Pure Steam Reforming of Municipal Solid Waste

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Abstract

In response to global environmental challenges, Elementa Group Inc. (Elementa) has developed a pure steam reforming process for Municipal Solid Waste (MSW) and other waste feedstock materials to produce clean and efficient renewable energy. The Elementa technology is a novel patented Waste-to-Gas conversion technology and is based on a unique pure steam reforming process that uses an indirectly fired rotary kiln at a high temperature and non-oxidizing environment. This technology thermo-chemically breaks down carbon based materials into a high quality synthesis gas (syngas), leading to a greater than 95% conversion of carbonaceous content in the waste feed into a useful and clean syngas. The developed process effectively diverts MSW from landfills, converts it into clean energy and significantly reduces greenhouse gases. Elementa's technology will be able to generate not only a very clean syngas which can be used most directly for generating combined heat and electrical power and/or alternately synthesized into liquid fuels, where feeds can be sourced from a variety of wastes and renewable sources.

Introduction

Reducing the emission of carbon dioxide and other greenhouse gases is one of the greatest environmental challenges of our time. In recent years, the quantity of globally produced waste has increased significantly. Typically, the waste is sent to landfills and the energy in waste is essentially lost, creating mountains of trash, emitting harmful pollutants into our air, water and soil. In landfill the biodegradable components of waste decompose and emit methane – a greenhouse gas 21 times more harmful than carbon dioxide and the cause of significant environmental problems [1]. With recent price inflation and increasing scarcity of traditional fuels (oil, natural gas, coal), there has been a trend towards the use of waste as feedstock for alternative energy including sources such as Municipal Solid Waste (MSW), industrial waste, biomass, etc. The most common technology for treating waste is incineration. Incineration is the combustion of waste using an excess of oxygen to ensure complete combustion. Incineration can be identified as a baseline competitor technology [2]. However, incineration is wasteful of resources – providing low energy conversion efficiency. Incineration converts only about 20% of the chemical energy of the solids into thermal and electrical energy. Gasification and/or plasma enhanced gasification represent potential alternatives for waste treatment [2]. Gasification technology is based on partial oxidation (POx) of the waste. Because of the oxidation/incineration component of these competitor systems that use POx they will generate noxious oxides. In addition, gasification of waste typically requires extensive and expensive waste feedstock pre-treatment and the produced syngas will be significantly diluted by the oxidation process which includes the nitrogen content of air [3]. Therefore, the heating value of syngas produced from the POx gasification process is significantly reduced. The lower quality syngas fuel generated from partial

oxidation gasification can be run in reciprocating engines, but generally cannot be used as a fuel for cleaner burning and more efficient gas turbines, due to its relatively low heating value. Another competing technology is pyrolysis. This system is anoxic but generates a problematic mixture of syngas, tars and pyrolytic char. Pyrolysis systems generate only about 40% of their energy end product as syngas, with ~30% as condensable oils and tars and ~30% as pyrolytic chars. This means that for electricity generation, pyrolysis systems typically cannot cool or clean the syngas before burning these mixed products (which then must include both particulate and volatilized contaminants) in a steam boiler combustion unit; otherwise they will lose the energy benefit of the condensable oils and tars. The end result is then not a lot different from simply burning contaminated wastes in the first instance. The energy recovery is then very analogous to incineration, i.e. low energy efficiency plus the additional challenge of developing a cleaning plant which must be very similar to that for incineration, in order to meet environmental emission limits.

Objective

In response to the environmental and technological challenges posed by waste and its conversion to energy, the objective of the present work by Elementa is to develop an alternative green technology to produce clean and efficient renewable energy from waste feedstock.

Background

Elementa is a Canadian based private company, with its head office located in Niagara-on-the-Lake, Ontario, Canada. The company was incorporated on January 30th, 2003, in the province of Ontario as EnQuest Power Corporation, with a name change to Elementa Group Inc. (Elementa) on October 29th, 2008. Elementa is a Research & Development Company that offers a unique patented technology, a Waste-to-Gas conversion technology, which is a new generation of waste conversion to produce clean and efficient renewable energy from waste feedstock materials (urban, municipal, industrial, commercial, forest, and agricultural waste) [4]. The technology has been run and proven to convert carbonaceous material into a high quality clean syngas at its Pilot Plant in Sault Ste. Marie, Ontario, Canada. Sample pictures of the Pilot Plant are shown below.

In Sault Ste. Marie a full commercial plant design is underway and build of the first commercial plant designed for ~50 000 tonne/year of MSW is scheduled to start early in 2014 to supply environmentally clean electricity to the local grid. The Elementa web-site is: www.elementagroup.com.

Figure 1 Elementa Pilot Plant

Figure 2 Steam Reformation Kiln

Technology

Elementa has developed a pure steam reforming process for Municipal Solid Waste (MSW) to produce clean and efficient renewable energy from this and other waste feedstock. Pure steam reforming refers to the absence of air or oxygen in the process. The Elementa technology is a novel patented Waste-to-Gas conversion technology and is based on a unique pure steam reforming process that uses an indirectly fired rotary kiln at a high temperature and non-oxidizing environment. This technology thermo-chemically breaks down carbon based materials into a high quality synthesis gas (syngas), leading to a greater than 95% conversion of carbonaceous content in the waste feed into a useful and clean syngas. The main products of the MSW ($C_aH_bO_c$) steam reformation are hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and light hydrocarbons (C_xH_y) which can be shown in a simplified representation as follows.

$$C_aH_bO_c + SH_2O \rightarrow dH_2 + eCO + fCO_2 + gCH_4 + hC_xH_y$$

Where the a, b, c averaged quantitative values of the waste molecule are typically in the order of ~6, 10 and 3 for MSW, where S represents stoichiometric water and on a volume % basis the products d, e, f, g and h as measured for the Elementa process are typically of the order of ~ 45-50%(H_2), 20-25%(CO), 15%(CO_2), 10-14% (CO_2) and 2-4%(C_xH_y).

The Elementa process has a number of advantages over traditional incineration and gasification of waste feedstock, including elimination of the formation of dioxins, furans and nitrous and sulphur oxides within the reforming process, a significant reduction in the process gas volume and a reduced volume of residual waste. The developed process effectively diverts MSW from landfills, converts it into clean energy and reduces greenhouse gases.

The Elementa technology uses commercially proven off the shelf equipment and has applied these to the Elementa process in a unique and proprietary manner to provide a break-through solution to the challenge of waste conversion. These have been applied to the reforming of municipal solid waste (MSW) and to the conditioning, cleaning and processing of the resulting syngas to ensure that contaminants have been removed from the produced syngas.

Elementa's technology will be able to generate not only a very clean syngas, but heat and power from a variety of wastes and renewable sources. The developed process diverts MSW from landfills, converts it into clean energy and significantly reduces greenhouse gases. Landfills release many smog related components, components of acid rain, and persistent organic pollutants, from both natural processes and landfill fires. Landfill fires, earth movements, groundwater flows, and development all contribute to landfill leachate to eventually seep and contaminate nearby ecosystems. By making landfill practices almost obsolete, Elementa will reduce or eliminate these potential risks today, and for generations to come. The application of the Elementa technology will eliminate pollution created by landfills and incineration and gasification processes, such as air, soil and water contaminations. The benefit of treating waste using the Elementa process is that by virtue of its non-incinerating methodology, the waste material is broken down into its simpler elements, with no noxious oxides being formed and then combined with its ground-breaking and proprietary heat recovery and cleaning technology that is able

to condense, filter, neutralize and segregate noxious contaminants, including heavy metals contained in the waste feed such that the end useable syngas is an exceptionally clean and beneficial end product. Excess recovered unused water will be cleaned and discharged to the sanitary sewer system. And finally the Elementa process will reduce the MSW feed product by up to 98% in volume with a 2% by volume inert residual, where the residual being inert can potentially be used as a construction aggregate material.

The syngas and residual waste heat can be used to power combined cycle gas turbines, reciprocating gas engines or potentially fuel cells for the generation of electricity and hydrogen. On the other hand because of the quality and high hydrogen to carbon monoxide ratio of its syngas, Elementa's technology is ideally suited for and can be coupled with a Gas-to-Liquids technology (e.g. Fischer-Tropsch) to produce higher value liquid synthetic fuels. Elementa's technology is one of the most promising pathways of energy production as a thermo-chemical conversion of waste feedstock into syngas and has the following key elements and benefits.

- Uses an indirectly fired rotary kiln reactor for the steam reformation of carbon based materials
- Allows for robust process operation of various heterogeneous feedstock (including MSW and biomass) with a significantly lower cost for pre-processing this feedstock
- Elementa's technology provides for a true non-incineration process – that is, the total exclusion of air and hence oxygen from the process
- Steam reformation of the waste is performed using a simple, single stage and non-catalytic process
- Conversion of carbonaceous materials into a high hydrogen content syngas, up to 50% by volume, and an H_2/CO ratio over 2 satisfying gas to liquids input requirements, with heating values typically twice those of competitor systems
- Emission is well below prescribed Ontario, European and California guidelines avoiding the generation of highly toxic emission gases that full incineration and partial oxidation typically generate
- Uses a unique scrubbing and gas cleaning system based on commercial off-the-shelf equipment to produce clean syngas and minimizes waste water and solid residue
- Elementa has designed a highly efficient and cost effective system, which maximizes heat recovery and provides for beneficial use of waste heat for internal processes
- The Elementa system provides for an electrical energy conversion efficiency level that exceeds 30% for small plants and will be well above 40% for large plants which is significantly higher than competitor technologies producing electrical conversion efficiencies in the range of 15% to 20%.

The base concepts have been run and proven at the Elementa Group Pilot Plant, in Sault Ste Marie, Ontario, Canada. The flow diagram of the Pilot Plant is shown Figure 3.

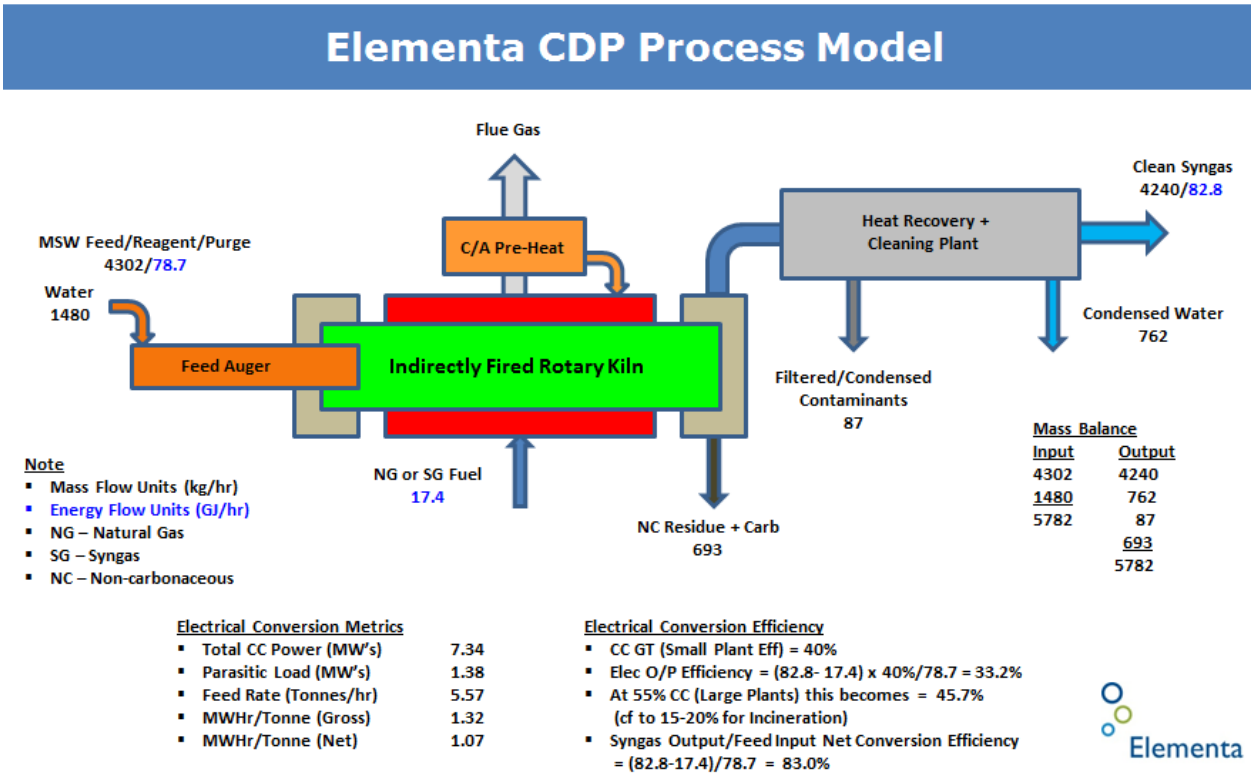
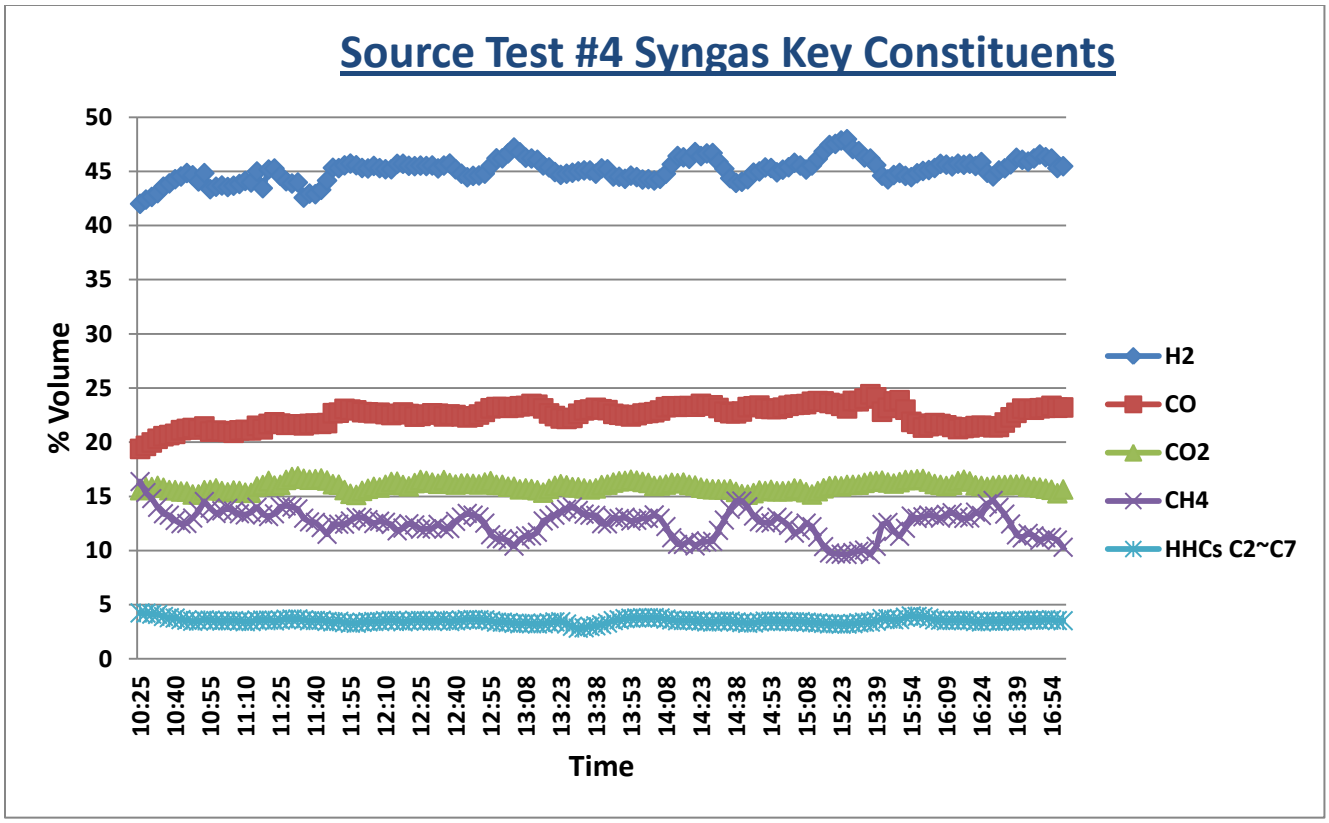


Figure 3 Flow Diagram of the Elementa SR Process Model

The Pilot Plant was run from 2007 through 2011, achieving a syngas with close to 50% hydrogen and a heating value (HHV) of ~13MJ/Nm^3 (~350 BTU/ft^3). The developed process is ideally suited to convert waste to higher-end products (ie a clean high heating value syngas and provides a near optimum syngas composition that can be used for producing liquid fuels) and recovers energy, more economically and efficiently and on a more appropriate scale than other conversion technologies. Syngas quality and the high hydrogen content achieved by the Elementa pure steam reforming process is as shown in the Gas Chromatograph data typical for Pilot Plant testing as given in Figure 4 and Table 1.



- Elementa Gas Chromatograph Measurements of Syngas Constituents
- Measured HV ~13MJ/Nm^3 (~ 350 BTU/ft^3)

Figure 4 Elementa Syngas Key Constituents from Source Test #4

Table 1

Elementa Clean Syngas Main Components

Component	Volume %
Hydrogen	45 - 50
Carbon Monoxide	20 - 25
Carbon Dioxide	15 - 16
Methane	10 - 14
Light Hydrocarbons	2 - 4

Typical minor components in the Elementa produced raw and clean syngas is presented in Table 2.

Table 2

Contaminant Content in Elementa Syngas

Component	Raw Syngas	Clean Syngas	Dimension
Hydrogen Chloride	1.22	0.07	mg/Nm^3
Hydrogen Fluoride	1.20	0.07	mg/Nm^3
Hydrogen Sulphide	440	25	mg/Nm^3
Hydrogen Cyanide	133	8	mg/Nm^3
Ammonia	3,435	16	mg/Nm^3
Particulate Matter	18,000	10	mg/Nm^3
Tar	17,000	10	mg/Nm^3
Mercury	0.2	0.002	mg/Nm^3

These data show the effectiveness of the Elementa cleaning system.

Emissions' testing was run as a Source Test to meet the Ontario Ministry of Environment Guideline A-7 and achieved gas cleanliness significantly lower than prescribed by these guidelines and also well below California and EU emission guidelines as shown in Table 3.

Table 3

Elementa Emissions Source Test Comparisons vs. Various Regulatory Limits

Parameter	Units	Ontario A-7	EU	California	Elementa Source Test
Particulate Matter	mg/Nm^3	17	9	16	0.34
Cadmium	$\mu g/Nm^3$	14	46	10	0.04
Lead	$\mu g/Nm^3$	142	n/a	140	0.63
Mercury	$\mu g/Nm^3$	20	46	60	0.14
Dioxins and Furans	ng/Nm^3	0.08	0.092	9	0.002
Hydrochloric acid	mg/Nm^3	27	9	27	0.59
Sulphur Dioxide	mg/Nm^3	56	46	56	8
Nitrogen Oxides	mg/Nm^3	207	183	202	177
Organic Matter	mg/Nm^3	66	9	n/a	1.214

Note: NOx emissions as tested represent flare NOx values whereas commercial gas turbine and/or recip engines with low NOx combustors will achieve further reductions in NOx levels.

The Elementa technology will eliminate pollution created by landfill, incineration and gasification processes. The incineration and partial oxidation systems generate noxious oxides, which are precluded in the Elementa system. These competing systems typically do not achieve complete conversion of the carbonaceous content into a useful syngas product. This underlines the essential differentiation of the Elementa technology with competitor systems.

There are a number of published reports comparing the various attributes of the developing thermal conversion processes and Elementa sees these as being in an evolving state. Elementa has made comparisons of its process and design with competitor systems and technologies and based on the

inherent benefits and positive attributes of a non-oxidizing, pure steam reforming process and using a robust, low maintenance rotary kiln that is very forgiving of material variability; there are seen important distinctions and advantages for the Elementa system. These comparisons will be the subject of future publications and/or reports.

The benefit of treating waste using the Elementa process is that by virtue of its non-incinerating methodology, the waste material is broken down into its simpler elements, with no noxious oxides being formed and then combined with its ground-breaking and proprietary cleaning technology that is able to condense, filter, neutralize and segregate any noxious contaminants, including heavy metals contained in the waste feed such that the end useable syngas is an exceptionally clean and beneficial end product.

Conclusion

The Elementa process provides a major enhancement in the methodology of clean energy production from waste. One of the most promising pathways of energy production as a thermo-chemical conversion of waste feedstock into synthesis gas (syngas) has been developed at Elementa. The developed Elementa technology represents a new generation of clean, high efficiency thermo-chemical waste conversion system to produce renewable energy from waste feedstock with significantly reduced environmental impacts than other waste disposal and waste conversion methods. Elementa's technology changes the concept of "waste" and will replace a portion of fossil fuels, providing a predictable, cost effective and environmentally sound supply of clean energy. The Elementa "Energy from Waste" process remains one of the most technically promising alternative technologies currently available.

References

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