U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOMASS PROGRAM

DESIGN CASE SUMMARY

Production of Mixed Alcohols from Municipal Solid Waste via Gasification

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Adapted from reports prepared by:

C Valkenburg BL Thompson SB Jones
Y Zhu MA Gerber DJ Stevens
CW Walton

of the Pacific Northwest National Laboratory

A two volume report “Municipal Solid Waste (MSW) to Liquid Fuels, Volume 1: Availability of Feedstock and Technology” & “Municipal Solid Waste (MSW) to Liquid Fuels, Volume 2: A Techno-economic Evaluation of the Production of Mixed Alcohols” is available online from Pacific Northwest National Laboratory. Volume 1 was prepared in December 2008 and Volume 2 was prepared in April 2009. Both volumes were prepared for the U.S. Department of Energy.

This design case summary was prepared in March 2010 by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of the Biomass Program.

Developing Design Cases to understand the cost of converting biomass to fuels

The Biomass Program is undertaking studies of biomass conversion technologies to identify barriers and conduct research to reduce conversion costs.

A diverse portfolio of conversion technology research, development, and deployment

The Office of Energy Efficiency and Renewable Energy's Biomass Program works with industry, academia, and national laboratory partners on a balanced portfolio of research in biomass feedstocks and conversion technologies. Biomass feedstocks are non-food sources of renewable material that can be produced domestically and in a sustainable manner. One type of biomass feedstock is the organic portion of municipal solid waste (MSW). The organic portion of MSW is composed of yard wastes, food scraps, and other biomass materials. This fraction of MSW can be separated from the non-renewable and recyclable components and converted to advanced, renewable biofuel.

The Biomass Program focuses its conversion technology efforts on creating biofuels, bioproducts, and biopower via two routes: biochemical and thermochemical conversion. In biochemical conversion, biomass is broken down into sugars using either enzymatic or chemical processes and then converted to fuels via fermentation. In thermochemical conversion, biomass is broken down into a liquid or synthesis gas using heat and then upgraded to fuels using a combination of heat and pressure in the presence of catalysts. MSW can be readily converted via the thermochemical pathway.

Lawn and yard waste is a significant component of municipal solid waste (MSW).

What is a Design Case?

The Biomass Program develops design cases to understand the current state of conversion technologies and to determine where improvements need to take place in the future. The best available bench and pilot scale conversion data is integrated with detailed process flow and engineering models to identify technical barriers where research and development could lead to significant cost improvements and to calculate the projected production costs. Past design cases focused on finding pathways toward cost-competitive production of ethanol and mixed alcohols via gasification of harvested biomass and on establishing cost targets for the production of diesel and gasoline blendstock from biomass via a fast pyrolysis process. This design case investigates the feasibility of using MSW as a feedstock and establishes detailed cost targets for the production of ethanol and other mixed alcohols via the gasification of the organic portion of separated MSW.

The Municipal Solid Waste (MSW) Gasification Design Case

Cost targets for converting MSW to ethanol and other mixed alcohols

MSW

The United States produces the most MSW in the world on a per capita basis. Biomass is estimated to constitute between 25% and 50% of MSW on a weight basis, and while some biomass-based MSW is separated for recycling, energy production, and composting, a significant fraction is landfilled. The organic portion of MSW has a higher heating value (HHV) of approximately 5,100 Btu/lb "dry and as received." MSW as a bioenergy feedstock poses unique challenges in terms of its heterogeneous composition, which results in an economic tradeoff between feedstock preparation costs and the gasifier capital and operating costs.

Gasification

In gasification, feedstocks are broken down using heat in a reactor vessel to form a synthesis gas, which is primarily composed of carbon monoxide and hydrogen. Biomass and MSW gasification is a commercially proven technology, and a variety of gasifier designs are in operation globally. Different gasifier types have unique advantages and drawbacks that can affect the end-product characteristics. Most of these are used to fire boilers for process heat and electricity. Before the synthetic gas can be converted into liquid fuels, it must first be purified. Synthesis gas cleanup and catalyst development is a research and development (R&D) priority of the Biomass Program. In addition, the Program is co-funding the deployment of a variety of pilot and demonstration scale, gasification-based biorefineries, including a 10-million-gallon-per-year MSW-to-ethanol facility being developed by Enerkem.

Renewable Biomass and Municipal Solid Waste

- The Energy Independence and Security Act of 2007 (EISA) modified and greatly expanded the Renewable Fuels Standard (RFS) created by the Energy Policy Act of 2005 (EPAct). To ensure that biofuels produced to meet the RFS targets are sustainable, EISA stipulates that feedstocks used for biofuels must come from "renewable biomass."
- EPAct included the cellulosic portion of MSW in the original RFS. EISA, while including yard and food wastes, did not include MSW.
- In February 2010, the EPA issued the final RFS2 rule. Among other things, the rule included a finding that the "EPA believes that the residues remaining after reasonably practicable efforts to remove recyclable materials other than food and yard waste (including paper, cardboard, plastic, textiles, metal and glass) from MSW should qualify as separated yard and food waste."*
- This finding means that biofuel produced from a portion of the cellulosic MSW stream qualifies as renewable biofuel under the RFS.

** Pg 79, Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program. Final Rule, Environmental Protection Agency. February, 2010.*

Liquid Fuel Synthesis from MSW Gasification

The liquid fuel synthesis from MSW gasification design case represents existing technologies that are commercially available today (though not in an integrated fashion). The process model and cost estimates were based on a design case for the gasification of woody biomass. All process efficiencies, equipment costs, and operating expenses were calculated assuming an established *nth* plant rather than a first-of-kind plant. A first-of-kind operation will have higher costs. The operating assumption was a feed rate of 2,200 short tons per day of refuse derived fuel (RDF) as the feedstock. RDF is preprocessed MSW that has been shredded to improve feed characteristics. The simplified process diagram for the MSW-to-ethanol process is shown in Figure 1. The process steps include:

- Preprocessing the MSW to generate refuse derived fuel (RDF)
- Drying and gasifying the RDF material to create raw synthesis gas
- Tar cracking and scrubbing to clean up the synthesis gas
- Synthesis gas purification and steam reforming to create a clean syngas stream
- Mixed alcohol synthesis using catalysts
- Product separation to distill ethanol from the higher alcohols
- Power generation from steam generated in various parts of the process

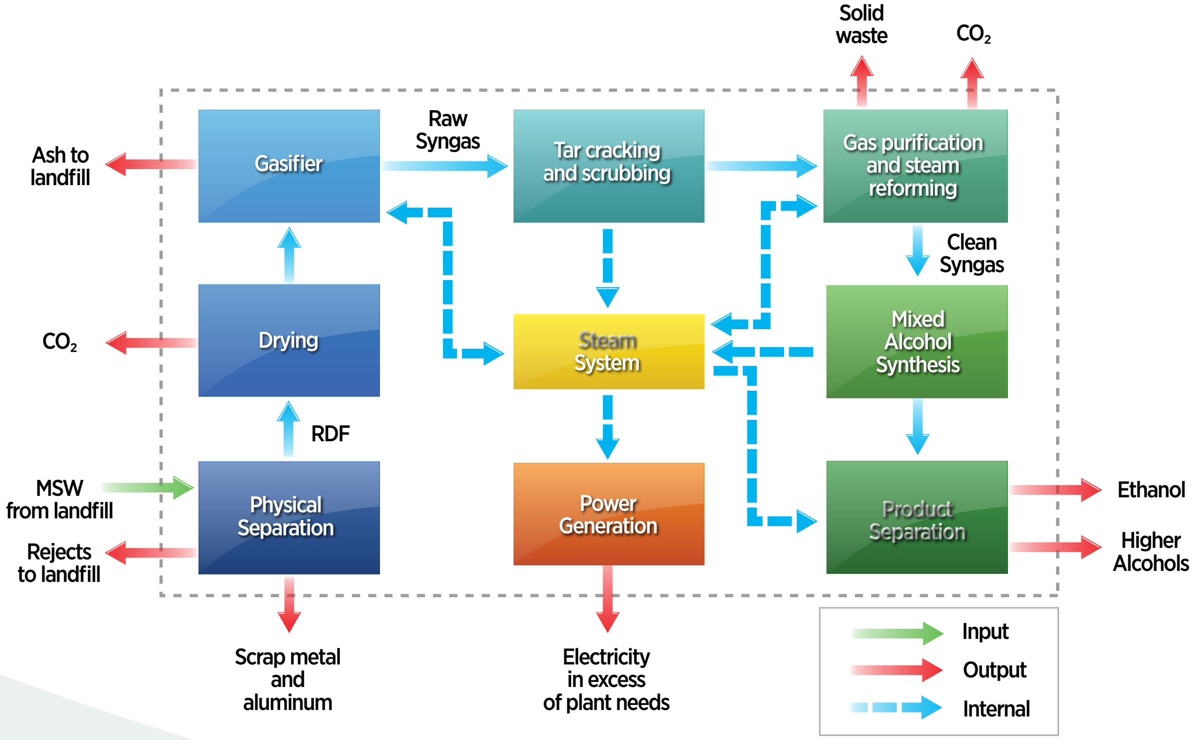

Figure 1: *Process flow diagram of the MSW-to-ethanol process.*

The design case also models expected improvements in syngas cleanup and alcohol catalysis that are expected to be demonstrated by 2012.

Results of the Analysis

The MSW gasification process is expected to process approximately 3,200 tons per day of delivered MSW. Preprocessing the delivered MSW to generate a more uniform RDF gasifier feedstock yields approximately 2,200 tons per day of feedstock. The expected yield is 38 gallons of ethanol and 13 gallons of higher alcohols per ton of RDF. This translates to a single plant capacity of 27 million gallons per year of ethanol and 9 million gallons per year of higher alcohols.

To calculate the production cost in dollars per gallon of ethanol, the total cost of constructing and operating an *nth* plant (assuming the resolution of all first-of-kind expenses) was estimated using CHEMCAD process modeling software and other analytical tools. The total project investment cost for a refinery co-located with a large landfill was calculated to be $449 million (in 2008 dollars). The syngas conditioning component of the plant was the largest contributor to the overall plant cost at 37%, followed by the RDF production component at 23% (Table 1).

Using this project investment cost with additional heat and material balance information, catalyst cost assumptions, energy prices, and labor, an ethanol cost-per-gallon of $1.85 was calculated. Despite higher capital costs as compared to the woody biomass design case, the synthesis of ethanol from MSW can be achieved at lower costs because feedstock costs are assumed to be $0, as compared to $60/ton for woody biomass. The costs are also lower because scrap metal recovered during the RFD production process can be sold to recycling facilities. The ethanol production cost does not include any costs downstream from the refinery (Table 2).

A sensitivity analysis was conducted to determine the effect of uncertainties surrounding key assumptions on the ethanol production cost. Given the large capital cost, a critical uncertainty is the rate of return the facility will need to generate to satisfy investors. The analysis assumes an internal rate of return (IRR) of 10%. A 20% IRR results in a production cost of about $4.85 per gallon. Another major uncertainty when dealing with MSW is the tipping fee, which is the amount the landfill charges to accept MSW. Nationally, tipping fees vary

Table 1: *Capital Costs for the MSW gasification and liquid fuel synthesis refinery (in 2008 dollars).*

Capital Costs	Millions $	% of Total
RDF production	$105	23%
Feedstock drying	$40	9%
Gasification, tar reforming, scrubbing	$67	15%
Syngas conditioning	$164	37%
Mixed alcohol synthesis	$20	4%
Mixed alcohol separation	$9	2%
Steam system and power generation	$34	8%
Remainder off-site battery limits	$9	2%
Total Capital Investment	**$449**	
Project Capitol investment per annual gallon ethanol	**$17/gal**	

Table 2: *Economic results for the synthesis of ethanol from MSW (in 2008 dollars).*

Operating Costs	$/gal
Raw Materials	
Feedstock (MSW)	0.00
Catalysts and Chemicals	0.10
By-product credits	
Higher alcohols	-0.39
Scrap Aluminum	-0.86
Scrap Iron	-0.58
Electricity sold to grid	-0.17
Waste treatment or Disposal	
Gasifier ash	0.00
MSW rejects	0.00
Spent carbon	0.00
Waste water treatment	0.03
Total variable cost, $/gal ethanol	-1.86
Fixed costs, $/gal ethanol	0.87
Capital depreciation, $/gal ethanol	0.82
Average income tax, $/gal ethanol	0.56
Average return on investment (10% IRR)	1.46
Estimated Selling Price (10% IRR), $/gal ethanol	**1.85**

per ton from about $25 to over $70, with an average fee of $34. It is uncertain how much, if any, of a tipping fee MSW-to-ethanol facilities will be able to charge. The analysis assumes no tipping fee, or $0 per ton feedstock. If the facility can charge the national average tipping fee, this generates a feedstock credit of about $30 per ton and lowers the ethanol production cost to $1.35. Also, if improvements in synthesis gas cleanup and catalysis expected by 2012 are realized, the production cost is lowered by more than $1/gallon. Other sensitivities include the RDF process, toxicity of the MSW, and scrap metal recycling. The effect of these on the ethanol production cost can be seen in Figure 2.

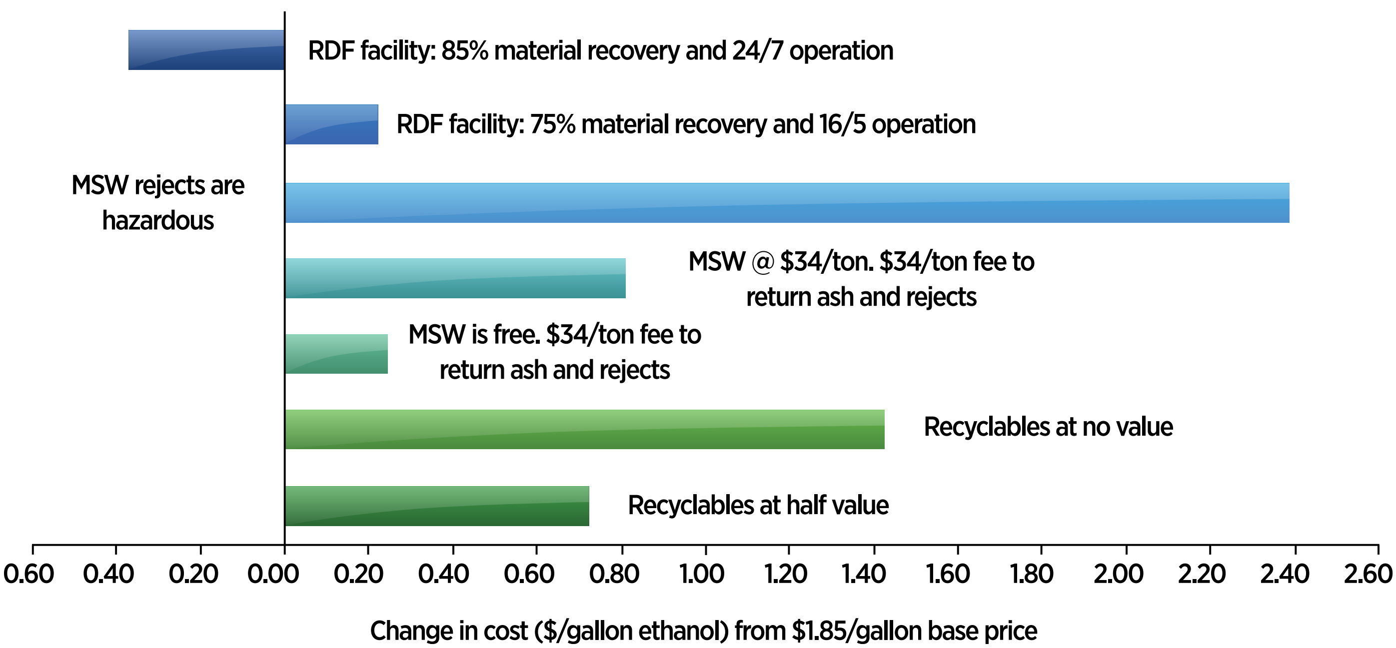

Figure 2: *Results of a sensitivity analysis of certain key assumptions on the ethanol production price.*

Conclusions

The publication of this design case for synthesis of liquid fuels from the cellulosic component of municipal solid waste (MSW) establishes a benchmark for the Biomass Program. By identifying key design capital and operating costs, as well as significant sensitivities to the cost of production, the Program can move forward in setting research, development, and deployment (RD&D) priorities to speed the commercialization of this advanced biofuel technology. Projected production costs for the *nth* plant are below $2 per gallon (in 2008 dollars), and make the gasification of MSW to produce ethanol a potentially attractive source of advanced, renewable biofuels. The Program is directing a diverse portfolio of RD&D activities to achieve commercial production of biofuels from gasified biomass. More information on project partners and technologies can be found by visiting *http://biomass.energy.gov*.

Development and commercialization of gasification, synthesis gas cleanup, and mixed alcohol catalysts will help meet the mandate in the *Energy Security and Independence Act of 2007* of 36 billion gallons (on an ethanol basis) of renewable fuel by 2022. Biofuels from gasification processes can also advance the Biomass Program's vision of a viable, sustainable domestic biomass industry that produces renewable biofuels, bioproducts, and biopower; reduces dependence on oil; provides environmental benefits, including reduced greenhouse gas emissions; and creates economic opportunities across the nation.

For additional information, visit http://biomass.energy.gov.

Complete report available here

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18482.pdf and *http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18144.pdf*

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