Entry: **The 21st Century Solution for 21st Century Wastes**

Title: Redefining Organic Waste Treatment

Team Name: EFF-GO Ltd

Entry Category: Growing and Producing by Rejuvenating Natural Systems

Please note that the references in the following document are hyperlinked

The Problem and the EFF-GO Solution

Currently Municipal Wastewater Treatment Plants (MWTPs) substantially utilise microbial communities, aerobic and anaerobic, to literally eat wastewater and thus render it fit for discharge.

However, modern wastewaters have increasing concentrations of non-biodegradable compounds, a function of our synthetic chemical industry, one of the pillars upon which our modern society is founded. These Persistent Organic Pollutants (POPs) and plastic micro/nano-particles pass through our MWTPs, generating subtle, devastating and potentially irreversible changes to the receiving freshwater, marine and terrestrial ecosystems. With these ecosystems ultimately linked by the Hydrologic Cycle, pollutants are effectively raining on us.

Our MWTPs are designed for wastewaters pre-synthetic chemical industry, they are not suited to 21st century wastewaters, which include varying concentrations of the estimated 30,000 synthetic compounds in use worldwide (1). Society needs 21st century solutions, physiochemical solutions, to support our microbe powered MWTPs.

EFF-GO offers such a solution, by harnessing the powerful and efficient treatment conditions created by SuperCritical Water. Water heated and pressurised beyond its critical point; 374°C & 221 bar; becomes a highly oxidative medium, in which organic matter and oxygen approach complete solubility, resulting in reactions measured in seconds and treatment efficiencies >99.99%.

EFF-GO the 21st century solution for 21st century waste.

Team EFF-GO – *a winning combination of innovation, experience and business acumen*

The Directors	
	**Simon Jury** *BSc(Hons), MSc, OHS Dip, CertHE Eng* The Scientist, with over 10 years as an Analytical Chemist, 6 years as a Waste Contract Manager (managing hazardous and non-hazardous wastes associated with significant UK industrial contracts) and over 5 years as a Health and Safety Advisor in the high risk NZ business sectors of fishing, quarrying & roading. Throughout his career he has demonstrated a penchant for innovation and the use of scientific principles to solve challenges.
	**Damian Buckley** *BA(Hons)* The Salesman, he has knowledge and experience of both the operational and management aspects of farming. During his career he has become an experienced Business Development Manager with a demonstrated history of working in the rural software industry and media world. He is skilled in Marketing, Negotiation, Business Planning, Advertising, and Sales.
	**Murray Holdaway** The Chairman, a 5th generation Dairy Farmer who has, through astute investment and hard work, doubled the size of his farming business over the last 45 years. His astute business acumen is recognised by his peers; he has sat on Fonterra's Board Remuneration Committee; he is currently Chair of the Manawatu/Rangitikei Federated Farmers Dairy Section.

The Specialists

- ✓ **Peter George** (Sentinel Inspection Ltd), a verifier of design fabrication, an accredited pressure vessel certifier and provider of NDT services. He will monitor the EFF-GO reaction chamber construction process and ensure it is built to the verified design.
- ✓ **Fergus Rhodes** (Rhodes Engineering), is an IPENZ certified pressure vessel design engineer and has provided EFF-GO with concept engineering drawings. Fergus has the contacts to ensure that the EFF-GO reaction chamber is manufactured to certified standards.
- ✓ **Dr Gaetano Dedual**, formerly of Otago University, in 2018 he completed his Chem Eng PhD in pyrolysis. He is thus skilled in the design, construction and testing of a high temperature and pressure treatment process. Gaetano is a Consulting Chemical Engineer for EFF-GO.
- ✓ **Dr Fabian Dolamore**, a postdoctoral Chem Eng research fellow of Otago University, he is currently researching novel compound separation processes utilizing his CFD modelling expertise. He has utilised his CFD knowledge to assess EFF-GO's SuperCritical Water management system and has determined that the design is feasible, no critical failings.
- ✓ **Campbell Dodds**, currently an Agronomist and formerly an Operational Manager of a Municipal Wastewater Treatment Plant. Introduced to EFF-GO by Peter Ellingham (CEDA Manawatu), Campbell has reviewed the potential of SuperCritical Water Oxidation and EFF-GO's proposed management of same and concluded that there is sufficient hard evidence that SuperCritical Water Oxidation does work to merit the construction of a prototype to further investigate EFF-GO's proposal.
- ✓ **Dr Selwyn Yorke**, as a Chairperson of Palmerston North Green Corridors, a member of the Manawatu Investment Group and a Director of a BioTech company, he is fully cognisant of the waste treatment challenges facing society. He has a passion for the environment and its protection. He provides EFF-GO with Financial Investment advice.
- ✓ **Brita Fromow** (CatalystIP), provider of patent and IP advice. CatalystIP reports confirm that the process is novel and has freedom to operate in NZ, Australia and the USA.
- ✓ **Peter Ellingham** (CEDA Manawatu), provider of funding and business development guidance.

The Environmental Context of EFF-GO's Users and their Needs

Why EFF-GO, why now? The uptake capacities of New Zealand's bio-sinks are being exceeded by the volume of organic matter generated by a flourishing human population and their associated activities in the primary, industrial and municipal sectors. This is evident by the increasingly frequent warnings of our rivers, lakes and coastal waters being un-swimmable and the fact that our native aquatic/marine wildlife is struggling to exist in these same waters (2).

New Zealand has long cultivated and promoted a "Clean, Green New Zealand" image. An image threatened by an absence of a coherent and sustainable mechanism to treat our increasing volumes of organic waste.

New Zealand needs a sustainable non-biological solution to support its conventional organic waste treatment processes, EFF-GO offers such a solution, a "Full-Stop" treatment solution.

EFF-GO will initially focus on the volumes of sewage sludge created by New Zealand's 323 listed Municipal Wastewater Treatment Plants (MWTPs). New Zealand's combined annual volume of sewage sludge is in the region of 600,000m^3 (3). EFF-GO in its mobile and static configurations, will offer these MWTPs an outlet for their sludges. An outlet that eliminates the deleterious components of sewage sludge, such as POPs, Emerging Organic Contaminants (EOCs) & pathogens, including the emerging cohort of antibiotic resistant bacteria (4).

Adoption of the EFF-GO process will aid those 55 NZ MWTPs, that are currently unconsented, and the 87 whose consents expire in the next decade, to gain discharge consents.

EFF-GO is a paradigm changing proposal, it will provide a sustainable full-stop solution for less cost than the currently favoured and unsustainable composting and landfill options.

	Cost per Ton	Reference & Comments
EFF-GO	$120 to $175 (energy recovery not included)	Full EFF-GO details submitted in 2019 WMF and PGF applications See also Energy Consumption & Economic Analyses of SCWO
Composting	$200 to $220	Composting NZ
Landfill	$270 to $370	landfill-charges

An Expanding Urban Population; simple economies of scale, there is an indirect correlation between population density and the cost of waste treatment per capita. The high-density city has its waste created relatively locally, minimising the transfer costs, and maintenance of same, to its specialised treatment facilities, the Municipal Wastewater Treatment Plant (MWTP). The overall cost of the MWTP operation is shared by the growing urban population; ergo less cost per capita. The downside is that the products of city sized MWTP can locally overload the receiving environment, be it aquatic or terrestrial.

EFF-GO can mitigate this eutrophication potential.

New Zealand's capital is expected by 2025 to be unable to landfill its sewage sludge, as there will not be enough general waste in the Wellington region to stabilise the sludge (5). The attempt to compost Wellingtons sewage sludge resulted in a $17m failure (6), due to odour issues, unexpected process costs and refusal by the public to buy the compost containing human waste. Even if the stabilisation challenge is resolved, the landfill capacity in the Wellington region will eventually reach zero and there will be less general waste available to act as a stabiliser as recycling rates increase.

A sustainable outlet for sewage sludge is required if our capital, and New Zealand in general, is to retain it clean green image. An image worth around $1.5bn per annum is surely worth protecting (7).

EFF-GO offers a sustainable treatment solution for sewage sludge, a solution that renders sewage sludge inert. A homegrown New Zealand solution that is readily exportable, in a static format for large urban centres and in a mobile format for rural communities. New Zealand innovation goes global.

Industrial Wastewaters; water, the universal solvent, is the ubiquitous component of industrial processes; as a coolant, reaction medium, cleaning solution, etc. As population densities increase so will the tradewaste loadings received by MWTPs serving them, as the industries and service outlets supporting the same populations expand to meet consumer demands. The scalability, small footprint and robust nature of the EFF-GO process will make it a prime treatment option for industry, either as site-specific treatment solution, or, by the creation of a Regional Hub, a shared treatment resource. Urban centres with a robust MWTP, by virtue of an EFF-GO treatment facility, will have an advantage when attracting industry and services.

Benefits – what does EFF-GO offer society?

EFF-GO's innovative reaction chamber design will facilitate the general application of SuperCritical Water Oxidation (SCWO) to New Zealand's municipal sewage sludges and other recalcitrant organic matter waste streams. The eutrophication potential of New Zealand's mounting volumes of organic waste will be reduced. Ecosystems not suited to abundant nutrient concentrations will be allowed to recover and the occurrence of toxic algae blooms will reduce.

SCWO is an internationally recognised treatment process that rapidly converts all organic matter into benign products (8):

$$\text{Organic Matter Solution} + O_2 \rightarrow CO_2{}^* + N_2 + H_2O + \text{Inorganic Salts } (SO_4 + PO_4, \text{ etc})$$

*Subsequent iterations of the process will sequester the CO_2 generated and create a circular market – see Figure 1 below

EFF-GO is a "Full-Stop" solution, organic matter passing through the EFF-GO reaction chamber is completely oxidised – *it is literally incineration in the liquid phase*.

- All bacteria and viruses are destroyed.
- All Persistent Organic Pollutants (POP's), Endocrine Disruptors and Emerging Organic Contaminants (EOCs) are disassembled into their component parts.
- The water exiting the process is a brine, containing inorganic salts and oxides, which can be recovered by an inorganic filtration process such as Aquafortus (9) to yield clean water.
- The CO_2 and N_2 gases are recoverable as they emitted from a point source.
- The efficiency of a MWTP is enhanced, as the EFF-GO process runs on 10% (m/v) organic matter, so for every 1kg of sewage sludge treated, 9L of sewage water from the Primary Treatment process are also treated.
- Waste to energy, SCWO has been shown to be autothermic at 600°C with an organic matter feed of around 10% (m/v), equivalent to 930kJ/kg (10). The precise concentration of the organic matter feed is dependent on the calorific content of the organic matter, dewatered sewage sludge typically contains 14MJ/kg (11), thus an aqueous 10% (m/v) solution of typical sewage sludge would contain 1.4MJ. So there is approx. 400kJ of excess thermal energy from every kg of sewage sludge treated, this excess thermal energy can be converted to electricity.

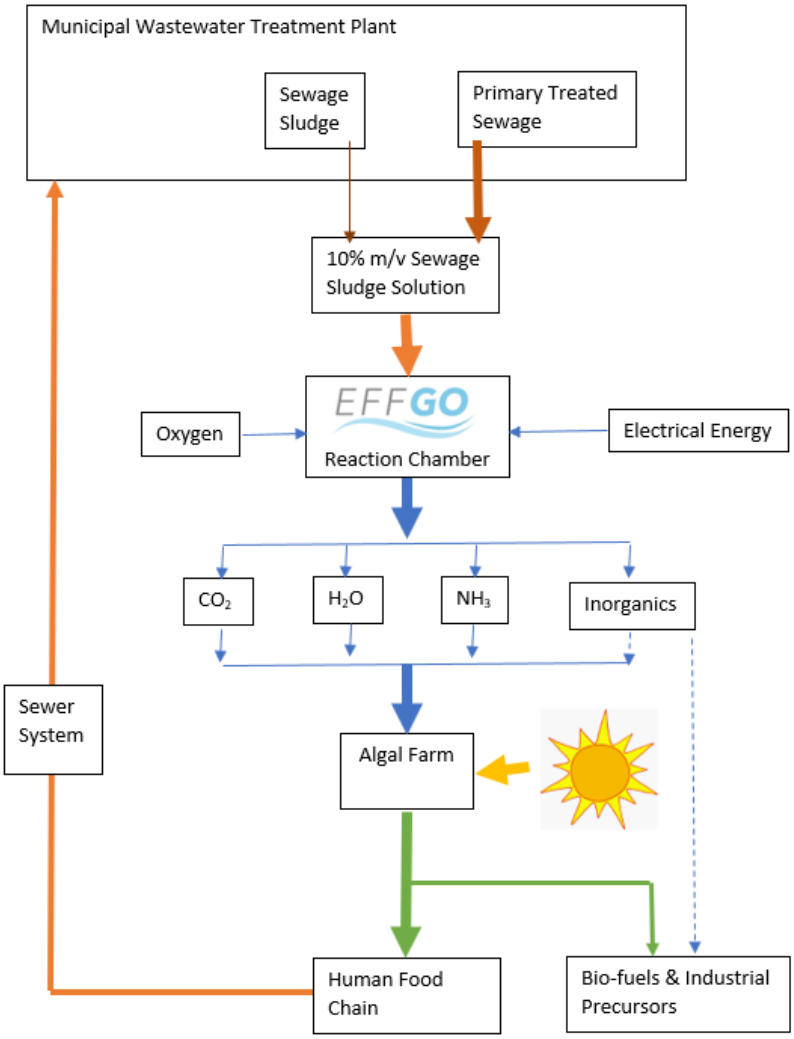

Figure 1 – Potential for the EFF-GO process to be part of a closed loop, supplying nutrients for photosynthesis, an Algal Farm in this example. The products of the EFF-GO process (heat energy not shown) promote algal growth. As algae prefer NH_3 to N_2 the EFF-GO process would run at 500°C to create NH_3 as oppose to N_2 at 600°C. The algae harvested would then feed the human food chain (directly or indirectly), which in turn feeds the sewage plant, which feeds the EFF-GO process and the cycle continues.

EFF-GO also offers:

- ✓ A minimal footprint – the high reaction and treatment efficiencies of SCWO make a 240L reaction chamber, running 24/7, enough for the treatment of the 11,000m^3 of sewage sludge created annually by a city the size of Palmerston North (population of 80,000). The reaction chamber and ancillaries will fit in two 6m cargo containers.
- ✓ Readily scalable - if increasing treatment capacity is required additional reaction chambers and pumps are deployed. No need for capital construction projects.
- ✓ Mobile – because the reaction chamber and its ancillaries will fit in two 6m cargo containers, the EFF-GO process is eminently suited to campaign treatment projects, e.g. the desludging of rural oxidation ponds. Onsite treatment reduces the carbon footprint and cost of the operation, by eliminating emissions from offsite transport and the cost of same.

- ✓ Toxic shock immunity – as a non-catalytic physiochemical process EFF-GO is immune from the biological or catalytic toxicity of the feedstock, all matter entering the chamber is oxidised, irrespective of its original character.
- ✓ Treatment immune from environmental conditions – as a physiochemical process EFF-GO functions come rain or shine, bioremediation processes are weather dependent.

The Concept – how will EFF-GO be delivered, is it feasible?

SuperCritical Water is a fact (12), it is the 4th phase of water, it happens when water is heated to >374°C and pressurised to >221 bar. When water is SuperCritical it ceases to be a polar solvent, it essentially becomes a viscous gas, with the carrying capacity of a liquid and the flow dynamics of a gas. Under these conditions organic matter and oxygen approach 100% solubility, consequently oxidation reactions occur rapidly and efficiently; process times are measured in seconds and treatment efficiencies can be > 99.99%. As a comparison, under Anaerobic Digestion conditions treatment rates are measured in weeks and treatment efficiencies rarely exceed 90%; i.e. biological processes are 3 orders of magnitude slower and less efficient than SCWO.

So, why has such a powerful process not already become a standard treatment option for wastewaters laden with organics?

The non-polar nature of SuperCritical Water causes the inorganic components of organic matter waste streams to precipitate. This has the potential to cause salt-plugging, erosion and corrosion issues in SuperCritical Water Oxidation reaction vessels (13).

EFF-GO has devised an innovative and functional reaction chamber to control the SuperCritical Water environment and in so doing mitigate these confounding factors, that have hitherto confined SCWO to niche waste-streams and precluded SCWO utilisation as a financially viable alternative to established biological waste treatment processes.

1. Salt-plugging – it is the innovative reaction chamber design that controls and eliminates this confounding factor; EFF-GO will disclose this IP to signatures of an NDA, available upon request
2. Erosion – as above, it is how the EFF-GO reaction chamber handles the supercritical water that allows the elimination of this factor
3. Corrosion – the material from which the reaction chamber is constructed facilitates the control of this confounding factor. The material is readily available and requires no research

The novelty and IP of the EFF-GO proposal is the management of the SuperCritical Water environment, the safety systems, pumps, heaters, control software, sensors, oxygen concentrators, etc are all tried and tested “off the shelf” items. This approach, blending proven and novel systems, greatly reduces the operational risks associated with the EFF-GO proposal and reduces the lead time to achieve full operational deployment from receipt of finance.

EFF-GO’s proposal is to construct a SCWO reaction chamber, using its innovative design, a design reviewed by Chemical Engineers and deemed credible by an IPENZ accredited pressure vessel Design Engineer. The design has been validated by Computational Fluid Dynamic (CFD) Modelling and the notion of treating New Zealand’s sewage sludges by SCWO has been well received by Wellington and Palmerston North City Councillors, Specialist Engineers, MP’s & Regional Council employees.

The initial concept for the EFF-GO reaction chamber design has been reviewed, refined and validated by peer review. It is worth noting that at no stage has the response been, “nice idea but can’t work because it contravenes a physical law”. The only roadblock facing EFF-GO is funding, hence the application to the Callaghan C-Prize, for financial aid and technical guidance to build the prototype. Once constructed, tested and demonstrated, private sector funding will soon follow, as EFF-GO represents a paradigm changing opportunity. A 21st Century solution for a 21st Century problem.

Signature of the EFF-GO NDA will provide access to EFF-GO's IP

Feasibility Study - Scientific

Proposal Facts:

1. SuperCritical Water Oxidation (SCWO) is an established high-performance organic waste treatment process. Water at temperatures >374°C and pressures >221 bar becomes supercritical, as such it is a non-polar solvent, organic matter and oxygen approach 100% solubility under these conditions, consequently oxidation reactions occur in seconds and can have treatment efficiencies >99.99% (14).
2. Any organic matter that can be shredded to a particle size of <200um and suspended in the aqueous infeed can be completely oxidised by SuperCritical Water. Maceration pumps will be employed to ensure a <200um particle size.
3. SCWO is an exothermic process and it becomes autothermic with organic matter feeds of 3 to 10% (m/v). The precise organic matter concentration, required to reach autothermic conditions, depends upon the calorific value of the organic matter being treated, this will be determined by Bomb Calorimetry and/or Chemical Oxygen Demand analysis, both being established analytical methodologies.
4. SuperCritical Water is immune to toxic shock, being a physiochemical process, the toxicity of the organic matter is irrelevant; save for its handling prior to treatment. PCB's, POP's, etc will effectively be disassembled into their component parts and effectively rendered inert.
5. SuperCritical Water will work come rain or shine; it is immune to the environmental conditions that cause biological processes efficiencies to fluctuate. It is a futureproof technology.
6. SuperCritical Water Oxidation, as employed by EFF-GO, is a full stop solution, all organic matter is converted to CO_2, N_2 (or NH_3 at lower temps), H_2O and the associated inorganics are converted to salts/oxides and presented in a recoverable format. All pathogens are destroyed. All Persistent Organic Pollutants are disassembled.
7. EFF-GO as greenhouse gas mitigation process. The CO_2 created by the complete oxidation of organic matter is made recoverable/reusable as it is vented from a point source. Please note that the volume of CO_2 created by the EFF-GO process is comparable to that liberated by biological processes. The main difference is that the EFF-GO process creates CO_2 rapidly and from a point source, these characteristics facilitate carbon capture via a variety of options; from the enhancement of photosynthetic efficiencies (15), to the catalytic transformation of CO_2 to CO_3 (16).

Measuring the impact of EFF-GO

Adoption of EFF-GO across New Zealand's MWTPs will eliminate the annual volume (600,000m^3) of sewage sludge currently entering New Zealand's landfills and composting sector.

In doing so landfill capacity will be preserved, for that fraction of solid waste that is yet untreatable and/or incompatible with commercial recycling processes. The risk of POPs, plastic microparticles, heavy metals and pathogens being spread across New Zealand, by the sale of composted sewage sludge, will be eliminated. Remember, composting at best only partially treats the organic components of 21st century sewage sludge and simply dilutes the inorganic components, hence the stringent compost use restrictions and tests applied to composting processes incorporating human sewage sludge in the EU (17).

Measurement of EFF-GO's impact will initially be via the annual reports issued by councils. As EFF-GO moves into the industrial sector their waste management reports will also be used. The generation of electrical energy, via heat recovery, will be another measure of EFF-GO's beneficial impact on society.

Technical Plan

Build and test a protype, the cost of which is estimated to be $400,000 (exc GST), 6 months have been assigned for the initial prototyping and demonstration that EFF-GO's reaction chamber design successfully and safely mitigates the salt-plugging, erosion and corrosion issues associated with SCWO.

- Reaction Chamber Design – Rhodes Engineering
- Reaction Chamber Fabrication Quality Control – Sentinel Inspection
- Process Control Software – Beta Solutions
- Prototype Project Management – Dr Gaetano Deudal
- CFD Modelling – Dr Fabian Dolamore
- Health & Safety – Simon Jury BSc(Hons) MSc OHS Dip CertHE Eng
- Sampling and Chemical Analysis – tbc, will be via an IANZ accredited independent laboratory, or Crown Research Institute, utilising recognised methodologies
- Financial Management/Governance – Naylor Lawrence Assoc.

Initially a synthetic facsimile of sewage sludge, of known composition, will be employed to test the EFF-GO protype, this will minimise confounding factors and facilitate R&D progress.

Ultimately sewage sludges from MWTPs will be employed to test the prototype.

Project Steps

1. Determine a host test site, preferably on, or adjacent to a MWTP; e.g. the former Awapuni Quarry adjacent to the Totara Rd MWTP, Palmerston North
2. Independent verification of the drawings created by Rhodes Engineering
3. Verified manufacture of the EFF-GO reaction chamber – ensure a detailed scan of the internal surfaces is recorded – this is a Sentinel Inspection task
4. HAZOP assessment – determine the hazards, identify controls and feed them into the design process – Callaghan Innovation?
5. Confirm plant layout and have the design independently verified – Callaghan Innovation?
6. Purchase/Lease the ancillary equipment - High Pressure Pumps, Oxygen Concentrator, corrosion resistant valves, sensors, etc
7. Assemble the EFF-GO processing plant to the verified design – Sentinel Inspection oversight
8. Test the assembled plant to confirm it is operating within acceptable parameters
9. Run the plant to process simulated waste and evaluate findings
10. Run the plant to process real sewage sludge and evaluate findings
11. Scrutinise the internal surfaces of the EFF-GO reaction chamber, if they have sustained insignificant change then the EFF-GO SuperCritical Water Oxidation management system will have been shown to be effective

The EFF-GO prototype process will be deemed successful if:

- The SuperCritical Water is contained – no unresolvable leaks and/or safety system failures
- There is no appreciable damage to the internal reaction chamber surfaces, this will be determined by independent review of SEM images of the chamber before and after use
- The process is autothermic, literature indicates this will occur at 10% (m/v) organic matter concentration
- Treatment efficiencies are >99% - determined by COD and marker compound destruction
- Treatment costs are less than landfill and compost options