



90-Billion Gallon Biofuel Deployment Study

Executive Summary

Sandia National Laboratories and General Motors' R&D Center conducted a joint biofuels systems analysis project from March to November 2008. Known as the “90-Billion Gallon Biofuel Deployment Study,” the purpose of the project was to assess the feasibility, implications, limitations, and enablers of large-scale production of biofuels in the United States.

Ninety billion gallons of ethanol (the energy equivalent of approximately 60 billion gallons of gasoline) per year by 2030 was chosen as the book-end target to understand the requirements of an aggressive biofuels deployment schedule. Since previous studies have addressed the biomass supply potential, but not the supply chain rollout needed to achieve large biofuels production targets, the focus of this study was to develop a comprehensive systems understanding of the evolution of the complete biofuels supply chain and key interdependencies over time.

The biofuels supply chain components examined in this study included direct agricultural land use changes, production of biomass feedstocks, storage and transportation of these feedstocks, construction of conversion plants, conversion of feedstocks to ethanol at these plants, transportation of ethanol and blending with gasoline, and distribution to retail outlets. To support this analysis, a ‘Seed to Station’ system dynamics model (Biofuels Deployment Model – BDM) was developed to explore the feasibility of meeting specified ethanol production targets. System dynamics was chosen as the primary modeling approach because it is well suited to dynamic, non-linear problems involving time-varying inputs and feedback – two central features of the biofuels enterprise.

Potential biofuels supply chain barriers examined in this study included impact on land availability and use; impact on water consumption; the transportation and distribution infrastructure challenges and bottlenecks; costs for feedstock, capital, and energy; the reluctance to make long-term investments due to risk; the pace of technological innovation; and the greenhouse gas footprint. Sensitivity analyses were conducted to determine key parameters affecting production volumes, cost, and greenhouse gas savings. The effectiveness and costs of selected policy options to mitigate potential barriers were also examined.

Study Conclusions

This study concludes that 90 billion gallons per year of biomass-derived ethanol can be produced and distributed with enduring government commitment and continued technological progress. Specifically, the model projects that 90 billion gallons of ethanol can be produced per year in the U.S.: 15 billion gallons per year from corn ethanol, with the balance from cellulosic ethanol.

In the study we also evaluated a scenario with 15 billion gallons of corn-derived ethanol and 21 billion gallons of cellulosic ethanol by 2022, an amount that meets the Energy Independence and Security Act advanced biofuels mandate. In this scenario, cellulosic ethanol continues to ramp up to 45 billion gallons per year by 2030, for a total ethanol production of 60 billion gallons per year. This scenario is the basis for the conclusions summarized below.

Producing 45 billion gallons per year cellulosic ethanol by 2030 requires 480 million tons of biomass, of which 215 million tons comes from dedicated energy crops. Allowing for storage, loss, and immature perennial crops, these energy crops utilize 48 million acres of planted cropland from what is now idle or pasture. The simulations assume technological progress in the conversion technologies, which results in average biomass conversion yields of over 95 gallons of ethanol per dry ton of biomass by 2030.

Biofuels capital expenditures necessary to achieve 60 billion gallons per year of installed production capacity are on the order of \$250 billion. Though large, these expenditures are actually of similar magnitude to petroleum-related investments required to establish and maintain 40 billion gallons per year of domestic oil production. However, large capital investments are challenging considering the present volatility of the oil and capital markets and the amount of regulatory risk.

This study demonstrates that cellulosic biofuels can compete with oil at \$90/bbl based on the following assumptions:

- 1) Average conversion yield of 95 gallons per dry ton of biomass
- 2) Average conversion plant capital expenditure of \$3.50 per installed gallon of nameplate capacity
- 3) Average farm-gate feedstock cost of \$40 per dry ton

Sensitivity analyses varying these assumptions individually gave potential cost-competitiveness with oil priced at \$70/bbl to \$120/bbl.



The cost competitiveness of ethanol is directly dependent on the price of oil and the realization of technological improvements. In particular, ethanol ‘seed-to-station’ floor cost is approximately \$1.50/gal-ethanol without taxes, and gasoline will undercut this if priced below \$2.25/gal-gasoline without taxes (about \$2.65 at the pump). Government policy incentives such as carbon taxes, excise tax credits, and loan guarantees for cellulosic biofuels have the ability to mitigate the risk of oil market volatility, thus reducing the risk and increasing the attractiveness of cellulosic biofuels investments. However, these policy incentives would have to protect cellulosic biofuels against low priced petroleum-based competitors for an extended period to attract significant capital investment.

Continued support of R&D and initial commercialization is also critical, because sustained technological progress and commercial validation are required to affordably produce the large volumes of ethanol considered in this study. Infrastructure investment is important to ensure that the rail network in the U.S. can support biofuels distribution; however, this is a small component of projected total rail demands resulting from future expanded economic activity.

Significant R&D effort is required for conversion plants to increase their yields to drive down the cost of biofuel production. Additionally, continued R&D efforts are required to achieve commercial cultivation of high-yield energy crops – key to producing significant volumes of sustainable biofuels without drawing upon land currently used for food and feed. Additionally, expanding feedstock production must target lands requiring little or no irrigation to keep water demands manageable.

Transportation CO₂ savings were 250 million tons CO₂ equivalent per year for 60 billion gallons of ethanol (excluding greenhouse gas emissions from land use change – a current topic of intense research). The energy in cellulosic ethanol is about 3.8 times the energy content of fossil fuels used for the entire supply chain (production and distribution; numbers based, in part, on assumptions in GREET). This is about 4 times the net energy ratio for gasoline (0.8).

Biofuels Commercialization Enablers

This study found no fundamental barriers to producing biofuels at large scale (e.g., supply chain or water constraints). However, multiple actions could be taken to enhance the successful build-out of the cellulosic biofuels industry.



Possible actions include:

- A multi-decade energy policy that values stable fuel prices that are high enough to enable energy diversity in light of oil price volatility and periodic economic dislocations
 - Options include greenhouse gas taxes and market incentives (e.g., \$50/ton CO₂ tax significantly reduces required incentives)
- Supportive policies to enable biofuel market success, including well-planned market incentives and carbon pricing, that could minimize investment risks
- Enhancement of biofuels' competitiveness with aggressive R&D- and commercialization-associated funding, despite current declining/low oil prices (Department of Energy, VCs, etc.)
 - Conversion investments to increase conversion efficiency and decrease capital cost
 - Improved energy crop technology to reduce cost, land use, and water use
 - Decreased timeframe for technologies to reach maturity (lowers investment risk)

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