OPTION 2I
GAS-TO-LIQUID AND
COAL-TO-LIQUID DIESEL FUEL

Summary

In this option, staff considers various scenarios that would result in greater use of gas-to-liquid (GTL) and coal-to-liquid (CTL) diesel fuels. Blends of GTL or CTL fuels with petroleum diesel are considered the likely application for California's transportation fuels market. Staff evaluates the cost and benefits of a ten cents per gallon subsidy applied to the GTL and CTL portion of a diesel fuel blend.

Overview

Natural gas is playing an increasingly important role in the global energy mix.[1] The earth has enormous reserves of natural gas and the extent of known reserves is increasing. Some natural gas reserves are under-utilized. Over the years, energy companies have accumulated large assets of "stranded gas," natural gas reserves that cannot economically be brought to market due to their distant locations. These stranded gas assets are candidates for future GTL production facilities.

The U.S. has enormous coal resources. Through CTL technology, the country potentially has over 1.5 trillion barrels of oil, using coal and shale deposits which offer energy security and energy diversity benefits. This volume is significantly greater than the estimates of 685 million barrels of oil reserves in the Middle East.[2] Both GTL and CTL are important and necessary stepping stones for the possible progression to biomass-to-liquid (BTL) derived fuels, which is discussed in detail in the *Renewable Diesel* [3] staff paper.

GTL and CTL fuels are made by the Fischer-Tropsch reaction, which converts gas into a synthetic diesel-like fuel. Recent advances in Fischer-Tropsch processes and GTL and CTL technologies promise environmentally clean, competitively priced diesel fuel. The GTL and CTL processes can produce a fuel identical in quality, physical properties, and specifications to traditional diesel.

Lower-cost fuels from GTL processes were commercially proven in 1996-1998.[4] This accomplishment sparked significant interest with nearly every major oil company. Today there are at least four new, multi-billion-dollar GTL plants which are either in the engineering-planning stage or under construction. The first of the new generation of GTL plants, using the improved process, is scheduled to begin production in 2006.

Background

Processing natural gas into petrochemicals has been a commercial option for many decades. Converting natural gas into gasoline or diesel has been slower to reach commercial status because it is much more expensive. The process for converting natural gas to gasoline or diesel was discovered in 1923 by Franz Fischer and Hans Tropsch. This chemical reaction is called the “Fischer-Tropsch” reaction and the resultant fuel is called either Fischer-Tropsch Diesel (a U.S. Department of Energy term) or gas-to-liquid (an industry term).

The GTL process has benefited from several improvements developed in the 1980s and mid-1990s, separately, by Sasol, Syntroleum, ARCO and Exxon. Since 1995 there has been a flurry of worldwide activity by nearly every major oil company with natural gas holdings to build GTL plants. Sasol Synfuels Incorporated significantly improved their commercial process in 1998. Since then, the capital expenditure cost of GTL has dropped from over $40,000 to less than $20,000 per barrel.[5] By comparison, new (world scale) petroleum refinery capital expenditures are $15,000 to $16,000 per barrel.[6] Conservative estimates of $24,000 to $26,000 per barrel for GTL are commonly cited in literature. As new GTL plants are built, these values are expected to decrease.

The United States Department of Energy (U.S. DOE) considers GTL to be 96-100 percent non-petroleum. In addition, U.S. DOE asserts that GTLs being substantially non-petroleum provides some energy security benefit.[7] According to U.S. General Accounting Office analysis, a GTL fuel’s non-petroleum nature could be more important than where it is produced.[8] Source diversity offered by GTL production from remote natural gas sources provides greater diversity of oil production within and among geographic regions that benefits all market participants.

U.S. DOE did not find that Fischer-Tropsch Diesel (FTD) yields “substantial environmental benefits" within the meaning of section 301(2) of the Energy Policy Act of 1992 (EPACT).[9] A finding that a candidate fuel offers ”substantial environmental benefits" is necessary to designate it as an alternative fuel under section 301(2). U.S. DOE will keep its FTD rulemaking docket active so that stakeholders may submit new data and information relevant to FTD. DOE will evaluate the data periodically to make future decisions with regard to FTD designation as an alternative fuel.

Coal-to-liquid (CTL)

Coal can also be gasified, then chemically converted into a diesel fuel via a Fischer-Tropsch chemical reaction. The process has been commercially used for over 20 years in South Africa. CTL is not a renewable fuel, but its process is amenable to commercial scale biomass-to-liquid (BTL) plants. At a minimum, the carbon dioxide (CO_2) emissions from future CTL plants are assumed to be at the same level as those from conventional petroleum refining. Proponents claim that CO_2 mitigation technology exists and is optimally suited for CTL plants. In the *Renewable Diesel Vehicles* [10] staff paper, staff evaluates BTL plants presuming that CTL plants are built first and subsequently fed with biomass as favorable economics and environmentally policies are adopted.

Current and Future Plants

The three currently operating GTL plants use natural gas or coal and a late-1980's technology. Currently 80 percent of all GTL is produced using coal but all new plants planned internationally will use natural gas. At least four plants in the engineering design or construction stage target production for 2005-2012. Total new production is advertised at over 400,000 barrels per day, up to 75 percent of which can be diesel. The rest will be naphtha, waxes, or other petrochemicals. All the new proposed GTL plants will produce diesel, which is the most economic GTL fuel to produce and which has strong worldwide demand growth, especially for premium diesel.

In October 2003, Royal/Dutch Shell Group announced its agreement to construct a 140,000 barrel per day, $5 billion GTL plant in Ras Laaffan, Qatar. This new plant will use Shell's second generation proprietary Fischer-Tropsch catalysts, which were proven in Shell's Malaysia plant. Soon after Shell's announcement, Exxon and then ConocoPhillips made their own announcements for similarly sized GTL plants.

On July 14, 2004, Exxon Mobil Company Subsidiary announced its agreement to build the world's largest GTL plant, also in Ras Laaffan, Qatar. Exxon Mobil expects this $7 billion plant will produce 150,000 barrels per day of GTL products using Exxon's patented AGC-21 GTL process.

Two CTL projects are underway in the U.S.; one in Iowa and one in Wyoming (in the feasibility study stage), with the intended diesel products transported to California's markets by rail.

Properties of GTL Produced Fuels

Regardless of the feedstocks (natural gas, coal, or biomass) used in a Fischer-Tropsch GTL technology, the resultant fuel properties are superior to conventional ultra-low sulfur petroleum diesel. The GTL fuel properties listed in Table 1 illustrate some of the differences, when compared to California Air Resources Board (CARB) compliant diesel.

Table 1. GTL Fuel Properties Comparison

Fuel Properties	Cal Average Petroleum Diesel	GTL Diesel
Sulfur (ppm)	<15 & 130 State Avg.	0-5
Cetane No.	42 - 52	70+
Aromatics (%)	21	0-3

Emission reductions, with the use of neat GTL based on the average of six test programs, are shown in Table 2. Based on Shell's emission testing of GTL blends relative to European diesel, the most cost-effective blends for maximum emissions reduction are 30 to 50 percent GTL blends. However, specific testing is lacking for California's diesel reference case. Table 2 lists the typical emission reductions, using neat GTL fuel, from various test programs. However, based on CARB's Diesel Toxicity Reduction Program's requirement of retrofitted aftertreatment systems after 2010, no emission reduction is likely with the use of GTL fuels.

Table 2. GTL Exhaust Emission Reductions Relative to CARB Diesel

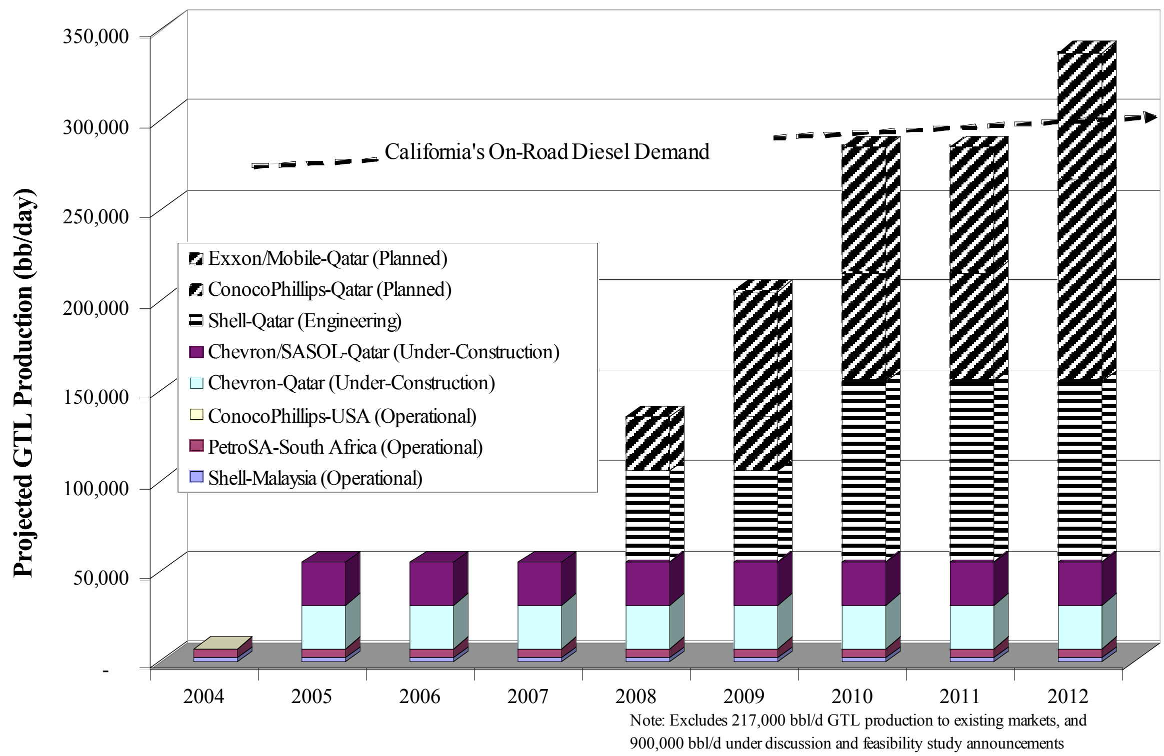
	Hydro-carbons	Carbon Monoxide	Oxides of Nitrogen	Particulate Matter	Carbon Dioxide
GTL (neat)	25 %	35 %	10 %	30 %	0-10 %[11]

According to the U.S. Environmental Protection Agency (EPA), a diesel fuel formulated with GTL derived from natural gas would normally satisfy federal requirements for registration as a baseline diesel fuel.[12] No federal limitation exists on the amount of GTL fuel that can be combined with petroleum diesel.

Supply

By 2010, worldwide production of GTL may increase significantly. Between now and 2012, some sources forecast GTL production to equal or exceed California's on-road diesel demand. (See Fig. 1) Although this new supply will flow to profitable markets and generally not to California, the state could establish policies that improve the prospects of using GTL to meet growing diesel demand.

Fig. 1 **Estimated Gas to Liquid Production of Diesel**



California Opportunity

From 1993 to 1998 four California refiners blended small quantities of GTL intermittently. When GTL costs were favorable, refiners could profitably blend GTL with U.S. EPA compliant diesel to make higher value CARB diesel. Small quantities of GTL blends, around 30 percent blended with petroleum diesel, were typically used during this period. GTL fuel can be blended in any ratio and generally maintains compliance with diesel fuel specifications.

Today, 5,000 barrels per day of GTL fuel is commercially available, but none is being used in California. On a few rare occasions in 2003, refineries blended GTL to produce diesel or bunker oil. This practice, however, has been largely discontinued, especially since Shell has created a GTL market in Thailand.

Shell markets Pura Diesel™, a blend of GTL fuel with conventional diesel, in over 150 retail stations in Thailand. In this market, consumers use this product in diesel vehicles to reduce smoke emissions. In major cities in Thailand, fines are issued to operators of diesel vehicles that produce excessive smoke. To avoid these fines, some drivers of diesel vehicles are prepared to pay a premium for this product.

While some consumers in Thailand will pay a premium for GTL fuel, Shell does not believe that this will be the case in other markets. In most markets, such as California, the majority of demand for diesel is from commercial users. These users are generally very price sensitive, operating on small margins, and experience suggests they will not pay a price premium for GTL fuel.

Since 2000, GTL demonstrations in California have shown very positive results. However, despite GTL's ease of use, and the benefits of reduced emissions and non-petroleum use, no state agencies or private consumers use this fuel today. In 2001, interested fleets could not use GTL as an emissions compliance mitigation strategy due to the fuel's lack of CARB emissions verification, and absence of air quality management policies accepting GTL's use as a mitigation or fleet compliance option.

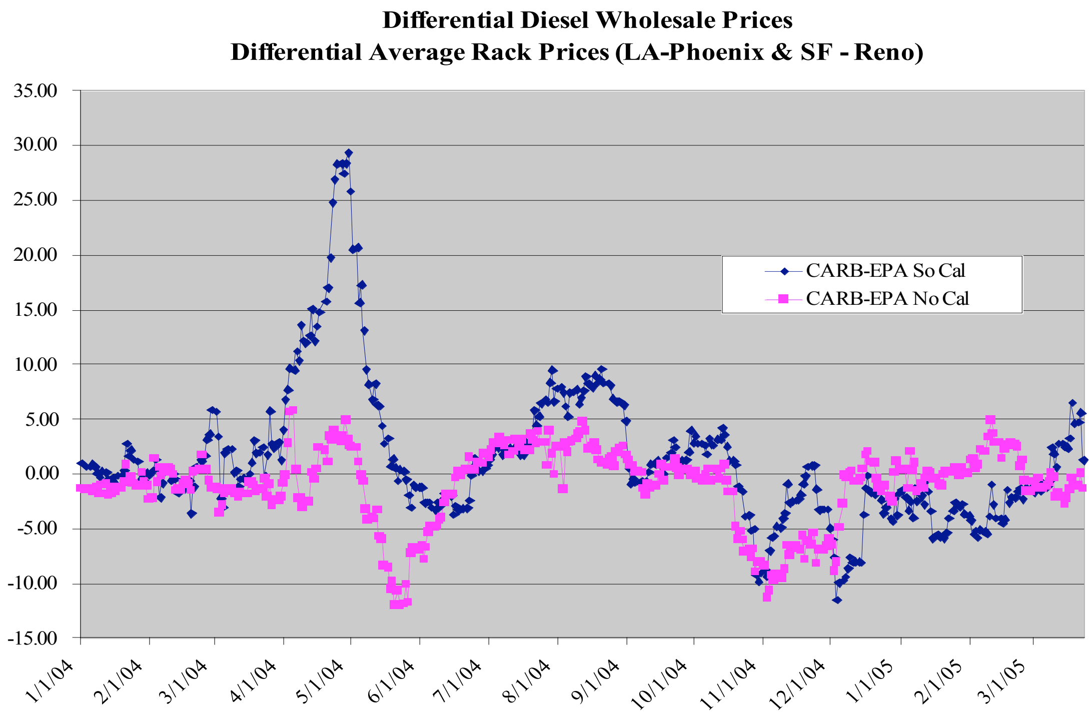
Status

Today, the major barriers to widespread use of GTL fuel are its higher cost and lack of availability. However, the first of the new wave of advanced GTL plants is scheduled to produce fuel this year and more plants are anticipated in 2007-2009.

Several refiners imported small volumes of GTL fuel from 1993 through 1998 to blend with heavier, less desirable crude oil to make greater volumes of California's unique low-aromatic diesel. CARB regulations require that diesel sold in California be limited to 10 percent by weight total aromatics, or meet an alternative formulation that produces equivalent emission benefits (i.e., an alternative formulation has 21 percent aromatics and 52 Cetane). Generally, all diesel sold in California meets CARB's optional specifications for total aromatic content and cetane number in lieu of the 10 percent diesel aromatic content.

Periodically, GTL fuel was economically blended when there was a sufficient price differential between CARB and U.S. EPA diesel. However, usually lower-price conventional crude sources exist and it is too risky to match the few high diesel price opportunities with the long lead time for GTL deliveries. Fig. 2 shows the differential wholesale rack price for CARB diesel and U.S. EPA diesel supplied in and out of California. For 2003 through 2005, the rack price of U.S. EPA diesel was significantly (over 5 cents per gallon) higher than CARB diesel 22 percent of the time [13] in Southern California. These price differentials can represent a GTL opportunity, however, blending GTL into lower grade fuels to make CARB diesel does not appear to be a consistently attractive option by itself.

Fig. 2



Assumptions

Given California's higher gasoline demand (61 percent of total demand) compared to diesel demand (18 percent of total demand), staff does not expect significant use of GTL beyond intermittent uses and plant turn-around practices unless demand significantly shifts away from gasoline and towards diesel. For California's market, staff foresees significant GTL use to be dependent on the increased use of light duty diesel vehicles (see the *Light-Duty Diesel Vehicles* [14] staff paper for more details). It is assumed that lower-priced conventional crude sources will always be available to refiners in California and that GTL, given its highly sought-after fuel properties, will command a premium price, at least at the refinery level.

For this analysis, staff assumes that, in 2008, GTL fuel is available to refineries at five cents per gallon over conventional, petroleum-derived diesel. This cost premium is expected to linearly decline to two cents within 10 years as additional GTL capacity is built and most conventional refineries (worldwide) are configured to produce ultra-low sulfur diesel fuel.

Staff estimated the ratio of GTL diesel blended with U.S. EPA diesel to comply with CARB specifications for an alternative diesel formulation. Typical values for the total aromatic content and cetane numbers (CN) for GTL fuel and U.S. EPA diesel are shown in Table 3. Based upon these specifications and a finished blended diesel with 20 percent aromatic content and a CN of 55, the ratio of GTL diesel to be blended with U.S. EPA diesel is 1:2 (one gallon of GTL is blended with 2 gallons of EPA diesel). The resulting mixture can be called GTL33. The desired aromatic and cetane values are within the ranges for CARB alternative diesel formulation specifications.[15]

If the suitable blending ratio of GTL fuel to U.S. EPA diesel is 1:2, the value of GTL fuel as a blendstock can be calculated from the sum of the wholesale price of U.S. EPA diesel and three times (a gallon of GTL fuel can used to produce three gallons of CARB diesel) the price differential between CARB and U.S. EPA diesel. For this example, the calculated GTL fuel value would have a range of $1.70 to $1.80 per gallon (before taxes).

Table 3. Diesel Fuel Specifications

Component	**Percentage**	**Aromatic Content, %**	**Cetane No.**	**Wholesale Price/gallon, $**
EPA Diesel	66.7	30	42.5	1.45
GTL Fuel	33.3	0	80	1.60
Blended Diesel (GTL33)	100	20	55	1.50

The wholesale cost differential between GTL fuel and CARB diesel is assumed to be 10 cents per gallon.[16] Because the blending value of GTL brackets this cost, GTL fuel can be an attractive blending component to produce CARB diesel.

Staff assumed that a refinery would blend GTL with lower-quality, less-processed streams to produce a higher quality CARB or U.S. EPA diesel fuel. Additionally, the refiner is assumed to save two cents per gallon in avoided processing (hydrotreating). A GTL tax subsidy of five cents per gallon (+/- three cents) of GTL is assumed. These subsidies could be funded by either 1) establishing tax parity for GTL fuels with compressed natural gas, liquid natural gas, and propane fuels, or 2) establishing a blender's credit similar to ethanol fuel sales. Consequently, the 33 percent GTL blended fuel would have 1.65 cents higher cost GTL base, 0.66 cents less refining expense, and 1.65 cents less excise tax, for a total of 0.66 cents less cost per GTL blended gallon of fuel. The final GTL fuel would retail at the identical price as CARB diesel.

Staff examined the cost effectiveness of GTL fuel under a mature market condition, which may be just emerging for this fuel by 2020. A present value calculation was performed on the incremental cost of using GTL33 over the life of a heavy-duty vehicle compared to conventional CARB diesel. Vehicle life was assumed to be 15 years. With the possible exception of a fuel price increment, the analysis used no other incremental costs related to vehicle acquisition or deployment of fueling infrastructure.

The analysis for a mature market assumes that the incremental cost of GTL fuel is 15 cents per gallon higher than U.S. EPA diesel. The U.S. EPA diesel that would be blended with the GTL fuel is assumed to cost five cents per gallon less than CARB diesel. From the refiners' perspective, the resulting three gallons of CARB diesel cost would have the equivalent cost of conventionally produced diesel.

Beginning in 2008, the use of GTL33 grows until it becomes the normal diesel fuel standard by 2019. At this time, the entire diesel fuel supply sold in California becomes GTL33. Thus, in this scenario, one-third of the projected base case diesel demand would be met by GTL fuel and the remaining balance by conventional petroleum diesel.

Life Cycle Emissions Considerations

Staff reviewed various life cycle analyses (LCAs) of the greenhouse gas (GHG) emissions from the production and distribution of GTL fuels. Results vary from GTL production being either GHG neutral to a plus or minus 10 percent penalty/benefit.[17] Considering all the referenced studies, staff assumed for this analysis that GTL fuel production will be GHG neutral and evaluated plus or minus 5 and 10 percent. The plus or minus 10 percent values fully capture the ranges of variation GHGs attributed to GTL production cited in the studies, and the plus or minus five percent captures the range of uncertainty that staff views as the most appropriate. To the extent that GTL fuels enables greater use of light duty diesels, an additional 30 percent reduction in GHG is possible.

Results

The results are shown in Tables 5 and 6 based on the Table 4 GTL & CTL assumed penetration rates. The results show that retailing GTL and CTL fuels at nominal petroleum based prices with a 10 cents/gallon subsidy applied provide net benefits with the assumed values for petroleum reduction and environmental impacts.

Table 4. Diesel Reduction from GTL and CTL Diesels

	Year		
	2015	**2020**	**2025**
Annual Reduction (millions of gallons of diesel)	571	878	1650
Reduction From Base Case Demand (percent)	15	20	33

Table 5. Petroleum Reduction and Benefits for GTL and CTL Diesel at 5 Percent Discount Rate

Alternative Fuel Option or Scenario	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand, percent	Highest Cumulative Benefit or Change, Present Value, 2005-2025, 5% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Low Fuel Price ($1.88/gal diesel)	1.7	33	0	(0.2)	0.1	0.9	0.8
High Fuel Price ($2.20/gal diesel)	1.6	33	0	(0.2)	0.1	0.9	0.8
Highest Fuel Price ($2.43/gal diesel)	1.7	33	0	(0.2)	0.1	0.9	0.8

Table 6. Petroleum Reduction and Benefits for GTL and CTL Diesel at 12 Percent Discount Rate

Alternative Fuel Option or Scenario	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand, percent	Highest Cumulative Benefit or Change, Present Value, 2005-2025, 12% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Low Fuel Price ($1.88/gal diesel)	1.7	33	0	(0.08)	0	0.43	0.35
High Fuel Price ($2.20/gal diesel)	1.6	33	0	(0.08)	0	0.43	0.35
Highest Fuel Price ($2.43/gal diesel)	1.7	33	0	(0.08)	0	0.43	0.35

Key Drivers and Uncertainties

The projected demand for GTL fuel depends on the following outcomes and assumptions:

- The worldwide production capacity for GTL fuel is built as shown in Figure 1. It is reasonable to assume that investment in additional production capacity is likely when crude oil prices are sustained at $20 per barrel or higher. The pace of investment would increase with higher oil prices.

- Sufficient numbers of light- duty diesel vehicles are sold in the U.S. and California to create enough market-pull for GTL.

- GTL fuel would flow to California if its value were sufficiently attractive for distributors and refiners. This can be assured if the fuel excise tax placed on diesel blended with up to 33 percent GTL fuel was reduced by one to three cents per gallon (effectively, a two to six cent per gallon reduction in the cost of GTL 100). This should give refiners a sufficient economic advantage to use GTL fuel to produce a diesel fuel meeting California's alternative diesel formulation requirements.

- GTL needs tax parity with compressed natural gas, liquid natural gas and liquid propane gases for it to compete in California's petroleum market. Can legislation be passed that brings Excise Tax Parity to GTL fuels?

End Notes

[1] Sasol SynFuels International, November 1998.

[2] Dr. Theodore Barna, Clean Fuel Initiative, Department of Defense, Congressional Briefing. February 2005.

[3] See *Options to Reduce Petroleum Fuel Use Addendum*, Option 2J Renewable Diesel Fuels, May 2005, CEC 600-2005-024 AD.

[4] Sasol commercially demonstrated the advanced slurry bed reactors in 1997.

[5] Meeting with Syntroleum Corporation June 26, 2000.

[6] Staff conversation with Chevron Oil Company staff, June 13, 2000.

[7] Discussion of Issues Pertinent to Rulemaking to Designate Fischer-Tropsch Diesel Fuel as Alternative Fuel Under Sec. 301 (2) of the Energy Policy Act of 1992, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, July 2002. p. 4.

[8] The U.S. General Accounting Office (GAO) determined: "In essence, the economic cost of oil price shocks depend largely upon the rise in the price oil coupled with the nation's dependence on oil consumption, rather than the level of imports. As long as market forces prevail, the price of domestic and world oil will be the same and will rise and fall with changes in the world oil market conditions." ENERGY SECURITY, Evaluating U.S. Vulnerability to Oil Supply Disruptions and Options for Mitigating Their Effects, GAO/RCED-97-6, December 1996, p.3.

[9] Notice of proposed notice of availability of status review, February 14, 2005, Federal Register.

[10] See *Options to Reduce Petroleum Fuel Use Addendum*, Option 2J Renewable Diesel Fuels, May 2005, CEC 600-2005-024 AD.

[11] Life Cycle Analysis's completed post 2002 conclude that GTL's global warming gas emissions are at par with conventional diesel to slightly less, depending on the market and co-products produced. PriceWaterhouseCoopers – studies of a Qatar GTL plant supplying fuel to Europe and USA.

[12] "Personal Communication" (e-mail) with Jim Caldwell, U.S. EPA, June 20, 2002. Baseline Diesel Requirements contained in Title 40 CFR 79.56(e)(3)(ii)(A).

[13] Only 8 percent of the time was EPA rack price more than 10 cents/gallon during 2003-3/2005.

[14] See *Options to Reduce Petroleum Fuel Use Addendum*, Option 1F Light-Duty Diesel Vehicles, May 2005, CEC 600-2005-024 AD.

[15] [www.arb.ca.gov], Certified Alternative Diesel Formulations, February 2002.

[16] The wholesale price of CARB diesel is derived from the long-term retail price used in the base case demand analysis, $1.65 per gallon. The retail price results from a (wholesale price + retail margin + federal excise tax + state excise tax) x (state sales tax rate). The wholesale price would include margins for producing and distributing the fuel to consumers, $.15 per gallon. The federal and state excise taxes for diesel fuel are $0.243 and $0.18 per gallon, respectively. A state sales tax rate of 7.75 percent was employed.

[17] Michael Wang, ANL, Greet Model; GM Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – European Study, September 27, 2002.;

European Commission Joint Research Centre, Well-To-Wheels Analysis of Future Automobile Fuels and Powertrains in the European Context, January 2004.; PriceWaterhouseCoopers, Shell Middle Distillate Synthesis, Update of a Life Cycle Approach to Assess the Environmental Inputs and Outputs, and Associated Environmental Impacts, of Production and Use of Distillates from a Complex Refinery and SMDS Route, May 21, 2003.; PriceWaterhouseCoopers, Sasol-Chevron.; ConocoPhillips; Five Winds International, Gas to Liquids, Life Cycle Assessment Synthesis Report, December 2004.