eleme	273973	2.5E-06	2.5E-03	1.1E-02	7.2E-04
Dioxin-like compounds	15.00	4.6E-02	1.1E-08	1.4E-08	9.3E-10

Half-life in soil for dioxins: 9-15 years in surface soils; 25-100 years in subsurface soils (ATSDR 1998, DEH 2004)
Half-life in soil for metals: OEHHA 2015

Exposure to Chemicals via Incidental Ingestion of Soil

$$Daily\ Chemical\ Intake_{IS} = C_S \bullet \frac{IR_S \bullet FI \bullet CF \bullet B \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Adults		
Ingestion Rate (IRs, mg/day)	50	ASC NEPM (residential landuse)
Fraction Ingested from Source (FI, unitless)	100%	All of daily soil intake occurs from site
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	29	Time at one residence as adult as per ASC NEPM
Body Weight (BW, kg)	70	For male and females combined (ASC NEPM)
Conversion Factor (CF)	1.00E-06	conversion from mg to kg
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	10585	ASC NEPM

Key Chemical	**Toxicity Data**				**Bioavailability (%)**	**Soil Concentration** (mg/kg)	**Daily Intake**		**Calculated Risk**			
	Non-Threshold Slope Factor (mg/kg-day)$^{-1}$	**Threshold TDI** (mg/kg/day)	**Background Intake (% TDI)**	**TDI Allowable for Assessment (TDI-Background)** (mg/kg/day)			**NonThreshold** (mg/kg/day)	**Threshold** (mg/kg/day)	**Non-Threshold Risk** (unitless)	**% Total Risk**	**Chronic Hazard Quotient** (unitless)	**% Total HI**
Cadmium (and thallium)		8.0E-04	60%	3.2E-04	100%	1.1E-02	3.2E-09	7.7E-09	--		0.0000240	44%
Mercury (as inorganic and e		6.0E-04	40%	3.6E-04	100%	1.1E-02	3.2E-09	7.7E-09	--		0.0000214	39%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	100%	1.4E-08	4.1E-15	1.0E-14	--		0.00000941	17%
								TOTAL			**0.0000548**	

Exposure to Chemicals via Incidental Ingestion of Soil

$$Daily\ Chemical\ Intake_{IS} = C_S \bullet \frac{IR_S \bullet FI \bullet CF \bullet B \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Young Children

Ingestion Rate (IRs, mg/day)	100	ASC NEPM (residential land use)
Fraction Ingested from Source (FI, unitless)	100%	All of daily soil intake occurs from site
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	6	Duration as young child
Body Weight (BW, kg)	15	Representative weight as per ASC NEPM
Conversion Factor (CF)	1.00E-06	conversion from mg to kg
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	2190	ASC NEPM

	Toxicity Data						Daily Intake		Calculated Risk			
Key Chemical	**Non-Threshold Slope Factor** (mg/kg-day)$^{-1}$	**Threshold TDI** (mg/kg/day)	**Background Intake (% TDI)**	**TDI Allowable for Assessment (TDI-Background)** (mg/kg/day)	**Bioavailability (%)**	**Soil Concentration** (mg/kg)	**NonThreshold** (mg/kg/day)	**Threshold** (mg/kg/day)	**Non-Threshold Risk** (unitless)	**% Total Risk**	**Chronic Hazard Quotient** (unitless)	**% Total HI**
Cadmium (and thallium)		8.0E-04	60%	3.2E-04	100%	1.1E-02	6.1E-09	7.2E-08	--		0.000224	44%
Mercury (as inorganic and e		6.0E-04	40%	3.6E-04	100%	1.1E-02	6.1E-09	7.2E-08	--		0.000199	39%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	100%	1.4E-08	8.0E-15	9.3E-14	--		0.0000878	17%
								TOTAL			**0.000511**	

Dermal Exposure to Chemicals via Contact with Soil

$$Daily\ Chemical\ Intake_{DS} = C_S \bullet \frac{SA_S \bullet AF \bullet FE \bullet ABS \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \qquad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Adults		
Surface Area (SAs, cm^2)	6300	Exposed skin surface area for adults as per ASC NEPM
Adherence Factor (AF, mg/cm^2)	0.5	Default as per ASC NEPM
Fraction of Day Exposed	1	Assume skin is washed after 24 hours
Conversion Factor (CF)	1.E-06	Conversion of units
Dermal absorption (ABS, unitless)	Chemical-specific (as below)	
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	29	Time at one residence as adult as per ASC NEPM
Body Weight (BW, kg)	70	For male and females combined (ASC NEPM)
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	10585	ASC NEPM

Maximum measured scenario

Key Chemical	Toxicity Data					Soil Concentration (mg/kg)	Daily Intake		Calculated Risk			
	Non-Threshold Slope Factor $(mg/kg\text{-}day)^{-1}$	Threshold TDI (mg/kg/day)	Background Intake (% TDI)	TDI Allowable for Assessment (TDI-Background) (mg/kg/day)	Dermal Absorption (ABS)		Non-Threshold (mg/kg/day)	Threshold (mg/kg/day)	Non-Threshold Risk (unitless)	% Total Risk	Chronic Hazard Quotient (unitless)	% Total HI
Cadmium (and thallium)		8.0E-04	60%	3.2E-04		1.1E-02			--		--	
Mercury (as inorganic and elem		4.2E-05	40%	2.5E-05	0.001	1.1E-02	2.0E-10	4.8E-10	--		0.0000192	52%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	0.03	1.4E-08	7.8E-15	1.9E-14	--		0.0000178	48%
								TOTAL			**0.0000370**	

Dermal Exposure to Chemicals via Contact with Soil

$$\text{Daily Chemical Intake}_{DS} = C_S \bullet \frac{SA_S \bullet AF \bullet FE \bullet ABS \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \qquad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Young Children		
Surface Area (SAs, cm^2)	2700	Exposed skin surface area for young children as per ASC NEPM
Adherence Factor (AF, mg/cm^2)	0.5	Default as per ASC NEPM
Fraction of Day Exposed	1	Assume skin is washed after 24 hours
Conversion Factor (CF)	1.E-06	Conversion of units
Dermal absorption (ABS, unitless)	Chemical-specific (as below)	
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	6	Duration as young child (ASC NEPM)
Body Weight (BW, kg)	15	Representative weight as per ASC NEPM
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	2190	ASC NEPM

Key Chemical	**Toxicity Data**					**Soil Concentration**	**Daily Intake**		**Calculated Risk**			
	Non-Threshold Slope Factor $(mg/kg\text{-}day)^{-1}$	**Threshold TDI** (mg/kg/day)	**Background Intake (% TDI)**	**TDI Allowable for Assessment (TDI-Background)** (mg/kg/day)	**Dermal Absorption (ABS)**	(mg/kg)	**Non-Threshold** (mg/kg/day)	**Threshold** (mg/kg/day)	**Non-Threshold Risk** (unitless)	**% Total Risk**	**Chronic Hazard Quotient** (unitless)	**% Total HI**
Cadmium (and thallium)		8.0E-04	60%	3.2E-04		1.1E-02			--		--	
Mercury (as inorganic and elem		4.2E-05	40%	2.5E-05	0.001	1.1E-02	8.3E-11	9.7E-10	--		0.0000384	52%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	0.03	1.4E-08	3.2E-15	3.8E-14	--		0.0000356	48%
								TOTAL			**0.0000740**	

Homegrown fruit and vegetables

Calculation of Concentrations in Plants

ref: Stevens B. (1991)

Uptake Due to Deposition in Aboveground Crops

$$C_p = \frac{DR \bullet F \bullet \left[1 - e^{-k \bullet t}\right]}{Y \bullet k}$$ (mg/kg plant – wet weight)

where:

DR= Particle deposition rate for accidental release (mg/m^2/day)
F= Fraction for the surface area of plant (unitless)
k= Chemical-specific soil-loss constant (1/years) = ln(2)/$T_{0.5}$
$T_{0.5}$= Chemical half-life as particulate on plant (days)
t= Deposition time (days)
Y= Crop yield (kg/m^2)

Uptake via Roots from Soil

$$C_{rp} = C_s \bullet RUF$$ (mg/kg plant – wet weight)

where:

Cs = Concentration of persistent chemical in soil assuming 15cm mixing depth within gardens, calculated using Soil Equation for each chemical assessed (mg/kg)
RUF = Root uptake factor which differs for each Chemical (unitless)

General Parameters	Units	Value
Crop		Edible crops
Crop Yield (Y)	kg/m^2	2
Deposition Time (t)	days	70
Plant Interception fraction (F)	unitless	0.051

Chemical-specific Inputs and calculations - Maximum receptor

Chemical	Half-life in plant ($T_{0.5}$) days	Loss constant (k) per day	Deposition Rate (DR) mg/m^2/day	Aboveground Produce Concentration via Deposition onto plants mg/kg ww	Root Uptake Factor (RUF) unitless	Soil Concentration (Cs) (agricultural) mg/kg	Below Ground Produce Concentration mg/kg ww
Cadmium (and thallium)	14	0.05	6.7E-06	3.4E-06	0.125	7.2E-04	9.0E-05
Mercury (as inorganic and eleme	14	0.05	6.7E-06	3.4E-06	0.225	7.2E-04	1.6E-04
Dioxin-like compounds	14	0.05	2.9E-11	1.5E-11	0.000876	9.3E-10	8.1E-13

Root uptake factors from RAIS (soil to wet weight of plant)

Exposure to Chemicals via Ingestion of Homegrown Fruit and Vegetables

$$\text{Daily chemical intake} = C_A \times \frac{IR_P \times \%A \times FI \times ME \times EF \times ED}{BW \times AT} + C_R \times \frac{IR_p \times \%R \times FI \times ME \times ED \times ED}{BW \times AT} \qquad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Adults		
Ingestion Rate of Produce (IRp) (kg/day)	0.4	Total fruit and vegetable consumption rate for adults as per ASC NEPM
Proportion of total intake from aboveground crops (%A	73%	Proportions as per ASC NEPM
Proportion of total intake from root crops (%R)	27%	Proportions as per ASC ENPM
Fraction ingested that is homegrown (%)	10%	Relevant to urban areas as per ASC NEPM
Matrix effect (unitless)	1	Assume chemicals ingested in produce is 100% bioavailable
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	29	Time at one residence as adult as per ASC NEPM
Body Weight (BW, kg)	70	For male and females combined (ASC NEPM)
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	10585	ASC NEPM

Key Chemical	**Toxicity Data**				**Bioavailability (%)**	**Above ground produce concentration**	**Root crops concentrations**	**Daily Intake**		**Calculated Risk**			
	Non-Threshold Slope Factor $(mg/kg\text{-}day)^{-1}$	**Threshold TDI** (mg/kg/day)	**Background Intake (% TDI)**	**TDI Allowable for Assessment (TDI-Background)** (mg/kg/day)		(mg/kg wet weight)	(mg/kg wet weight)	**NonThreshold** (mg/kg/day)	**Threshold** (mg/kg/day)	**Non-Threshold Risk** (unitless)	**% Total Risk**	**Chronic Hazard Quotient** (unitless)	**% Total HI**
Cadmium (and thallium)		8.0E-04	60%	3.2E-04	100%	3.4E-06	8.97E-05	6.3E-09	1.5E-08	--		0.0000476	38%
Mercury (as inorganic and element		6.0E-04	40%	3.6E-04	100%	3.4E-06	1.61E-04	1.1E-08	2.6E-08	--		0.0000731	58%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	100%	1.5E-11	8.14E-13	2.6E-15	6.2E-15	--		0.00000590	5%
									TOTAL			**0.000127**	

Exposure to Chemicals via Ingestion of Homegrown Fruit and Vegetables

$$\text{Daily chemical intake} = C_A \times \frac{IR_P \times \%A \times FI \times ME \times EF \times ED}{BW \times AT} + C_R \times \frac{IR_P \times \%R \times FI \times ME \times ED \times ED}{BW \times AT} \quad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Young children		
Ingestion Rate of Produce (IRp) (kg/day)	0.28	Total fruit and vegetable consumption rate for children as per ASC NEPM
Proportion of total intake from aboveground crops (%A	84%	Proportions as per ASC NEPM
Proportion of total intake from root crops (%R)	16%	Proportions as per ASC NEPM
Fraction ingested that is homegrown (%)	10%	Relevant to urban areas as per ASC NEPM
Matrix effect (unitless)	1	Assume chemicals ingested in produce is 100% bioavailable
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	6	Duration as young child (ASC NEPM)
Body Weight (BW, kg)	15	Representative weight as per ASC NEPM
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	2190	ASC NEPM

Key Chemical	Toxicity Data				Bioavailability (%)	Above ground produce concentration	Root crops concentrations	Daily Intake		Calculated Risk			
	Non-Threshold Slope Factor (mg/kg-day)$^{-1}$	Threshold TDI (mg/kg/day)	Background Intake (% TDI)	TDI Allowable for Assessment (TDI-Background) (mg/kg/day)		(mg/kg wet weight)	(mg/kg wet weight)	NonThreshold (mg/kg/day)	Threshold (mg/kg/day)	Non-Threshold Risk (unitless)	% Total Risk	Chronic Hazard Quotient (unitless)	% Total HI
Cadmium (and thallium)		8.0E-04	60%	3.2E-04	100%	3.4E-06	8.97E-05	2.7E-09	3.2E-08	--		0.000100	37%
Mercury (as inorganic and element		6.0E-04	40%	3.6E-04	100%	3.4E-06	1.61E-04	4.6E-09	5.3E-08	--		0.000149	55%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	100%	1.5E-11	8.14E-13	2.0E-15	2.3E-14	--		0.0000220	8%
									TOTAL			0.000271	

Ingestion of eggs

Calculation of Concentrations in Eggs

Uptake in to chicken eggs

$$C_E = (FI \times IR_C \times C + IR_S \times C_S \times B) \times TF_E$$ (mg/kg egg – wet weight)

where:
FI = Fraction of pasture/crop ingested by chickens each day (unitless)
IRc = Ingestion rate of pasture/crop by chicken each day (kg/day)
C = Concentration of chemical in grain/crop eaten by chicken (mg/kg)
IRs = Ingestion rate of soil by chickens each day (kg/day)
Cs = Concentration in soil the chickens ingest (mg/kg)
B = Bioavailability of soil ingested by chickens (%)
TFE = Transfer factor from ingestion to eggs (day/kg)

General Parameters	Units	Value	
FI (fraction of crops ingested from property)		1	Assume 100% of crops consumed by chickens is grown in the same soil
IRc (ingestion rate of crops)	kg/day	0.12	Assumed ingestion rate from OEHHA 2015 (assume concentration the same as predicted for aboveground crops)
IRs (ingestion rate of soil)	kg/day	0.0024	Based on data from OEHHA 2015 (2% total produce intakes from soil)
B (bioavailability)	%	100%	

Chemical-specific Inputs and calculations - maximum measured scenario

Chemical	Concentration in crops ingested by chickens mg/kg ww	Soil Concentration - Agriculture (Cs) mg/kg	Transfer factor to eggs day/kg	Egg Concentration mg/kg ww
Cadmium (and thallium)	3.4E-06	7.2E-04	1.0E-02	2.1E-08
Mercury (as inorganic and elementa	3.4E-06	7.2E-04	8.0E-01	1.7E-06
Dioxin-like compounds	1.5E-11	9.3E-10	1.0E+01	4.0E-11

Transfer factors from OEHHA 2015 unless otherwise noted

Exposure to Chemicals via Ingestion of Eggs

$$\text{Daily chemical intake} = C_E \times \frac{IR_E \times FI \times ME \times EF \times ED}{BW \times AT}$$

(mg/kg/day)

Parameters Relevant to Quantification of Exposure by Adults		
Ingestion Rate of Eggs (IRE) (kg/day)	0.014	Ingestion rate of eggs relevant for adults as per ASC NEPM
Fraction ingested that is homegrown (%)	100%	Assume all eggs consumed in urban area are from backyard chickens
Matrix effect (unitless)	1	Assume chemicals ingested in produce is 100% bioavailable
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	29	Time at one residence as adult as per ASC NEPM
Body Weight (BW, kg)	70	For male and females combined (ASC NEPM)
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	10585	ASC NEPM

Key Chemical	Toxicity Data				Bioavailability (%)	Egg concentration	Daily Intake		Calculated Risk			
	Non-Threshold Slope Factor (mg/kg-day)$^{-1}$	Threshold TDI (mg/kg/day)	Background Intake (% TDI)	TDI Allowable for Assessment (TDI-Background) (mg/kg/day)		(mg/kg wet weight)	NonThreshold (mg/kg/day)	Threshold (mg/kg/day)	Non-Threshold Risk (unitless)	% Total Risk	Chronic Hazard Quotient (unitless)	% Total HI
Cadmium (and thallium)		8.0E-04	60%	3.2E-04	100%	2.13E-08	1.8E-12	4.3E-12	--		0.0000000133	0%
Mercury (as inorganic and element		6.0E-04	40%	3.6E-04	100%	1.70E-06	1.4E-10	3.4E-10	--		0.000000945	11%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	100%	3.99E-11	3.3E-15	8.0E-15	--		0.00000754	89%
								TOTAL			**0.00000850**	

Exposure to Chemicals via Ingestion of Eggs

$$\text{Daily chemical intake} = C_E \times \frac{IR_E \times FI \times ME \times EF \times ED}{BW \times AT} \quad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Young children		
Ingestion Rate of Eggs (IRE) (kg/day)	0.006	Ingestion rate of eggs relevant for young children as per ASC NEPM
Fraction ingested that is homegrown (%)	100%	Assume all eggs consumed in urban area are from backyard chickens
Matrix effect (unitless)	1	Assume chemicals ingested in produce is 100% bioavailable
Exposure Frequency (EF, days/year)	365	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	6	Duration as young child (ASC NEPM)
Body Weight (BW, kg)	15	Representative weight as per ASC NEPM
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	2190	ASC NEPM

Key Chemical	Toxicity Data				Bioavailability (%)	Egg concentration (mg/kg wet weight)	Daily Intake		Calculated Risk			
	Non-Threshold Slope Factor (mg/kg-day)$^{-1}$	Threshold TDI (mg/kg/day)	Background Intake (% TDI)	TDI Allowable for Assessment (TDI-Background) (mg/kg/day)			NonThreshold (mg/kg/day)	Threshold (mg/kg/day)	Non-Threshold Risk (unitless)	% Total Risk	Chronic Hazard Quotient (unitless)	% Total HI
Cadmium (and thallium)		8.0E-04	60%	3.2E-04	100%	2.13E-08	7.3E-13	8.5E-12	--		0.0000000266	0%
Mercury (as inorganic and element		6.0E-04	40%	3.6E-04	100%	1.70E-06	5.8E-11	6.8E-10	--		0.00000189	11%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	100%	3.99E-11	1.4E-15	1.6E-14	--		0.0000151	89%
								TOTAL			**0.0000170**	

Rainwater tanks

Calculation of Concentrations in Rainwater tank

$CW = DM/(VR*Kd*\rho)$ (mg/L)

where:

DM = Mass of dust deposited on roof each year that enters tank (mg) = DR x Area x 0.1 x 1 year
DR = Deposition rate from model for TSP (mg/m^2/year)
Area = Area of roof (m^2)
VR = Volume of water collected from roof over year (L) = (R x Area x Rc x 1000)/1000
R = Rainfall each year (mm)
ρ = Soil bulk-density (g/cm^3)
Rc = Runoff coefficient (unitless)
Kd = Soil-water partition coefficient (cm^3/g)
1000 = Conversion from mm to m; and conversion from m^3 to L

General Parameters			
Average rainfall (R)	mm	533.6	mean for all years (1941-2022) for Laverton RAAF station (087031)
Roof area (Area)	m^2	200	4 bedroom australian home
Runoff coefficient (Rc)	-	0.7	assumes 30% loss in capture into tank
Volume of rainwater (VR)	m3/year	74.704	calculated
Volume of rainwater (VR)	L	74704	calculated
Bulk density of deposited dust	g/cm^3	0.5	assumed for loose deposited dust on roof (similar to upper end measured for powders)

Chemical-specific Inputs and calculations - maximum receptor

Chemical	Deposited dust entering tank		Kd	Particulate Concentration in water	Dissolved Concentration in water	Total (particulate and dissolved) - worst-case
	Deposition Rate TSP (DR) mg/m^2/year	Mass deposited each year into tank (DM) mg	(cm^3/g)	mg/L	mg/L	mg/L
Cadmium (and thallium)	2.5E-03	4.92E-02	75	6.6E-07	1.8E-08	6.8E-07
Mercury (as inorganic and eleme	2.5E-03	4.92E-02	52	6.6E-07	2.5E-08	6.8E-07
Dioxin-like compounds	1.1E-08	2.14E-07	63100	2.9E-12	9.1E-17	2.9E-12

Kd for dioxins and furans based on Log Koc of 6.8 and 1% organic carbon (0.01 Foc), Kd = Koc x Foc

Drininking water guideline mg/L	Proportion of DWG Particulate	Proportion of DWG Dissolved
0.002	0.03%	0.0009%
0.001	0.07%	0.0025%
1.60E-08	0.02%	0.0000006%

Workers at grid maximum

Inhalation exposures

Inhalation - gases and particulates - worker (i.e. grid maximum location)

$$InhalationExposureConc_V = C_a \bullet \frac{ET \bullet FI \bullet EF \bullet ED}{AT} \qquad (mg/m^3)$$

Parameters Relevant to Quantification of Community Exposures - Commercial/Industrial		
Exposure Time at Home (ET, hr/day)	8	Workers present for 8 hours per day as per enHealth (2012)
Fraction Inhaled from Source (FI, unitless)	1	Assume workers at the same location each day
Exposure Frequency - normal conditions (EF, days/yr)	240	Days at work (normal conditions), as per NEPM (1999 amended 2013)
Exposure Duration (ED, years)	30	As per NEPM (1999 amended 2013)
Averaging Time - NonThreshold (Atc, hours)	613200	As per NEPM (1999 amended 2013)
Averaging Time - Threshold (Atn, hours)	262800	As per NEPM (1999 amended 2013)

	Toxicity Data				**Concentration**	**Daily Exposure**		**Calculated Risk**			
Key Chemical	**Inhalation Unit Risk** (mg/m^3)$^{-1}$	**Chronic TC Air** (mg/m^3)	**Background Intake (% Chronic TC)**	**Chronic TC Allowable for Assessment (TC-Background)** (mg/m^3)	**Estimated Concentration in Air - Maximum anywhere (Ca)** (mg/m^3)	**Inhalation Exposure Concentration -** NonThreshold (mg/m^3)	**Inhalation Exposure Concentration -** Threshold (mg/m^3)	**Non-Threshold Risk** (unitless)	**% Total Risk**	**Chronic Hazard Quotient** (unitless)	**% Total HI**
Hydrogen chloride (HCl)		2.6E-02	0%	2.6E-02	4.0E-05	3.8E-06	8.8E-06	--		0.000337	4%
Hydrogen fluoride (HF)		2.9E-02	0%	2.9E-02	7.0E-06	6.6E-07	1.5E-06	--		0.0000529	1%
Ammonia		3.2E-01	0%	3.2E-01	7.0E-05	6.6E-06	1.5E-05	--		0.0000479	1%
Cadmium (and thallium)		5.0E-06	20%	4.0E-06	1.4E-07	1.3E-08	3.1E-08	--		0.00767	92%
Mercury (as inorganic and elemental)		2.0E-04	10%	1.8E-04	1.4E-07	1.3E-08	3.1E-08	--		0.000170	2%
Dioxin-like compounds		8.1E-09	54%	3.7E-09	5.6E-13	5.3E-14	1.2E-13	--		0.0000331	0%
							TOTAL	**0.0E+00**		**0.00831**	

Direct contact with soil

Calculation of Concentrations in Soil

$$C_s = \frac{DR \bullet \left[1 - e^{-k \bullet t}\right]}{d \bullet \rho \bullet k} \bullet 1000$$ **(mg/kg)** ref: Stevens B. (1991)

where:

DR= Particle deposition rate (mg/m^2/year)

K = Chemical-specific soil-loss constant (1/year) = ln(2)/T0.5

T0.5 = Chemical half-life in soil (years)

t = Accumulation time (years)

d = Soil mixing depth (m)

ρ = Soil bulk-density (g/m^3)

1000 = Conversion from g to kg

General Parameters		**Surface (for direct contact)**	**Depth (for agricultural pathways)**	
Soil bulk density (p)	g/m^3	1600000	1600000	Default for fill materials
General mixing depth (d)	m	0.01	0.15	As per OEHHA (2015) guidance
Duration of deposition (T)	years	70	70	As per OEHHA (2015) guidance

Chemical-specific Inputs and calculations - grid maximum

Chemical	**Half-life in soil**	**Loss constant (K)**	**Deposition Rate (DR)**	**Surface Concentration in Soil**	**Agricultural Concentration in Soil**
	years	**per year**	**mg/m^2/year**	**mg/kg**	**mg/kg**
Cadmium (and thallium)	273973	2.5E-06	8.8E-02	3.9E-01	2.6E-02
Mercury (as inorganic and eleme	273973	2.5E-06	8.8E-02	3.9E-01	2.6E-02
Dioxin-like compounds	15.00	4.6E-02	3.5E-07	4.6E-07	3.1E-08

Half-life in soil for dioxins: 9-15 years in surface soils; 25-100 years in subsurface soils (ATSDR 1998, DEH 2004)
Half-life in soil for metals: OEHHA 2015

Exposure to Chemicals via Incidental Ingestion of Soil

$$\text{Daily Chemical Intake}_{IS} = C_S \bullet \frac{IR_S \bullet FI \bullet CF \bullet B \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

Parameters Relevant to Quantification of Exposure by Adults		
Ingestion Rate (IRs, mg/day)	25	ASC NEPM (commercial/industrial landuse)
Fraction Ingested from Source (FI, unitless)	100%	All of daily soil intake occurs from site
Exposure Frequency (EF, days/year)	240	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	30	Time at one residence as adult as per ASC NEPM
Body Weight (BW, kg)	70	For male and females combined (ASC NEPM)
Conversion Factor (CF)	1.00E-06	conversion from mg to kg
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	10950	ASC NEPM

Key Chemical	Toxicity Data				Bioavailability (%)	Soil Concentration (mg/kg)	Daily Intake		Calculated Risk			
	Non-Threshold Slope Factor (mg/kg-day)$^{-1}$	Threshold TDI (mg/kg/day)	Background Intake (% TDI)	TDI Allowable for Assessment (TDI-Background) (mg/kg/day)			NonThreshold (mg/kg/day)	Threshold (mg/kg/day)	Non-Threshold Risk (unitless)	% Total Risk	Chronic Hazard Quotient (unitless)	% Total HI
Cadmium (and thallium)		8.0E-04	60%	3.2E-04	100%	3.9E-01	3.9E-08	9.1E-08	--		0.000283	44%
Mercury (as inorganic and e		6.0E-04	40%	3.6E-04	100%	3.9E-01	3.9E-08	9.1E-08	--		0.000252	40%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	100%	4.6E-07	4.6E-14	1.1E-13	--		0.000102	16%
								TOTAL			**0.000637**	

Dermal Exposure to Chemicals via Contact with Soil

$$Daily\ Chemical\ Intake_{DS} = C_S \bullet \frac{SA_S \bullet AF \bullet FE \bullet ABS \bullet CF \bullet EF \bullet ED}{BW \bullet AT}$$ **(mg/kg/day)**

Parameters Relevant to Quantification of Exposure by Adults		
Surface Area (SAs, cm^2)	3800	Exposed skin surface area for workers as per ASC NEPM
Adherence Factor (AF, mg/cm^2)	0.5	Default as per ASC NEPM
Fraction of Day Exposed	1	Assume skin is washed after 24 hours
Conversion Factor (CF)	1.E-06	Conversion of units
Dermal absorption (ABS, unitless)	Chemical-specific (as below)	
Exposure Frequency (EF, days/year)	240	Days at home (normal conditions), as per ASC NEPM
Exposure Duration (ED, years)	30	Time at one residence as adult as per ASC NEPM
Body Weight (BW, kg)	70	For male and females combined (ASC NEPM)
Averaging Time - NonThreshold (Atc, days)	25550	ASC NEPM
Averaging Time - Threshold (Atn, days)	10950	ASC NEPM

Key Chemical	Toxicity Data					Soil Concentration (mg/kg)	Daily Intake		Calculated Risk			
	Non-Threshold Slope Factor (mg/kg-day)$^{-1}$	Threshold TDI (mg/kg/day)	Background Intake (% TDI)	TDI Allowable for Assessment (TDI-Background) (mg/kg/day)	Dermal Absorption (ABS)		Non-Threshold (mg/kg/day)	Threshold (mg/kg/day)	Non-Threshold Risk (unitless)	% Total Risk	Chronic Hazard Quotient (unitless)	% Total HI
Cadmium (and thallium)		8.0E-04	60%	3.2E-04		3.9E-01			--		--	
Mercury (as inorganic and elem		4.2E-05	40%	2.5E-05	0.001	3.9E-01	3.0E-09	6.9E-09	--		0.000274	54%
Dioxin-like compounds		2.3E-09	54%	1.1E-09	0.03	4.6E-07	1.1E-13	2.5E-13	--		0.000232	46%
								TOTAL			0.000506	

THIS PAGE WAS INTENTIONALLY LEFT BLANK
NO FURTHER CONTENT

This page indicates the end of all supporting appendices.