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Renewable chemicals and biofuels for sustainable communities: a commercial reality in Edmonton, Alberta with Enerkem's thermochemical technology

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ABSTRACT: Each year, 1.3 billion metric tons of municipal solid waste ("MSW") are generated around the world (source: World Bank, 2012). Approximately 407 million metric tons of this MSW would be suitable for conversion into advanced ethanol and chemicals using Enerkem's thermochemical technology. At current yields, that is the equivalent of 40 billion gallons of ethanol that could be produced.

This breakthrough technology is capable of converting chemically and structurally heterogeneous waste materials (such as MSW) into a chemical-grade syngas, which is then turned into biomethanol, ethanol and other renewable chemicals using catalysts.

Enerkem will begin producing biomethanol in the coming weeks at one of the first commercial biorefineries in North America. This game-changing facility, which was built in partnership with the City of Edmonton (Alberta), will convert the City's MSW into methanol and ethanol – building blocks for olefins and acrylates. The City is seeking to increase its waste diversion rate from 60% to 90%. Additional biorefineries are currently being developed by the company in North America and globally.

Retail consumers are increasingly aware of health and environmental concerns, which translates into increased demand for greener components or a "cradle to cradle" solution in consumer products. In turn, producing chemicals from waste provides communities with a sustainable alternative that fits with their current waste management practices, thereby reducing landfilling while being economically advantageous when compared to other options such as incineration. This is now a commercial reality in Edmonton, Alberta.

Keywords: Biofuels, waste conversion, biorefinery, clean energy.

INTRODUCTION

Enerkem, with the assistance of the City of Edmonton and Alberta Innovates – Energy and Environment Solutions (AIEES), has made significant advancements in addressing the challenge and opportunity presented by the conversion of wastes and of low grade biomass to fuels and added value bio-products. The initial phase of the development effort was realized through a research effort, at the bench scale level, to obtain empirical data (yields, selectivity, material and energy balances and PFDs) used to establish and develop an advanced biofuels and bio-products technology platform. The purpose of the research was to characterize specific process parameters in order to support the design and implementation of the platform that will provide data for eventual full scale facilities. The project specifically focused on the utilization of syngas from various low cost materials (urban waste among them) for the production of methanol, ethanol, and other bio-products. The team has also assessed the technological and economic potential of specific green chemical products derived from its own methanol and ethanol such as Dimethyl ether (DME), Dimethyl carbonate (DMC), bio-olefins, and acrylates.

The research is being performed by Enerkem Inc. which began its research efforts in Sherbrooke, Quebec (Canada) and has expanded to an Advanced Energy Research Facility in Edmonton, Alberta (Canada) to continue advancements in this field of science and technology. The research data and engineering analysis obtained at the Sherbrooke and Edmonton research facilities have resulted in a validated techno-economic model which Enerkem uses to guide scale-up and process optimization decisions in its Demonstration Facility in Westbury, Quebec (Canada). This effort has culminated in the design and construction of a full scale commercial waste-to-biofuels plant. These two facilities combined with the City of Edmonton Waste Management Centre's progressive recycling and waste diversion program have become an international example of urban sustainability and environmental responsibility with the following additional benefits:

- A biofuels strategy based on non-homogeneous residual biomass, a multi-feedstock approach well suited for urban and regional development.
- A potential GHG emissions reduction which can reach 3 t CO2 per 1 t of biomass used (dry basis), when considering the three following contributions: biofuels blending with fossil fuels; CO2 removal and use for either Enhanced Oil Recovery or synthesis of green chemicals; and avoidance of fugitive methane emissions from landfills.
- Economic growth and employment for the region in the strategic "cleantech" space
- A long-term, sustainable, and cost-effective waste solution
- A local supply of bio-based raw materials and biofuel needed by local industries.

Photo 1: Enerkem's demonstration facility in Westbury, Quebec, Canada

DEVELOPMENTAL OVERVIEW

A significant outcome of the research effort was the definition of the final parameters and process integrations to be utilized in this proprietary waste to ethanol process. Research was performed in the following areas:

FEEDSTOCK PREPARATION

Feedstock pretreatment is the process of converting garbage to a form that is more amenable to downstream processing. This refined waste is commonly referred to as RDF. RDF however can take various forms and the cost of converting the Waste to RDF depends on how it is going to be used. Enerkem worked in its early development with the City of Edmonton to minimize the amount of pretreatment required to convert Edmonton waste to RDF. This collaborative effort resulted in the production and use of a fluff RDF rather than a pelletized RDF which reduced the pre-processing cost by an estimated 40 %. The reduction in pre-processing of waste conversion to RDF also results in significant CAPEX and GHG reductions.

GASIFICATION OF FLUFF RDF

Enerkem pursued the processing of the RDF fluff at the pilot scale (200 kg per hour) starting in 2002. Gas composition and Yield optimization for Biofuels production prove-out has since been done with numerous representative feedstocks and blends. The company has also operated its Demonstration scale Westbury Facility (2000 kg per hour) since 2009. Installation of a commercial scale gasification system is now completed in Edmonton with a design scale of 14.5 wet tonnes per hour (moisture is 15 wt%) of RDF. Commissioning of the Enerkem Alberta Biofuels commercial gasification system in Edmonton, Alberta (Canada), is now underway. The system has already produced syngas that is suitable for conversion to biofuels and chemicals.

Photo 2: The Enerkem Alberta Biofuels facility in Edmonton, Alberta, Canada

METHANOL SYNTHESIS

Stable production of methanol with high purity and yield has been demonstrated in Sherbrooke at the pilot scale since 2007. Syngas to methanol production has also been proven at the Demonstration Scale since 2011. All relevant operational results have met or exceeded the production targets set for this process operation, including methanol production rate and rate of catalyst deactivation. Methanol production is currently commencing at the Enerkem Alberta Biofuels plant.

CARBONYLATION

Selective conversion of MeOH and CO to an acetate-ester was achieved at the bench scale since 2008. This process was optimized for yield and selectivity and has since been scaled up at the demonstration facility in Westbury Quebec utilizing methanol produced from waste products at this same facility. The Enerkem carbonylation process is the first of two steps in Enerkem's proprietary methanol-to-ethanol conversion process. This process has been piloted at Enerkem's fully integrated Westbury demonstration facility.

HYDROGENOLYSIS

Hydrogenolysis utilizes hydrogen produced in the gasification process to split the ester into two moles of alcohol. This process has also been scaled up and fully integrated with the carbonylation process at the Westbury demonstration facility.

SEPARATION AND PURIFICATION

Enerkem's exclusive waste-to-ethanol process has a key advantage over competing ethanol production technologies in that the final ethanol product does not need to be separated from water. Ethanol produced at the Westbury demonstration methanol-to-ethanol facility has been certified to meet ASTM-D4806 for fuel grade ethanol. Another key aspect of the methanol-to-ethanol demonstration completed is that all process steps required for the full scale methanol-to-ethanol process including intermediate separation and recycle streams have been operated together at this

facility to produce the certified ethanol product. The yield of ethanol has also increased about 6% from initial projections to 380 liters of ethanol per dry tonne of waste entering the gasifier.

CONCLUSION: The key result is that the company has successfully demonstrated and operated all aspects of its waste-to-ethanol technology and is progressing to commercial scale with unrivaled ethanol productivity per raw tonne of biomass feedstock and unrivaled access to the feedstock due to the ability to directly utilize a broad range of feedstocks, including waste biomass, urban waste, and industrial waste.

The bench scale and pilot work on the ethanol production process were able to provide empirical data on each of the individual process steps and transitions to the next step in the process. This testing has demonstrated that production targets and selectivity were reliably hit across a broad range of conditions. Constraints were also identified and were built into the proprietary process design. Information on intermediate product separations and recycle loop effects, was much more difficult to determine at the bench scale as many of these processes work more efficiently at the full scale or will entail specific conditioning of the recycle stream that will affect input and thus output compositions. Iterations of distillation efficiencies recycle loops and the variation it had on the model made it apparent that it was again necessary to obtain this information empirically with a fully integrated pilot process.

The ethanol pilot plant has been built and is operating in Westbury to confirm bench results obtained to date on an intermediate scale and to optimize the process from an integration and operability standpoint. The mission of the pilot is to eliminate as much as possible uncertainties associated with the process, particularly with separation steps, recycle loop compositions and accumulations, and overall operability. The pilot plant was commissioned in Q1 of 2012 and produced its first ethanol in March of 2012. Characterization of all individual process units supported the techno-economic model, production yields, and compositions predicted by the Hysys simulation and observed with bench scale testing. This was followed by fully integrated testing using Enerkem methanol from waste through to fuel grade ethanol. Subsequent testing of the Enerkem process resulted in ethanol yield increasing from the projected 360 liters per tonne of waste to approximately 380 liters of ethanol per tonne of waste. The quality of the ethanol produced was good and was deemed suitable in all regards for blending as per ASTM-D4806-11A.

Commercialization of this waste-to-ethanol technology represents a significant development in the efficient utilization of carbon in waste to build chemical products. The thermochemical platform upon which this proprietary waste-to-ethanol process is built can readily be applied to the production of other biofuels and renewable chemicals as market conditions demand.