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

BIOMASS PROGRAM

DESIGN CASE SUMMARY

Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating, and Hydrocracking

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The full report “Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case” is available online from Pacific Northwest National Laboratory. The report was prepared in February 2009 for the U.S. Department of Energy.

Complete report available online

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The design case summary was prepared 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 grown domestically and in a sustainable manner. After harvesting, biomass feedstocks can be converted to valuable sources of renewable energy.

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 to sugars using either enzymatic or chemical processes and then converted to ethanol via fermentation. In thermochemical conversion, biomass is broken down to a liquid oil or a synthesis gas using heat and upgraded to fuels using a combination of heat and pressure in the presence of catalysts.

Harvesting a hybrid poplar plantation.
Photo courtesy of the Regional Feedstock Partnerships.

The Pyrolysis Design Case

Cost targets for converting biomass to renewable gasoline and diesel fuel

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 are 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 production costs. Past design cases focused on finding pathways toward cost-competitive production of ethanol. This design case is the first to establish detailed cost targets for the production of diesel and gasoline blendstock from biomass via a fast pyrolysis process.

Pyrolysis

Pyrolysis is a thermochemical process during which biomass feedstocks are broken down using heat in the absence of oxygen. This process produces a bio-oil intermediate that can be further refined to create renewable hydrocarbon transportation fuels. The decomposition occurs at lower temperatures than thermochemical gasification processes and produces a liquid oil instead of a synthesis gas. This bio-oil varies in oxygen content and viscosity depending on the feedstock that is used. A specific type of processing called "fast pyrolysis" involves rapidly heating the biomass in a reactor to approximately 500 degrees Celsius for less than 1 second. The bio-oil produced has to be hydrotreated in order to produce a liquid feedstock resembling crude oil. This bio-crude oil can be transported to an existing refinery and blended with petroleum crude oil. Blended oil then can go through the normal refinery process and the resulting product is a mixture of renewable gasoline and renewable diesel that is nearly identical to fossil-based gasoline and diesel. Alternatively, renewable gasoline and diesel can be produced from a stand-alone operation. This stand-alone option is highlighted in the design case.

Thermochemical Conversion:

Gasification

- Biomass is fed into a reactor at a high temperature and turned into a gas.
- This synthesis gas (syngas) is primarily carbon monoxide and hydrogen. Syngas must be cleaned and conditioned prior to catalytic upgrading.

Pyrolysis

- Biomass is broken down to to a bio-oil at lower temperatures than in gasification reactors.
- The bio-oil is highly oxygenated and must treated to reduce oxygen content prior to hydrocracking.

Pyrolysis is a process that breaks down woody biomass into bio-oil.

The Fast Pyrolysis Design Case

The fast pyrolysis design case represents technology that has been demonstrated at laboratory scales or is in the early stages of commercialization and includes advancements potentially achievable by 2017. 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 likely have higher costs. The operating assumption was a feed rate of 200 tons per day of hybrid poplar woody biomass as the feedstock. Hydrotreating the bio-oil to reduce the oyxgen content requires a supply of hydrogen. For the 2017 case, the process assumed that the bio-oil would be hydrotreated using hydrogen produced from natural gas via steam reforming. A conceptual diagram of process steps to take the hybrid poplar feedstock from delivery to the refinery to production of renewable gasoline and diesel is shown in Figure 1. These steps include:

1. Pretreating the feedstock, including drying and size reduction.
2. Processing the treated feedstock using fast pyrolysis to create a highly oxygenated liquid product.
3. Hydrotreating the fast pyrolysis oil to create a stable hydrocarbon oil with less than 2 percent oxygen.
4. Hydrocracking the heavy portion of the stable hydrocarbon oil.
5. Distilling the hydrotreated and hydrocracked oil into gasoline and diesel fuel blendstocks.
6. Producing hydrogen to support the hydrotreater reactors.

The design case also considers the option of producing the hydrogen via biomass gasification.

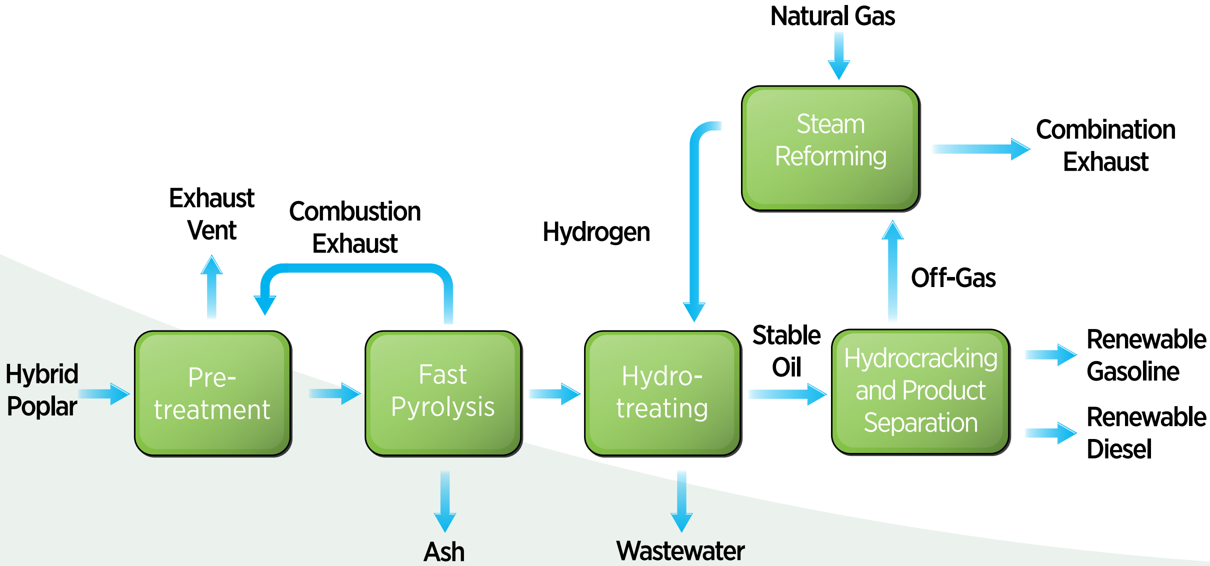


Figure 1: *The fast pyrolysis – hydrotreating – hydrocracking process to produce hydrocarbon blendstocks. This process illustrates a stand-alone refinery. Other pathways exist for stable pyrolysis oil, such as blending with fossil crude oil and feeding into existing refinery operations.*

Results of the Analysis

Based on experimental data, it is estimated that fast pyrolysis processes can produce about 29 pounds of renewable gasoline and diesel blendstock per hundred pounds of hybrid poplar feedstock at 7 percent moisture. This is roughly 100 gallons of fuel per ton of woody biomass. This includes the input of natural gas during the hydrotreating step. Relying only on biomass-generated hydrogen results in lower product yields. The basic assumption of the analysis is a stand-alone plant with the capacity to process 200 tons per day of woody biomass. This translates to a capacity of 76 million gallons per year of fuel production.

To calculate the production cost in dollars per gallon of gasoline equivalents, 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 the design case stand-alone plant was calculated to be U.S. $303 million. The fast pyrolysis, hydrotreating, and hydrogenation components of the plant were found to contribute almost a third of the cost each, with the remainder for hydrocracking and utilities (Table 1).

Using this project investment cost with additional heat and material balance information, catalyst cost assumptions, and 2007 energy prices, a cost-per-gallon of $2.04 was calculated. This represents the production cost of renewable gasoline and diesel fuel from woody biomass at the plant gate and does not include any costs downstream from the refinery. The largest single component of the production cost is the assumed feedstock cost of $50.70 per dry ton of hybrid poplar (Table 2). In the analysis, the possibility of substituting natural-gas-derived hydrogen with hydrogen derived from biomass was considered; however, this lowers the yield and raises production costs and was not considered feasible by 2017.

Table 1: *Total Project Investment Cost for the Design Case Stand-Alone Plant.*

	Cost, in million 2007 dollars	Contribution
Fast Pyrolysis	$92	30%
Hydrotreating	$81	27%
Hydrocracking and Separations	$29	10%
Hydrogen Generation	$86	28%
Utilities, etc.	$14	5%
Total Cost	**$303***	**100%**

** Summation higher due to rounding*

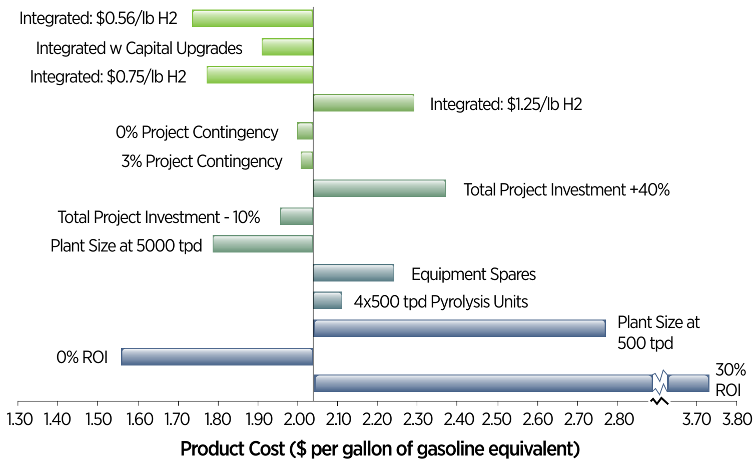
Table 2: *Economics for a Stand-Alone Pyrolysis Oil Production Plant , on an average annual basis. The main capital and operating contributions to the production cost are shown.*

	2007 dollars per gallon of product	Contribution
Feedstock (at $50.70 per dry ton)	$0.48	23%
Natural Gas (at $7.68 per square foot)	$0.32	16%
Catalysts and Chemicals	$0.15	7%
Waste Disposal	$0.01	negligible
Utilities (Cooling Water, Electricity, Steam)	$0.17	8%
Fixed Costs (Labor, Operating Supplies, etc.)	$0.22	11%
Capital Depreciation	$0.20	10%
Average Income Tax	$0.13	7%
Average Return on Investment*	$0.36	18%
Production cost, $ per gallon gasoline equivalent	**$2.04**	**100%**

Production Cost Ethanol Equivalent Basis, $/gallon 1.34
**Assumes a 10% after tax internal rate of return*

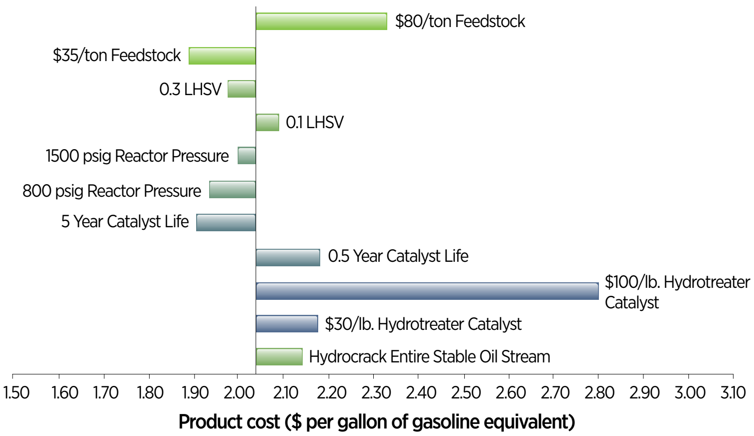
Sensitivity Analysis

A sensitivity analysis was conducted to determine the effect of uncertainties surrounding key assumptions on the production cost. Co-location with an existing refinery could lower costs. Financial and market parameters were varied, as well as research sensitivities. The financial and market sensitivites shows that the production cost is most sensitive to to the assumed Return on Investment (ROI), followed by the plant size, in tons per day (tpd) (Figure 2). The research sensitivities showed that the modeled production cost is most sensitive to catalyst cost, followed by delivered feedstock price (Figure 3).



ROI = return on investment
tpd = tons per day

Figure 2: *Financial Sensitivities to the cost of production of pyrolysis oil based renewable gasoline and diesel fuel.*



LHSV is the liquid hourly space velocity
psig is the pressure in the upgrading reactor; the base case assumed reactors at 2500 psig

Figure 3: *Research Sensitivities to the cost of production of pyrolysis oil based renewable gasoline and diesel fuel.*

Conclusions

The publication of this design case for fast pyrolysis of biomass to gasoline and diesel blendstock 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 priorities to speed the commercialization of this advanced biofuel technology. Production costs near $2 per gal (in 2007 dollars) and petroleum industry infrastructure-ready products make the production and upgrading of pyrolysis oil to hydrocarbon fuels an economically attractive source of renewable fuels. The program is directing a diverse portfolio of research, development, and deployment activities to achieve commercial production of pyrolysis oils. More information on project partners and technologies can be found by visiting *http://biofuels.energy/gov*.

Development and commercialization of pyrolysis oils 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. Pyrolysis oils 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.

Complete report available here

www.pnl.gov/main/publications/external/technical_reports/PNNL-18284rev1.pdf

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