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Alternative Liquid Fuels Simulation Model (AltSim)

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ABSTRACT

The Alternative Liquid Fuels Simulation Model (AltSim) is a high-level dynamic simulation model which calculates and compares the production costs, carbon dioxide emissions, and energy balances of several alternative liquid transportation fuels. These fuels include: corn ethanol, cellulosic ethanol, biodiesel, and diesels derived from natural gas (gas to liquid, or GTL) and coal (coal to liquid, or CTL). AltSim allows for comprehensive sensitivity analyses on capital costs, operation and maintenance costs, renewable and fossil fuel feedstock costs, feedstock conversion efficiency, financial assumptions, tax credits, CO_2 taxes, and plant capacity factor.

This paper summarizes the preliminary results from the model. For the base cases, CTL and cellulosic ethanol are the least cost fuel options, at $1.60 and $1.71 per gallon, respectively. Base case assumptions do not include tax or other credits. This compares to a $2.35/gallon production cost of gasoline at September, 2007 crude oil prices ($80.57/barrel). On an energy content basis, the CTL is the low cost alternative, at $12.90/MMBtu, compared to $22.47/MMBtu for cellulosic ethanol. In terms of carbon dioxide emissions, a typical vehicle fueled with cellulosic ethanol will release 0.48 tons CO_2 per year, compared to 13.23 tons per year for coal to liquid.

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Introduction

This report summarizes initial progress in creation of an Alternative Liquids Simulation Model (AltSim). This model development was funded as a late start LDRD at Sandia National Laboratories. This report summarizes the preliminary results from this work. The model is very much still a work in progress, so all results are preliminary in nature and should not be further disseminated.

The Alternative Liquid Fuels Simulation Model (AltSim) is a high-level dynamic simulation model which calculates and compares the production costs, carbon dioxide emissions, and energy balances of several alternative liquid transportation fuels. These fuels include: corn ethanol, cellulosic ethanol, biodiesel, and diesels derived from natural gas (gas to liquid, or GTL) and coal (coal to liquid, or CTL). AltSim allows for comprehensive sensitivity analyses on capital costs, operation and maintenance costs, renewable and fossil fuel feedstock costs, feedstock conversion efficiency, financial assumptions, tax credits, CO_2 taxes, and plant capacity factor.

AltSim also includes several policy tools, which examine land use requirements for corn, CO_2 pricing, and ethanol tax credits. The model is useful to executives and staff in the Congress, the Administration and private industry for understanding the economic viability, sustainability, and current feasibility of the alternative liquid transportation fuels.

AltSim is written in Powersim Studio Enterprise 2007[5], a dynamic simulation-modeling software package. The model's easy to use policy screens allow the user to explore "What-if?" questions, such as:

- Under what conditions can corn ethanol compete economically with reformulated gasoline—and how sensitive to corn prices is the price of ethanol?

- What capital costs (and/or capacity utilization) allow gas to liquid to compete with low sulfur diesel?

- What type of tax credits (cents/gallon) makes corn ethanol the least cost option and how much will this cost taxpayers?

- How might adoption of a mandatory renewable fuels policy affect the amount of available arable land if corn ethanol is the sole source of alternative fuels?

This paper provides an overview of the model structure, base case results and detailed sensitivity analysis on capital costs, feedstock prices, and feedstock efficiencies.

[5] Powersim Studio Enterprise 2007 is a product of the Powersim Corporation: www.powersim.com

Model Structure and Assumptions

AltSim calculates projected levelized cost of energy (LCOE)[6] for a wide variety of liquid fuel technologies: corn and cellulosic ethanol, biodiesel, coal to liquid, gas to liquid, reformulated gasoline and low sulfur diesel.[7] All values are for new plants, and where a technology has not yet been implimented on a commercial scale, the best estimates from industry and experts were used. The base case technical and economic assumptions are summarized in Tables 1 and 2. Further details about each option will be included in a companion document to this preliminary, end of year progress report.

[6] Sometimes referred to as production costs.
[7] The costs given in this paper are for newest available technologies for each option.

Table 1. Cost and Performance Characteristics for Liquid Transportation Fuels (US$)

	Capital ($/Daily Barrel or Gallon)	O&M ($/ Barrel or Gallon)	Feedstock ($/Unit)	Years to Construct	Plant Size (Daily Output)	Capacity Factor (%)	Fuel Efficiency (fuel per feedstock)
Gasoline (Barrel)	41,400	5.75	80.57 crude	6	53,182	90.0	1.00
Diesel (Barrel)	110,108	5.75	80.57 crude	6	19,996	90.0	1.00
Corn Ethanol (Gallon)	904	0.31	$3.55/ bushel corn	2	374,797	97.0	2.78
Cellulosic Ethanol (Gallon)	1039	0.11	$50/ dry ton corn stover	2	189,863	96.0	70.00
Biodiesel (Gallon)	414	0.24	$0.35/ lb soy oil	2	27,397	90.0	0.13
Gas to Liquid (Barrel)	107,142	14.70	$4.00/ thousand cubic feet	6	140,000	90.0	0.09
Coal to Liquid (Barrel)	75,000	24.00	$24.00/ ton	6	120,000	90.0	1.59

Table 2. Other Fuel Cost Assumptions

	Cost ($/Unit)
Electricity (kWh)	0.05268
Coal (MMBtu)	1.76
Gas (MMBtu)	6.36

LCOE is often used as an economic measure of energy costs as it allows for comparison of technologies with different capital and operating costs, construction times, and capacity factors. The LCOE calculation is given by:

$$LCOE = \frac{I * FCR}{Q} + \frac{O \& M}{Q} + \frac{E}{Q} \qquad (1)$$

where:
- I = Capital investment, including financing charges (interest rate initially set at 10%)
- FCR = Fixed charge rate
- Q = Annual plant output
- O&M = Fixed and variable O&M
- E = Externality costs.

The fixed charge rate (FCR) is calculated using:

$$FCR = \frac{CRF[1 - bT\sum_{n=1}^{M} V_n /(1 + d_n)^n - t_c]}{(1 - T)} + p_1 + p_2 \qquad (2)$$

where:
- CRF = capital recovery factor
- b = fraction of investment that can be depreciated
- T = effective tax rate
- M = Depreciation period
- V_n = fraction of depreciable base in year n
- d_n =nominal discount rate
- t_c = tax credit
- p_1 = annual insurance cost
- p_2 = other taxes

Depreciation follows the depreciation method Modified Accelerated Cost Recovery System (MACRS). Under IRS regulations, most utility type investments use either a 15 or 20 year depreciation schedule. Certain investments, such as renewables, are allowed to use a 5 year depreciation schedule. The capital recovery factor (CRF) is calculated using:

$$CRF = r * \frac{(1 + r)^n}{(1 + r)^n - 1} \qquad (3)$$

where:
- r = real discount rate (initially set at 10%)
- n = plant life (initially 20).

Financing costs assume that capital expenditures are uniformally distributed over the time of construction.

To begin, the model looks at the most important factor in the alternative liquid fuels debate -- crude oil. Crude is the driving force behind gasoline and diesel prices and as the world looks to replace these, it is important to look at the alternative sources for the conventional fuels, including tar sands and oil shale. Figure 1 is a screenshot of the tar sands section of the model. This allows the user to change the source of the crude and the market prices used throughout the model. The base cases assume that market-priced crude is the feedstock for the gasoline and diesel. From this screen, one can select either tar sands or oil shale as the feedstock for purposes of comparison.

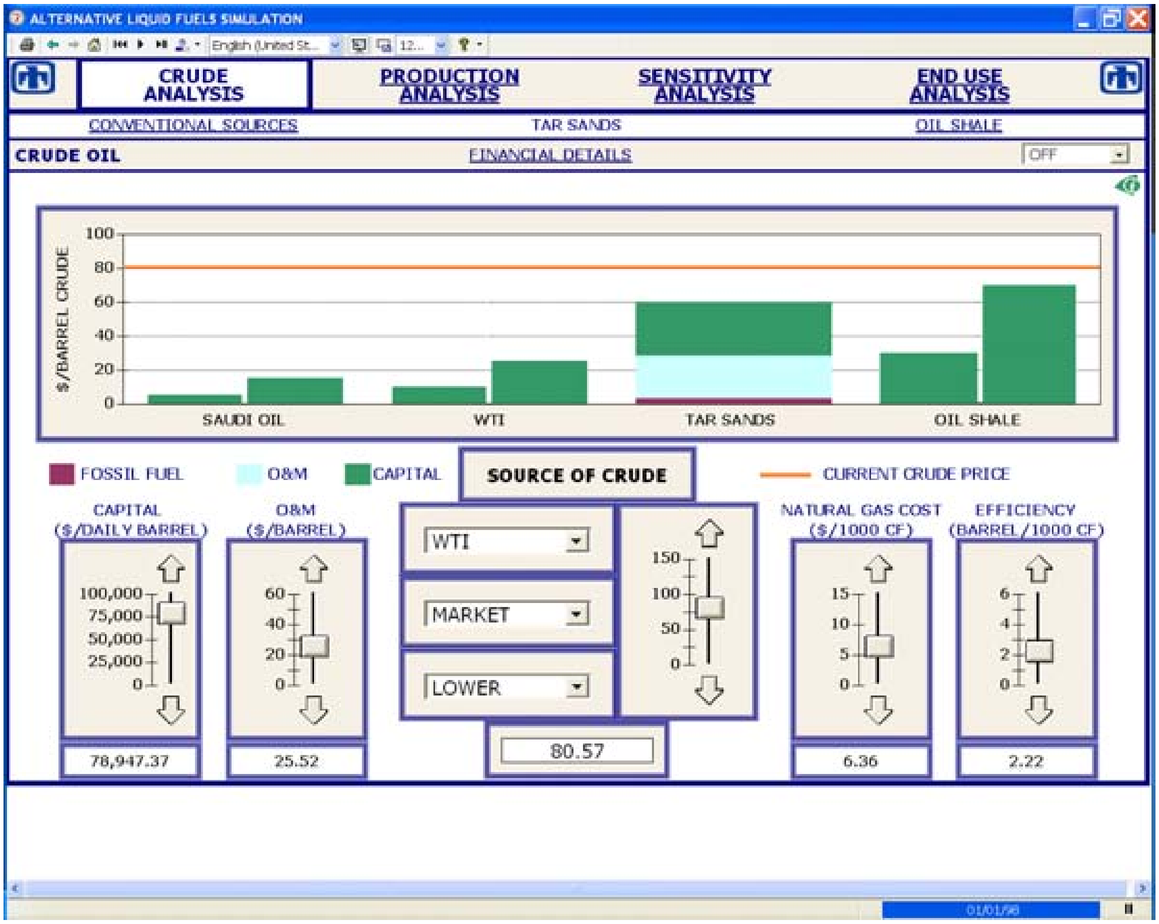

Figure 1. Representative AltSim Crude Analysis Screen (tar sands) Showing Production Costs for all Crude Sources by $/barrel

Figure 2 shows a representative production analysis screen (corn ethanol). Hyperlinks along the top allow the user to change screens. For example, clicking on gasoline moves the user to the gasoline specific production screen. These production screens show the estimated cost per gallon for each of the alternative liquid fuels. The same data is available in tabular form by pressing the "Table" hyperlink, Figure 3. The model also allows comparison of the fuels on an energy basis ($/MMBtu) by clicking on the "$/MMBtu" hyperlink. As illustrated by Figure 4, the production cost by energy content reveals a significant difference.

Figure 2. Representative AltSim Production Analysis Screen (corn ethanol) Showing Production Costs for all Fuels by $/gallon

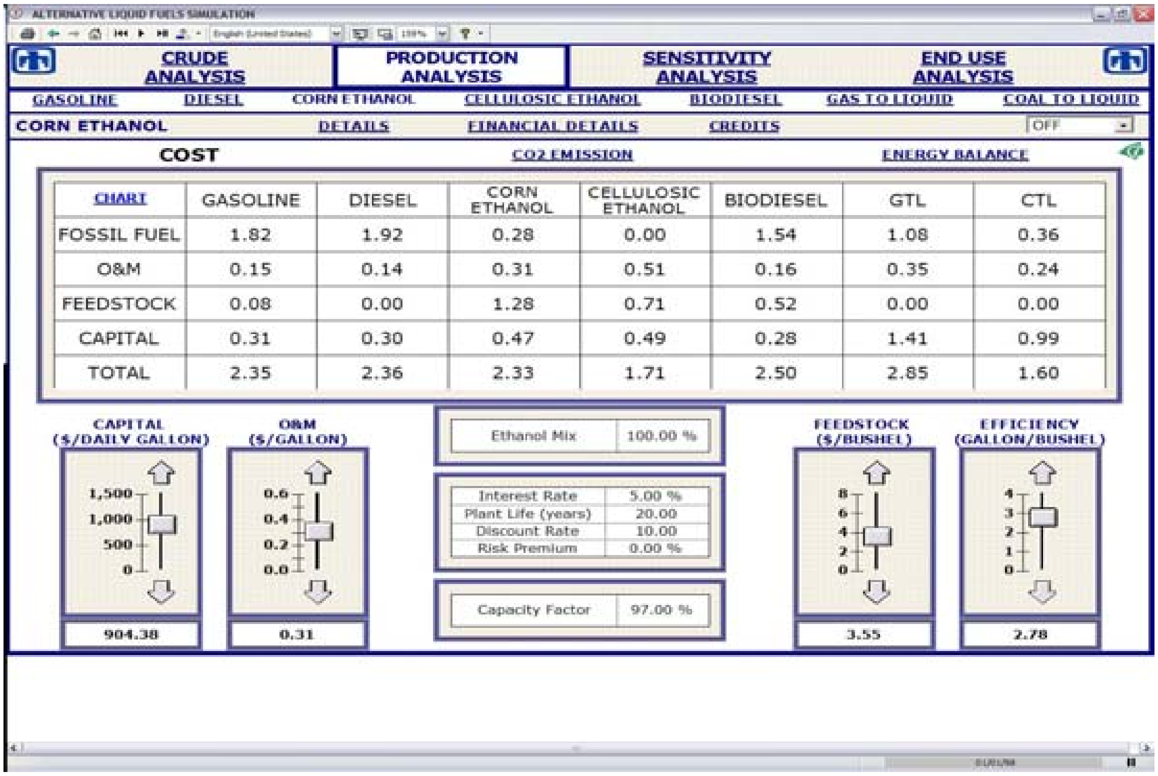

CHART	GASOLINE	DIESEL	CORN ETHANOL	CELLULOSIC ETHANOL	BIODIESEL	GTL	CTL
FOSSIL FUEL	1.82	1.92	0.28	0.00	1.54	1.08	0.36
O&M	0.15	0.14	0.31	0.51	0.16	0.35	0.24
FEEDSTOCK	0.08	0.00	1.28	0.71	0.52	0.00	0.00
CAPITAL	0.31	0.30	0.47	0.49	0.28	1.41	0.99
TOTAL	2.35	2.36	2.33	1.71	2.50	2.85	1.60

Figure 3. Tabular Results for $/Gallon

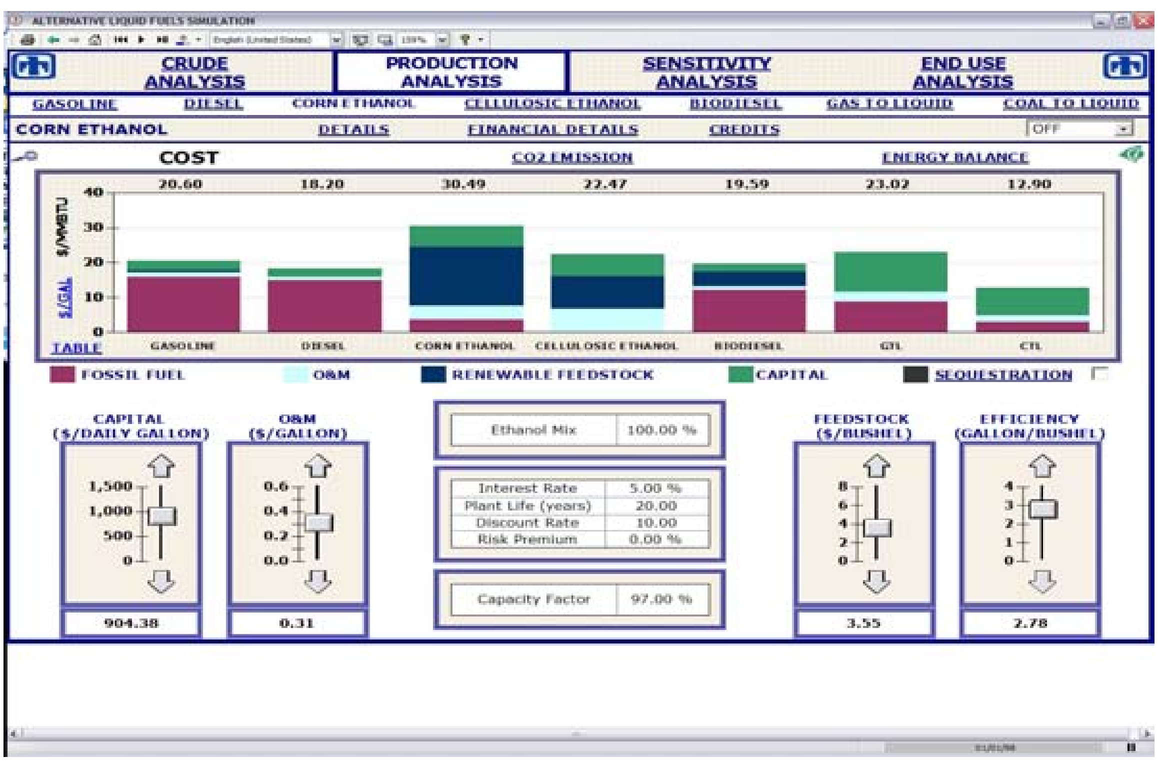

Figure 4. Representative AltSim Production Analysis Screen (corn ethanol) Showing Production Costs for all Fuels by $/MMBtu

The end use analysis of AltSim compares per mile and annual fuel costs for average vehicles in the U.S. For example, the annual cost to produce the fuel for a gasoline powered vehicle that gets 23.1 mpg and is driven 12, 500 miles per year is $1,276, Figure 5. The end use analysis section also includes estimates of the total CO2 released during the annual operation of these vehicles and the total energy required to produce the fuel for these vehicles

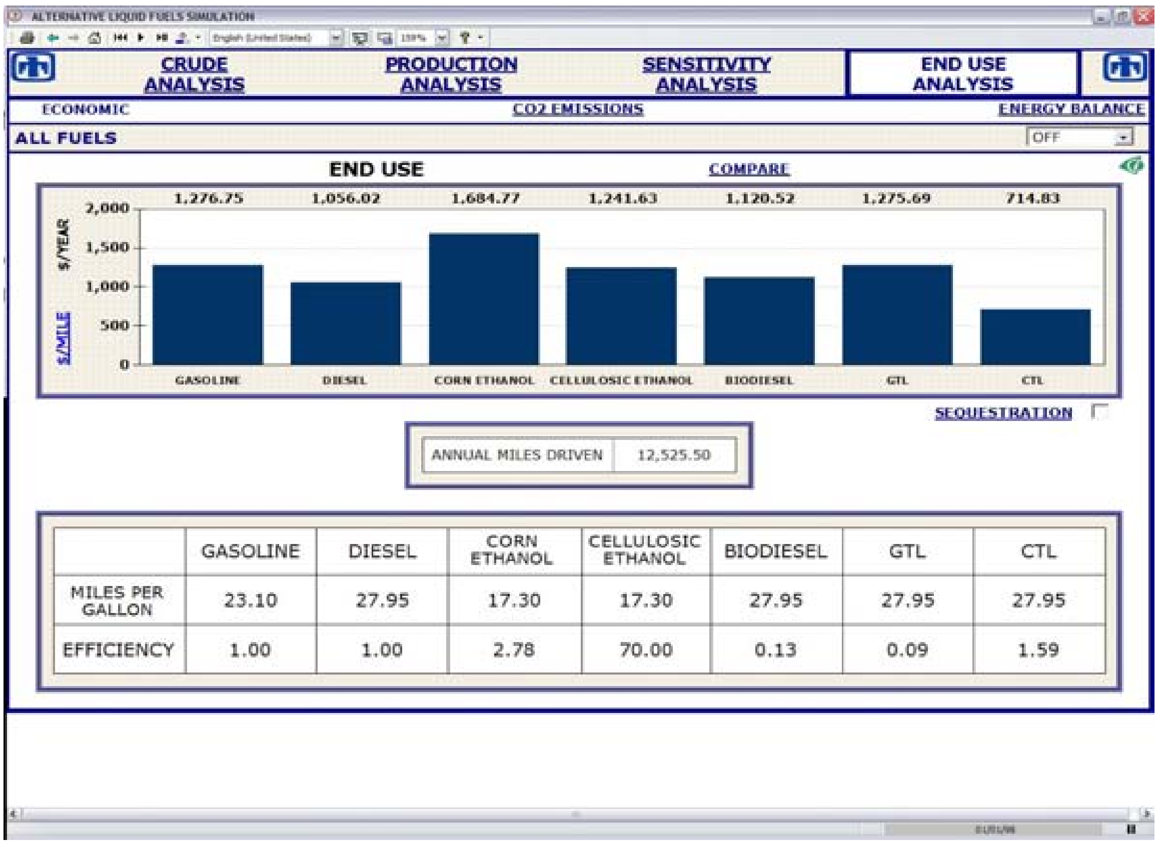

Figure 5. Representative AltSim End Use Analysis Screen Showing Annual Costs for all Fuels

Table 3 summarizes the production costs by fuel on both a volumetric ($/gallon) and energy content ($/MMBtu) basis. These production costs do not include renewable tax credits, carbon dioxide pricing, distillers grain credit, or sequestration. On a volumetric basis, the CTL ($1.60) and cellulosic ethanol (1.71) are the low cost options. However, on an energy content basis, CTL ($12.90) is the clear winner.

Table 3. Comparison of Base Case Results Between Gallons and MMBTU

	$/gallon	$/MMBtu
Gasoline	2.35	20.60
Diesel	2.36	18.20
Corn Ethanol	2.33	30.49
Cellulosic Ethanol	1.71	22.47
Biodiesel	2.50	19.59
Gas to Liquid	2.85	23.02
Coal to Liquid	1.60	12.90

The CO_2 emissions are calculated on a "well to wheel" basis using estimated carbon coefficients from Argonne National Laboratory's GREET model[8]. Figure 6 illustrates the emissions per mile (in grams CO2 per mile) for the various liquid fuels. While AltSim projects that CTL is the low cost fuel, the estimated emissions are more than double those of conventional gasoline if the CTL production does not include carbon capture and sequestration. The estimated emissions from the corn and cellulosic ethanol are lower than conventional gasoline.

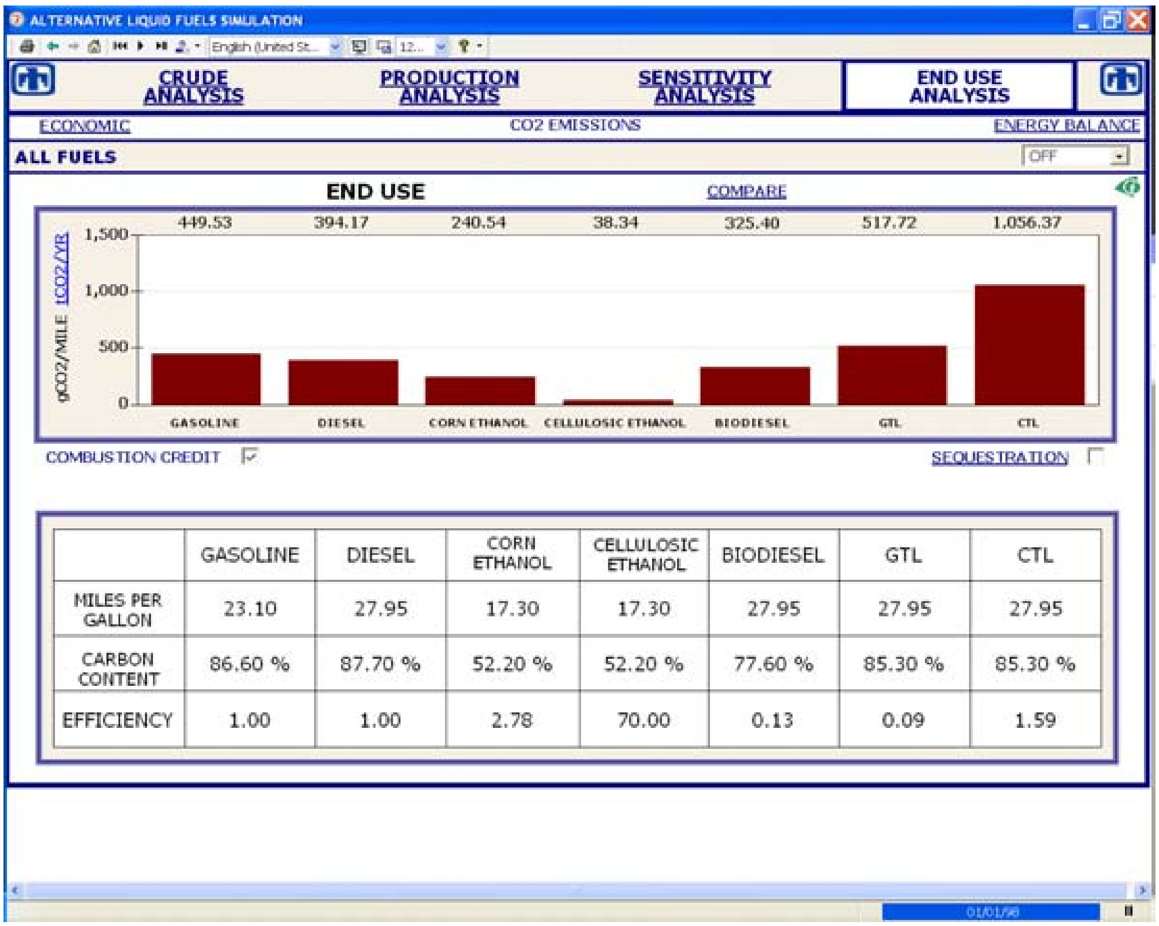

Figure 6. Representative AltSim CO_2 Emissions Analysis Screen

[8] Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation or GREET model.

The sensitivity analysis screen in the model allows the user to adjust several key variables, including capital cost; feedstock cost; and conversion efficiencies. Figure 7 illustrates the main sensitivity screen. Moving the slider for the cost of a bushel of corn changes the estimated production cost. Using this feature, it is possible to quickly find breakeven points with alternative fuels. Just as in the production analysis, the sensitivity analysis can be shown on either a $/gallon or a $/MMBtu basis.

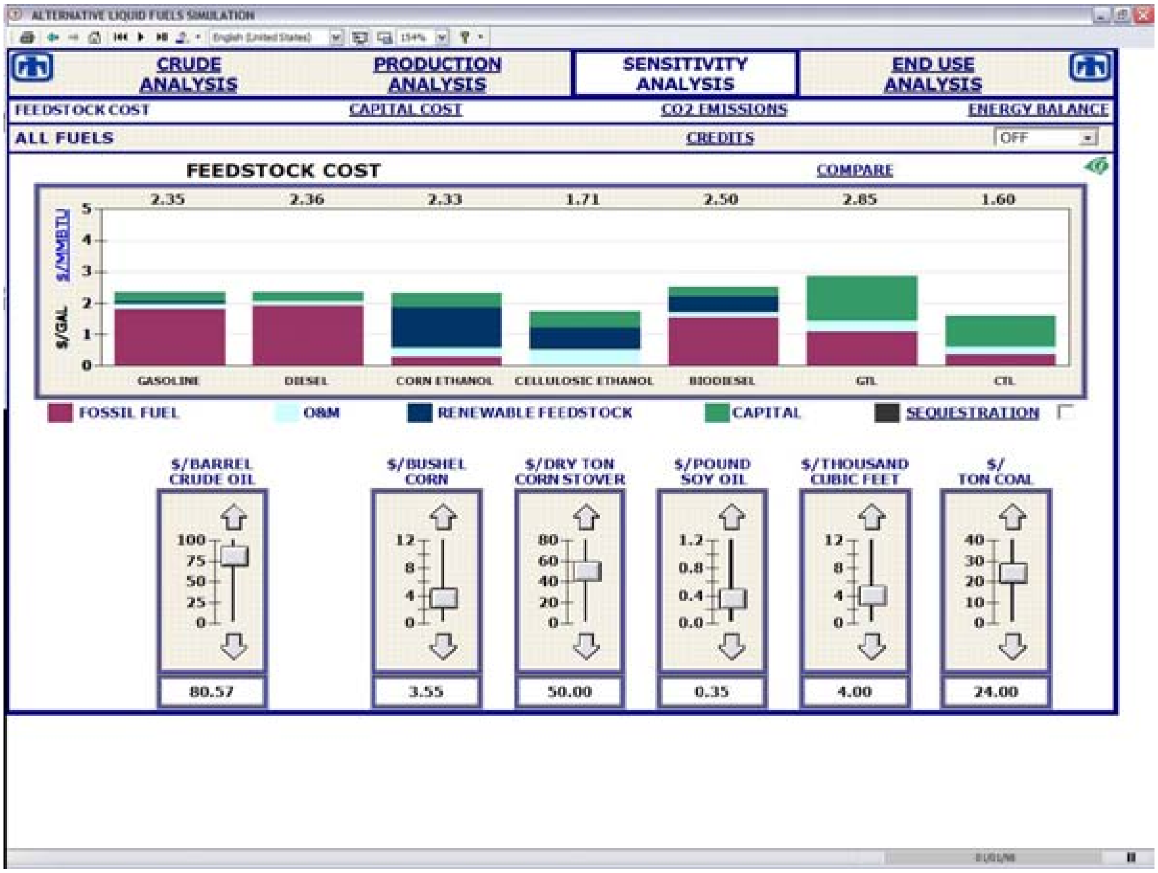

Figure 7. Representative Sensitivity Analysis Screen (Feedstock)

Sensitivity Analysis

The sensitivity screens are useful for examing scenarios such as: at what crude price would cellulosic ethanol be too expensive to produce? The answer, using the sensitivity screen, is that crude would need to drop to $51.50 per barrel before cellulosic ethanol was too expensive. This has important implications given the volatility in crude prices. Using the same process, corn ethanol stops being cost competitive at $79, which shows just how dependent the fuel is upon tax credits, such as the $0.51/gallon federal production tax credit.

The following three sections provide a more detailed sensitivity analyses, derived from AltSim. In the first section, production costs for various technologies are plotted against their respective capital cost. This type of analysis is useful for determining how the senstivity of these results in terms of the estimated capital costs. The next section determines the feedstock cost breakeven points, such as at the cost of corn at which corn derived ethanol can compete with cellulosic ethanol. The third section discusses the results of sensitivity analysis for the conversion efficiency of the fuels. As some technologies are new and have room for improvement, the future feasibility can be examined with this analysis.

Capital Costs Sensitivity Analysis

Figures 8-11 illustrate breakeven points based on varying capital costs.

The overall sensitivity of the capital cost for CTL is shown in Figure 8. The default CTL capital cost is $75,000 per daily barrel (db). This analysis suggests CTL can compete economically with low sulfur diesel produced from $81 per barrel oil for capital costs below $132,500/db.

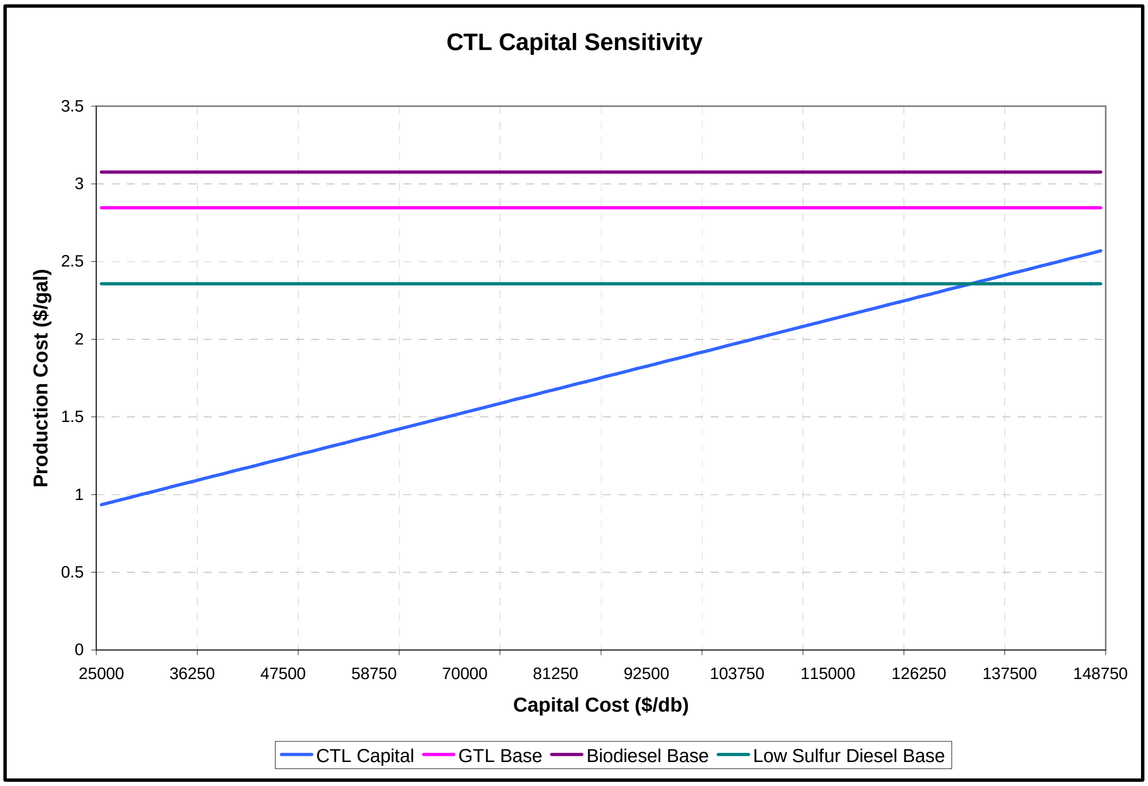

Figure 8. Coal to Liquid Capital Cost Sensitivity

Figure 9 shows the sensitivity of the GTL capital costs. The default GTL capital cost is $107,142/db. At a capital cost of $70,000/db, gas to liquid technology is cost competitive with low sulfur diesel. Even with a quartering of capital cost, GTL still cannot compete with CTL.

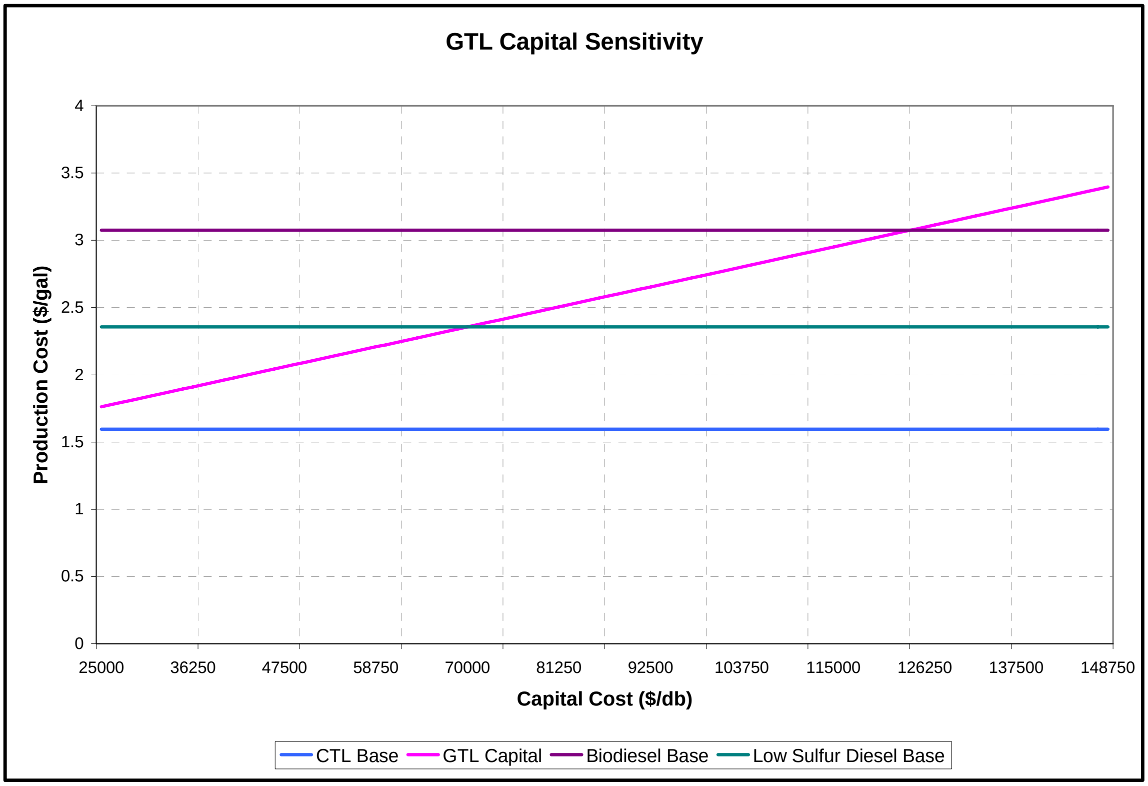

Figure 9. Gas to Liquid Capital Cost Sensitivity

In Figure 10, corn ethanol capital costs are compared to the base cases of its replacement fuels. The default corn ethanol capital cost is $904 per daily gallon (dg). A capital cost of $950/dg is the breakeven for gasoline. This sensitivity analysis suggests it will take more than just lower capital costs for corn ethanol to compete with cellulosic ethanol.

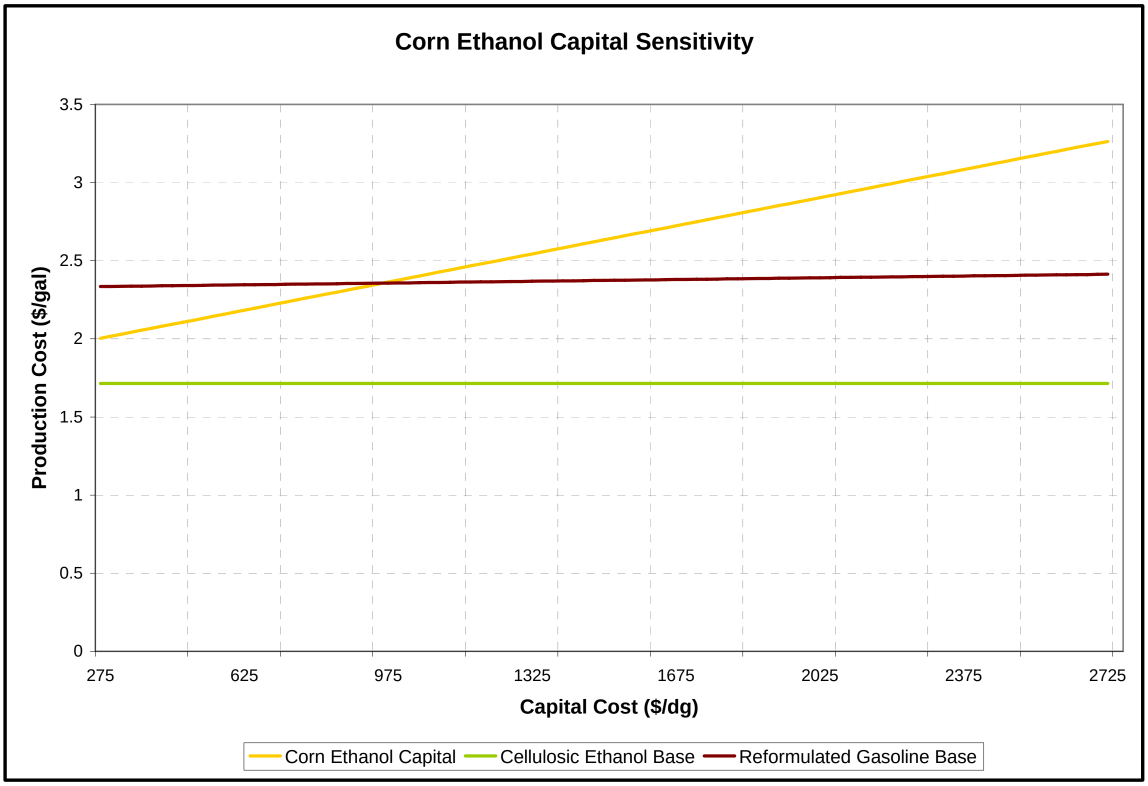

Figure 10. Corn Ethanol Capital Cost Sensitivity

Figure 11 illustrates the sensitivity of cellulosic ethanol capital costs. The default corn ethanol capital cost is $1,039/dg. At capital costs of $2325/dg cellulosic breaks even with corn ethanol and at $2400/dg it breaks even with gasoline. This is a more than doubling of capital costs buffer of economic feasibility.

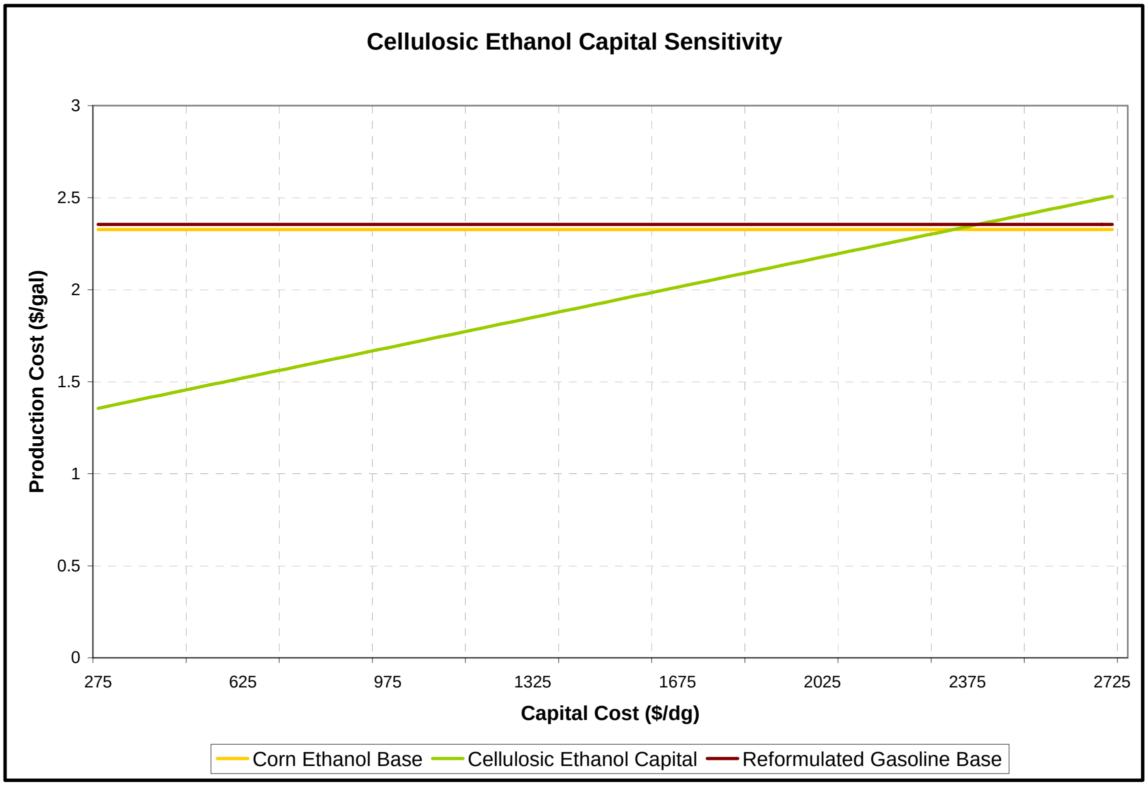

Figure 11. Cellulosic Ethanol Capital Cost Sensitivity

Feedstock Price Sensitivity Results

Figures 12 – 16 illustrate the sensitivity of the results to feedstock costs.

Figure 12 shows that the results are not highly sensitive to the assumed cost of coal. Coal prices would have to more than double from the assumed cost of $24 per ton for CTL not to be the low cost option, holding all else constant.

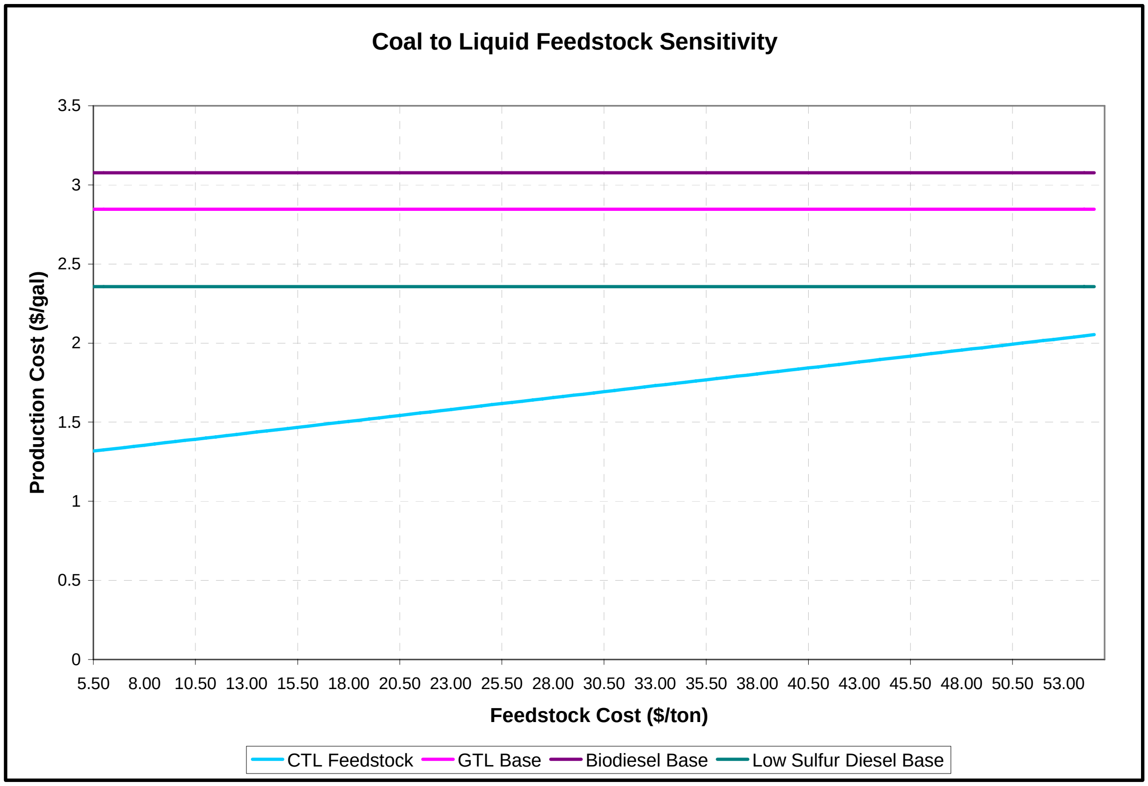

Figure 12. Coal to Liquid Feedstock Sensitivity

The estimated production costs for GTL are highly sensitive to natural gas costs, Figure 13. In the base case, Altsim's natural gas prices are based on the estimated value of the stranded natural gas assets in Qatar ($4/thousand ft^3). Holding all else constant, GTL is not competitive with the other fuels for natural gas prices above $4.85/ thousand cubic feet, making GTL an unlikely option in most regions of the world.

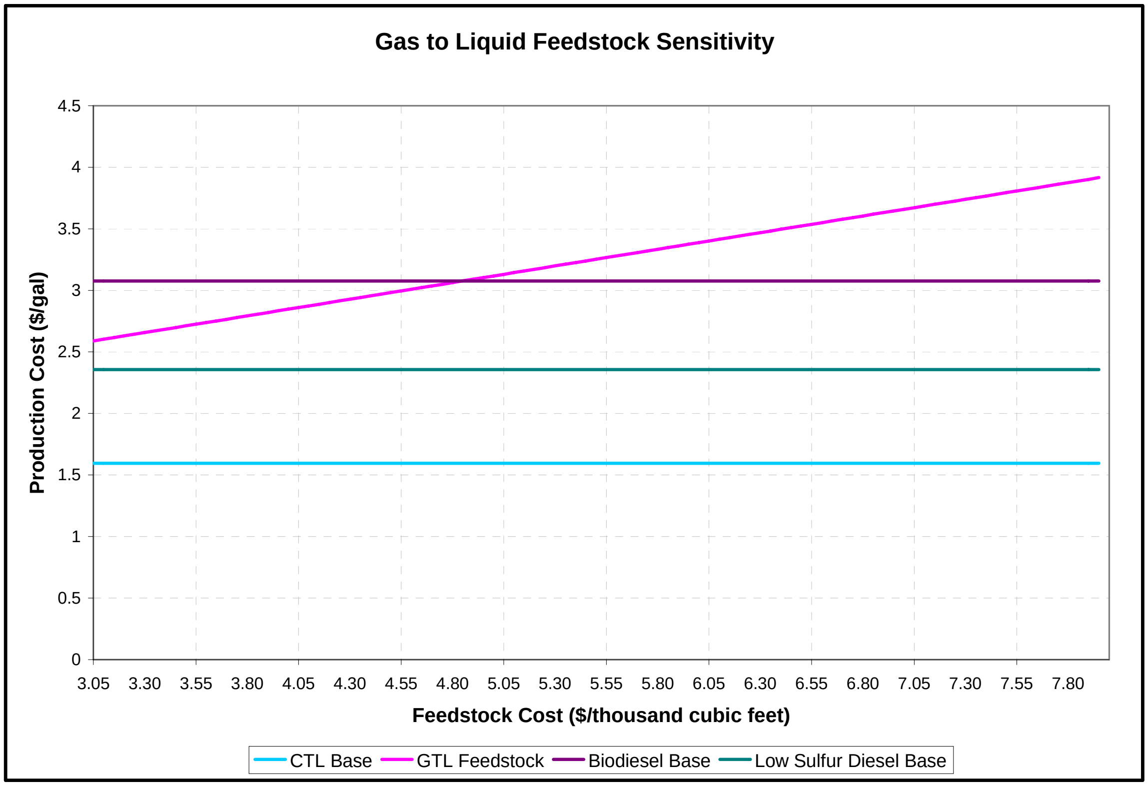

Figure 13. Gas to Liquid Feedstock Sensitivity

Corn prices have risen dramatically in the last year due to the increasing demand for ethanol production. Figure 14 shows that ethanol production costs are highly sensitive to the feedstock costs. At a cost of $3.65/bushel, corn ethanol can compete with gasoline, which itself has ethanol in it due to the federal replacement of MTBE with ethanol. The sensitivity to the price of corn allows the fuel to compete with cellulosic at $1.85/bushel.

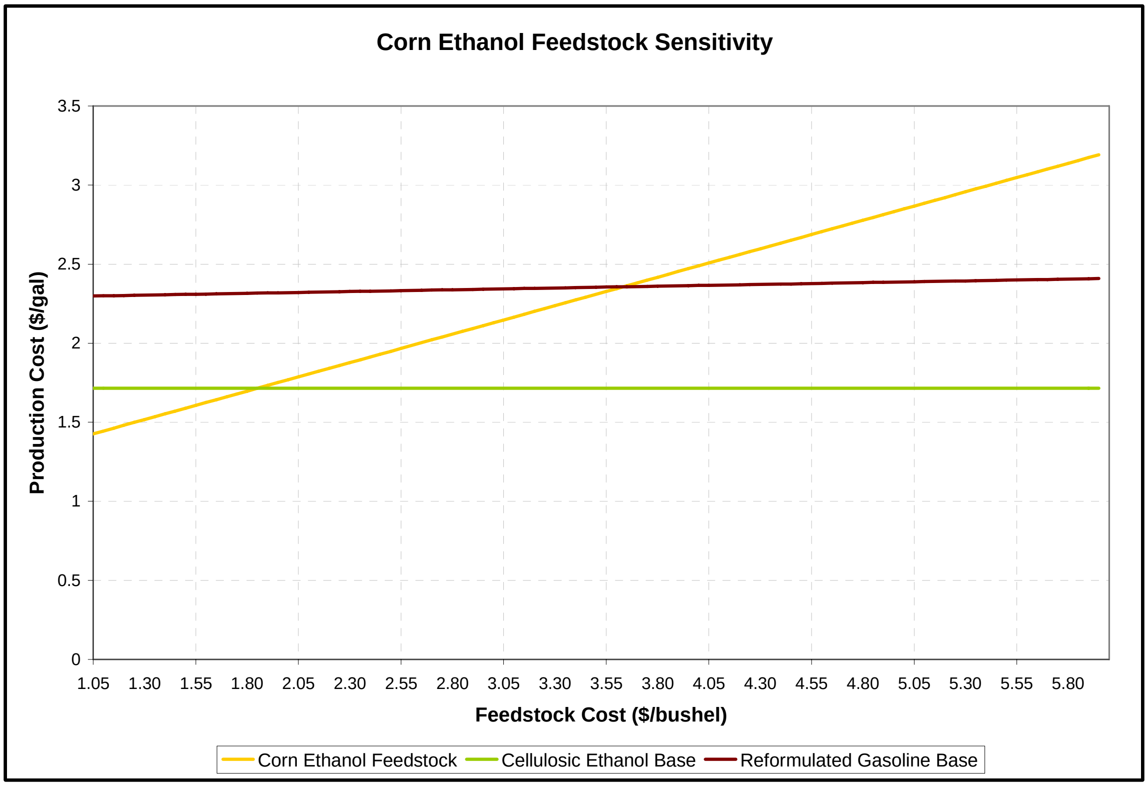

Figure 14. Corn Ethanol Feedstock Sensitivity

Wide-scale use of corn for ethanol production is limited by arable land requirements. Further scaling up of ethanol use in this country will require cellulosic feedstocks. There is considerable uncertainty about the overall economic viability of cellulosic ethanol. This sensitivity analysis provides an examination of just how the pricing can define the future of the fuel. As seen in Figure 15, the price of corn stover can increase up to $93/dry ton before the breakeven point with Corn Ethanol.

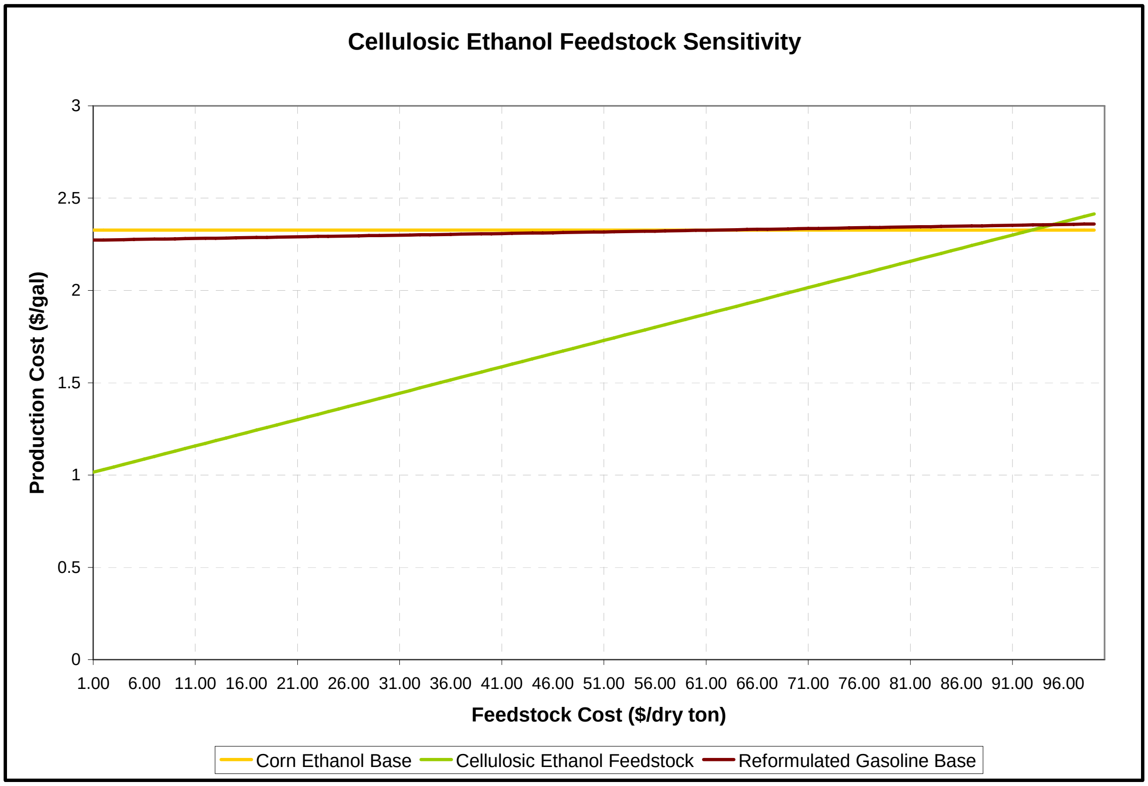

Figure 15. Cellulosic Ethanol Feedstock Sensitivity

Figure 16 shows the sensitivity of gasoline and diesel to crude prices. This analysis illustrates some of the key breakeven points for alternative fuels. Corn based ethanol, for example, is not competitive at crude prices below about $80 per barrel without tax credits. By comparison, cellulosic ethanol is competitive above crude prices of $52 per barrel and CTL above $49 per barrel. GTL is unlikely to be economical for crude prices below $100/barrel.

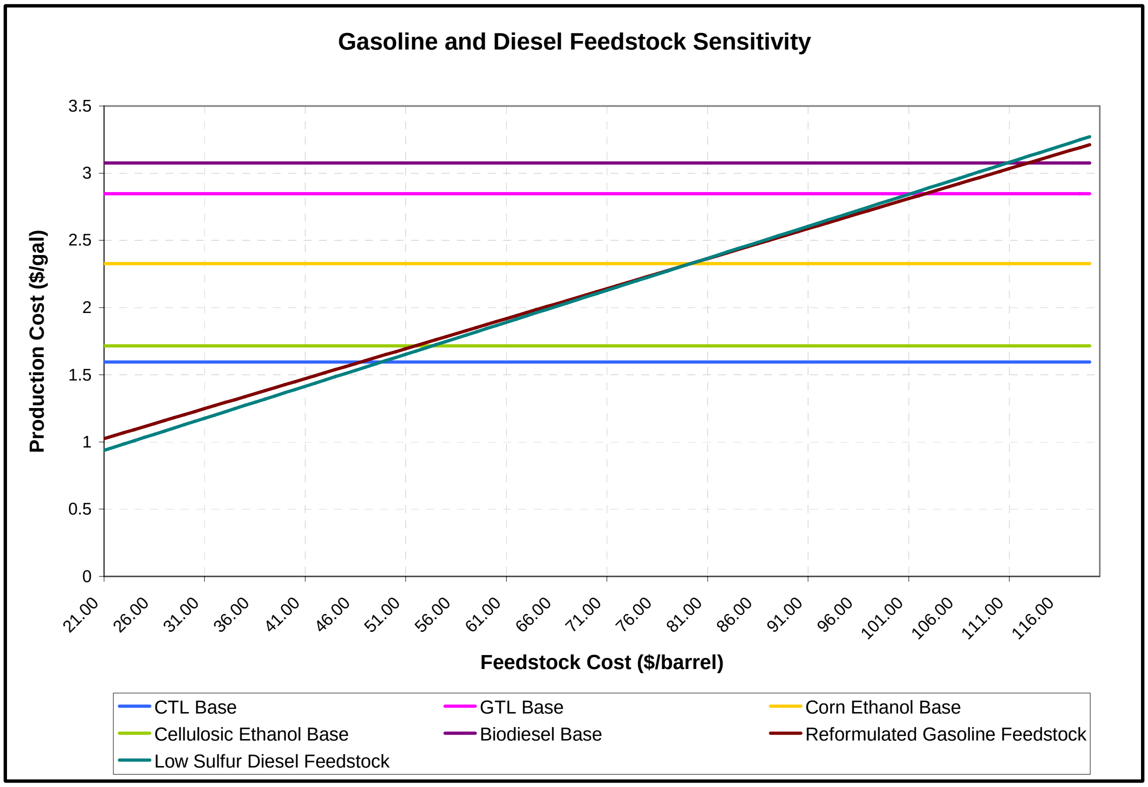

Figure 16. Gasoline and Diesel Feedstock Sensitivity

Efficiency Sensitivity Analysis

The amount of feedstock needed to product a unit of each of the fuels is an inherent driving force in the feasibility of each fuel. Figures 17 and 18 are two examples of the technologies which stand the best chance of benefiting from technological advances.

The first of the two fuels is coal to liquid, which has a base efficiency of 1.59 barrels/ton. As seen in Figure 17, a change in the conversion rate does little to change the basic economic result suggested by AltSim.

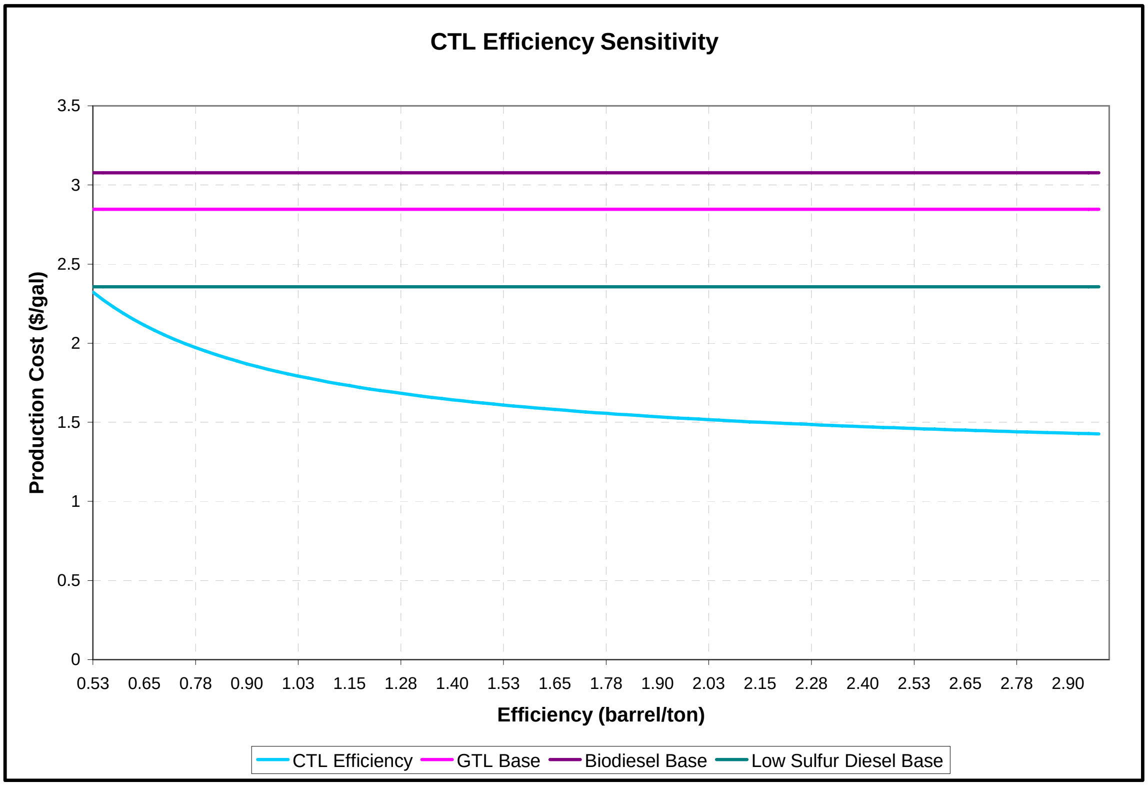

Figure 17. Coal to Liquid Efficiency Sensitivity

Figure 18 shows the sensitivity of the price of the feedstock for cellulosic ethanol – in this case, corn stover. For the conversion ratio analyzed here (50 to 100 tons per gallon), the production costs drop by $0.50 per gallon. The base case assumes a conversion efficiency of 70 gallons/dry ton.

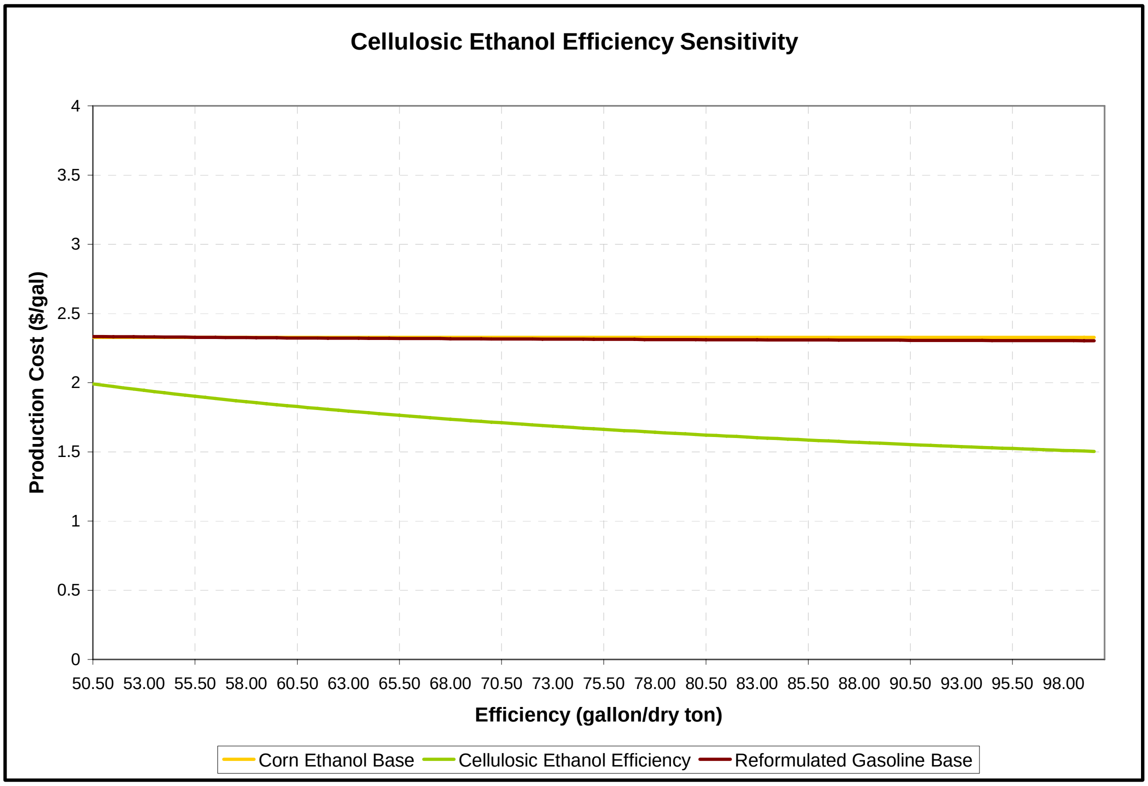

Figure 18. Cellulosic Ethanol Efficiency Sensitivity

Policy Tools

AltSim includes several tools for examining policy issues associated with these fuels. It is important to policy makers to look not just at the basic economics, but how different taxes, credits, or policies will change the fuel's economics and environmental impact.

One of the major concerns of the fossil fuel alternatives is the large amount of carbon dioxide emissions released in the production processes. AltSim includes an option to use sequestration for CTL and GTL. This changes the economics, emissions, and energy balance of both fuels, illustrating how the use of this technology can make these fuels cleaner and competitive. The production cost of CTL and GTL change from $1.60/gallon to $2.47/gallon and $2.85/gallon to $3.05/gallon, respectively. This increase in cost results in a reduction of emissions for a typical vehicle from 13.23 tons/year and 6.48 tons/year to 6.35 tons/year and 4.57 tons/year, respectively.

AltSim also includes consideration of carbon taxes as a policy tool. Inclusion of carbon taxes has a considerable effect on the base case results, Figure 19. Cellulosic ethanol becomes even cheaper due to its renewable carbon credit, while CLT can become the least economical. For example, a carbon tax of $50 per ton CO_2 adds $1.00/gallon to the cost of CTL.

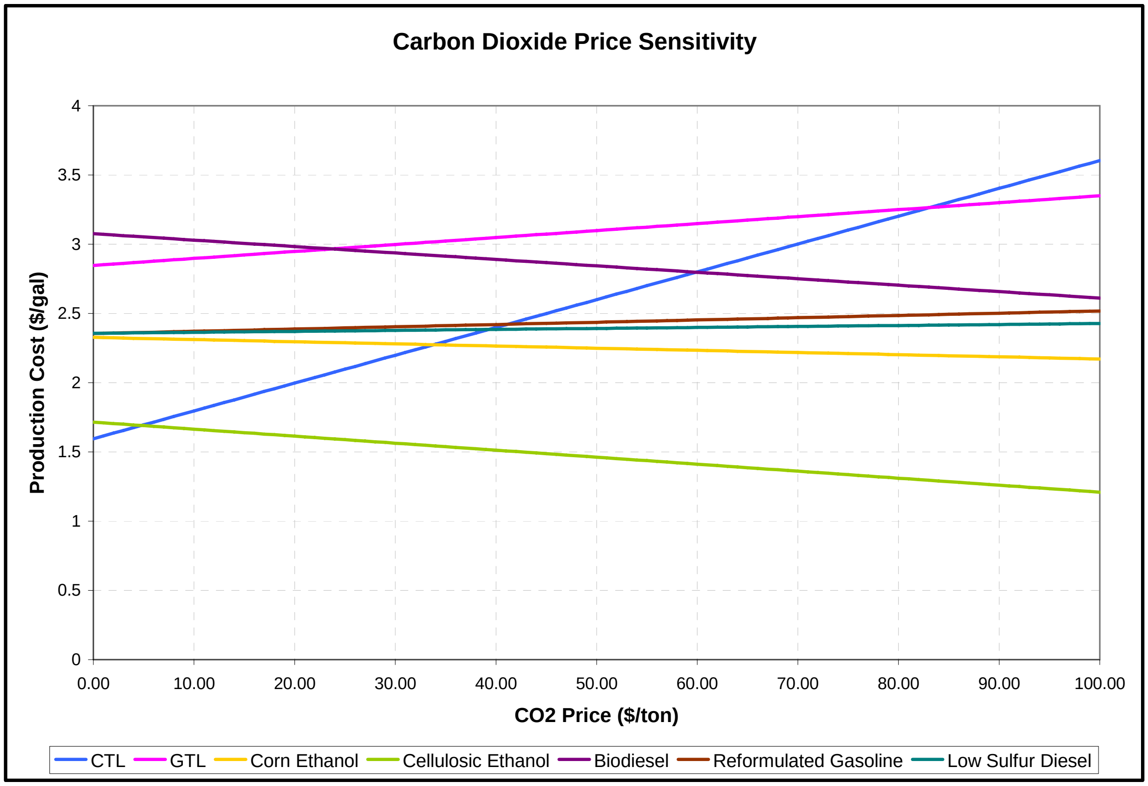

Figure 19. Carbon Dioxide Price Sensitivity

Future Work

AltSim is a work in progress. Preliminary versions of this model have been shown to various government agencies, World Resources Institute, and at the 27th Annual Conference of the U.S. and International Association of Energy Economists (USAEE/IAEE). Based on comments from these meetings, additional refinement to AltSim is recommended before these results are disseminated. In particular, the following are priority items for continued development:

- Examination of non-liquid fuels for comparison (i.e. hybrid or electric cars)
- Sequestration options for fuels other than GTL and CTL
- Consideration of water requirements
- Vehicle efficiency (CAFE) analysis
- Economics of oil shale
- Addition of biocrude
- Consideration of alternative tax structures (i.e. royalties for tar sands, Canadian vs. U.S. taxes)

- Expand feedstock choices for cellulosic (model now includes corn stover and switchgrass options)
- Break out the fossil fuel costs for cellulosic ethanol (corn stover) as is done for corn ethanol
- Transportation cost for feedstock
- Consideration of distribution costs (model only includes production costs at this time)

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