WORKING PAPER

Synfuels to Replace Crude Oil Soon

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Synfuels to Replace Crude Oil Soon

Yale Graduates in Energy
Robert Ames, Anthony Corridore, Edward Hirs, Paul W. MacAvoy*

Introduction: The US energy strategy that would change the outlook worldwide is that for replacing crude oil with other liquids fuels to run automotive engines. Other strategies wander off into exotics requiring subsidies to produce heat or electricity not diesel, heating oil or gasoline. There is no "Plan" to produce a substitute for gasoline in our lifetimes (we are all more than 30 years old).

There are three rationale for undertaking a massive search for substitute liquid fuels: 1) national security, 2) we may be peaking domestically on exploration and development of crude oil, and 3) to reduce carbon emissions.

But there are designs for inserting into the current crude oil infrastructure new fuels. Consider for example just the most discussed synthetic, liquefied natural gas now in relative abundance with more than twice the proved reserves over the last year (due to advances in horizontal drilling technologies) but it would require billions in new liquefaction facilities, thousands of new stations or at least large pressure tanks at existing gasoline stations and new tanks on all vehicles.

What is required for success in the immediate two decade period is a focus on new liquids that can be refined to be priced at the pump competitively with crude oil based products. No subsidized new liquid meets the test if it is subject to Federal Budgets (consider the thirty year failure of Federally sponsored coal research, the shutdown of Synfuels Corp, requirements for all pumps to have X% new bio fuels etc.).

But it would be utopian to expect that diesel and gasoline would disappear in our lifetime. At most it would be a "declining industry" like that of sewing machines. At best, diesel/gasoline would reduce their share at lower prices geared to short term marginal cost or more likely at current prices exclusive of carbon taxes or the costs of carbon sequestration.

There are four candidates for that process of roles replacement. How does one get there? The technology of liquefaction would have to go through four stages: 1) Design, 2) Small scale test plant, 3) Full scale commercial plant, 4) Numerous commercial plants of different companies. We consider four possible synfuels to go through the four stages before the end of the 2020 decade.

First the coal to liquids, CTL, is now a good part of the way to the end of the third stage but the plants being developed are small and have been stalled by subsidies making current operations profitable. Second, natural gas to liquids, GTL, is halfway to a full scale plant in the Middle East and as such has now to demonstrate that being built in ten years at a three fold cost overrun is commercial if undertaken in the US. Third, the hybrid electric powered vehicle HEV has impressive numerous points of private initiative, good production and distribution but still needs more technology to match

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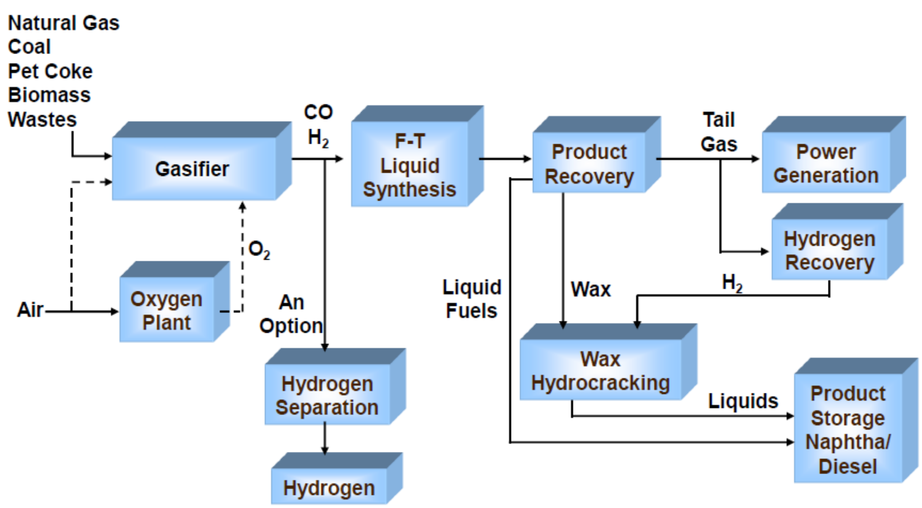
gasoline autos in the market place. Fourth, biofuels are available as far as analysts can see, but prices as a substitute fuel are controversial.

Our review suggests that next year the new liquids are not likely in 2016 to account for more than a few percentage points of total crude based liquids. In 2021 there will be more. But these are speculative forecasts. Something can go wrong to each of the four new sources or in all of them at the same time. It depends critically on the level and stability of the crude oil price and the predictable risks of plant level technology that would keep marginal cost above the crude price.

Coal to Liquids Technology To Reduce The Use of Crude Oil: E. Hirs

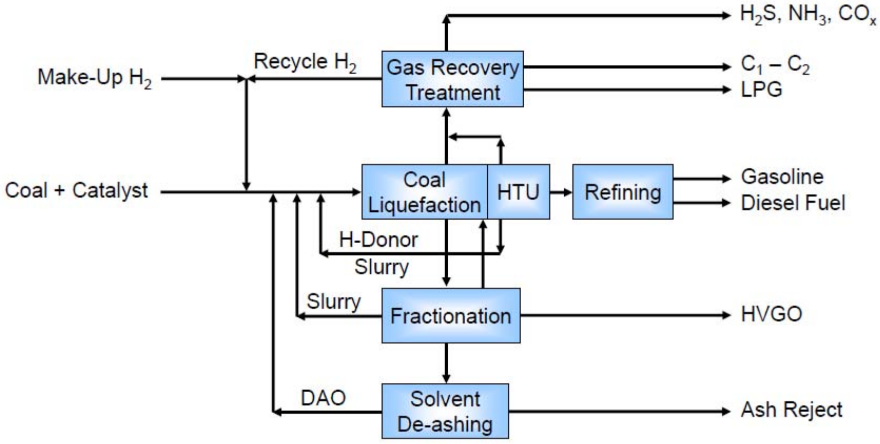
Liquid fuels derived from coal have been produced since the 1920s. Coal to Liquids ("CTL") is produced either through an indirect process **(See Figure B1)** in which the coal is first gasified and then treated with catalysts via the Fischer-Tropsch process, or via a direct process **(See Figure B2)** which requires hydrogen and heavy oils. South Africa's Sasol Corporation has used the indirect process for the commercial production of diesel fuel since 1955. But, the product has required higher crude oil prices in order for the coal derived diesel to be competitive with diesel from crude oil. South Africa instituted crude oil import quotas and tariffs in order to provide the price support for the coal derived liquid fuels.

Figure B1 - Indirect Liquefaction via Fischer-Tropsch process[1]



[1] "Coal Conversion and Carbon Management" by Guido DeHoratiis, Office of Sequestration, Hydrogen and Clean Coal Fuels, US Department of Energy, Western Colorado Coal Conference, September 24, 2010

Figure B2 - Direct Liquefaction[2]



Sasol operates the largest CTL facilities in the world today in Secunda, South Africa. The company processes more than 40-metric tons of coal into 150,000 barrels per day of liquid fuels and associated chemicals. As world crude oil prices have increased, Sasol has intensified its marketing campaign to sell its technology to oil importing nations. A proposed $10 billion facility in China is currently pending approval.

There is a 1-to-1 gasoline/diesel equivalence with CTL production. CTL produces gasoline and diesel directly for blending with usual additives to produce motor fuels.

A National Energy Technology Laboratory report (January 14, 2009) details that CTL is economically competitive with crude oil prices of $86 per barrel (using 2008 constant dollars, assumed 20% rate of return for the owner of the manufacturing facility, and a delivered price of Illinois high sulfur coal of $1.78/MMBtu). Because CTL produces transportation quality fuel without further processing, the $86 price per barrel results in a wholesale diesel price of $2.04 per gallon. The NETL study pegs the price of sequestering CO2 produced by the CTL process of 7-cents per gallon or $2.94 per barrel. NETL notes that because the lifecycle carbon production of CTL is less than that of diesel refined from crude oil that any carbon prices or taxes will impact crude oil more than CTL thereby lowering the breakeven price of crude required for CTL to be competitive.[3]

In a study presented by DKRW Advanced Fuels on the Medicine Bow Fuel and Power Project, the proposed plant expects 10-times the profits of a typical petroleum refinery for the production of gasoline at $2.59/gallon with the following breakdown of component costs:[4]

Cost of Coal (at $4/mmBtu):	$ 1.23
CTL (processing cost)	1.00

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[2] *Ibid*
[3] *Affordable, Low-Carbon Diesel Fuel from Domestic Coal and Biomass*, DOE/NETL-2009/1349, January 14, 2009, National Energy Technology Laboratory
[4] Presentation to 4th Annual Wyoming CO2 Conference, June 30, 2010. Assumes $85/bbl oil price plus $5/bbl average crack spread at the refinery.

Depreciation	.49
Interest	.21
Profit	1.19

Large scale facilities for fuel production have not, based on this technology, been constructed in the US. The legacy plant of the US Synfuels Corporation (the Great Plains Synfuels Plant operated by Dakota Gasification Company, a for-profit subsidiary of Basin Electric Power Cooperative) converts 18,000 tons per day of lignite coal into 145 million cubic feet of synthetic natural gas and various chemicals. The CO2 produced by the process is captured and sequestered. We estimate that this is equivalent to approximately 14,000 barrels per day;[5] but we do not have an estimate of marginal costs.

DOE estimates that production plants of 50,000 barrels per day of capacity will have a capital cost of $100,000 per barrel per day of capacity. Smaller plants will cost somewhat more. No Fischer-Tropsch or indirect CTL process plants have been built worldwide since the 1980s. But currently DOE estimates that there are 20 proposed CTL plants in the US of which four plants have advanced to the "engineering design" phase. Of these, one is a joint venture that includes Sasol, to convert Anthracite, with a prospective size of 5,000 barrels per day ("bpd"). The Medicine Bow, Wyoming facility targets Bituminous coal with a capacity of 21,000 bpd. The remaining two are facilities targeting petcoke or coal with a biomass facility with capacities of 28,000 bpd and 53,000 bpd respectively.

With a competitive price forecast based on the EIA forecast price for West Texas Intermediate (WTI) in the Lower 48, and an estimated breakeven price of crude oil required for CTL plants to operate economically, we project that these plants will be built by 2016 and provide a total supply of 107,000 bpd. As of early 2011, the NYMEX forward curve for crude oil indicates a price per barrel in excess of $90 through 2019. An operator of a CTL plant could lock in a profit by selling production forward today.

For those plants in design studies, the total productive capacity would be an additional 400,000 bpd requiring approximately $40.0 billion in additional capital expenditure. Under the price forecasts prepared by DOE and the ability of a CTL plant operator to sell production forward, these plants would be economic to build and operate. Therefore, we project that by 2021 these additional 400,000 bpd will be supplied. The industry may be able expand more rapidly. The technologies required for direct liquefaction, indirect liquefaction, and biomass conversion are well-known and proven in pilot plants and in Sasol's CTL operations for more than fifty years. The challenge to our supply forecast in the US will be the availability of capital, not a difficult challenge if our cost and price estimates are even roughly accurate. After all, the price/cost margins are substantially profitable. But the delays associated with electricity generation and chemical refining new plant construction will surely permeate state and federal licensing of such facilities. We put forward these estimates as having a (Bayesian) likelihood of taking place but of one half on the timing as early as 2021.

Natural Gas To Liquids Technology to Reduce the Use of Crude Oil: P. MacAvoy

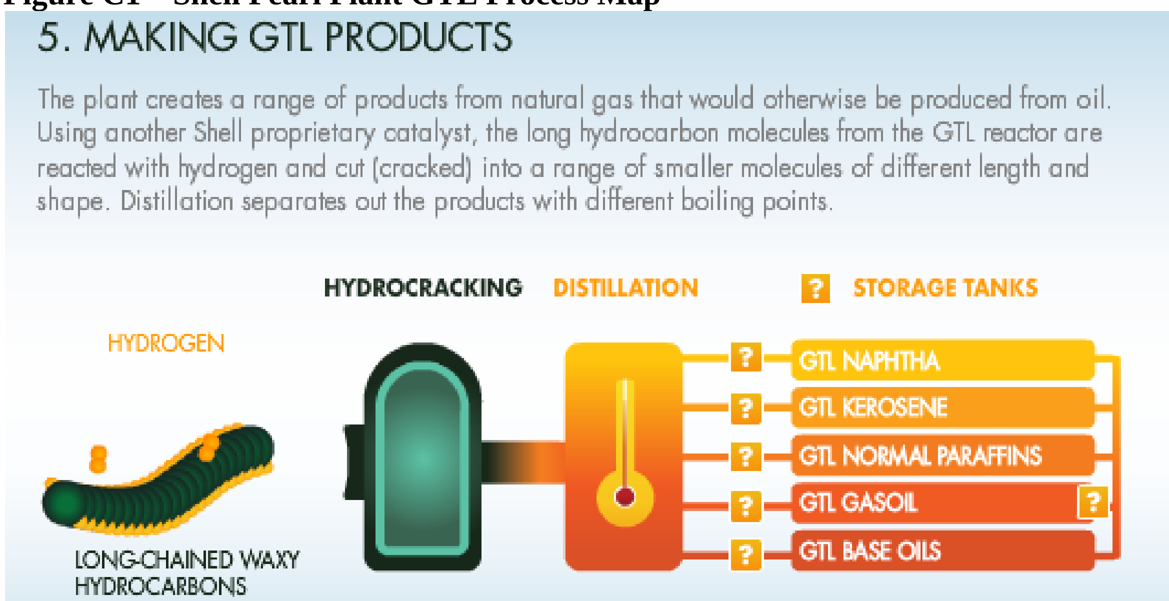
Since at least the early 1990s the international crude oil and natural gas producing companies, both private and public, have undertaken design projects and small scale construction of plants to utilize natural gas as feedstock for production of diesel, chemicals and waxes. Gas generically has been

[5] "Gas to Liquids (GTL)," Topic Paper 9, National Petroleum Council, July 18, 2007

produced with crude, as a driving force to bring the liquid to the surface and then flared or re-injected into the well. Only if the gas volume is relatively large is it compressed and shipped as a heating fuel for generating electricity. There is then a conceptual case for taking the gas in gas/oil extraction not as a marginal product but as a feedstock for liquids production.

In the last five years Qatar and Shell have undertaken to build and operate a plant in Qatar that utilizes offshore gas to produce liquids at large commercial scale. With technology largely based on that of a Shell plant built in Malaysia in1993, this plant will take approximately ten years to complete (inclusive of drilling wells, producing a crude equivalent raw material from the gas, and finally a series of refined products including diesel and chemicals). According to design this plant when finished will produce 0.83 million barrels per day, possibly beginning in 2015, for approximately fifteen years[6].

Figure C1 – Shell Pearl Plant GTL Process Map[7]



Pearl is not a project that will generate a product to directly displace crude oil or its products in US markets in 2016 or even 2021. But a replication of this plant in the US or under license from Shell or as reproduced by another of the large international petroleum products companies could generate up to one million barrels per day of replacement liquids. The probability of that taking place is low, for the following reasons:

1. Pearl would have to have access to gas at less than $2.00 per mcf, half of the US marginal cost, as “part of the deal” in the joint venture agreement. This internal transaction price is necessary for the final products to be equivalent to $80.00 per barrel raw material (crude oil equivalent) liquids.

2. Any gas to liquids plan based on Pearl would have to be free of cost run-up’s that indicate in Pearl terms that at the liquids stage, marginal cost does not exceed $100 per (crude equivalent)

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[6] Pearl the world’s largest GTL plant, http://www.shell.com.qa/home/content/qat/products_services/pearl/
[7] http://www.shell.com/home/content/aboutshell/our_strategy/major_projects_2/pearl/process/

barrel. Current but unverified estimates for Pearl, starting at $5 billion for construction, now range from $15 to $18 billion to completion.

3. The scale of such a plant far exceeds that of a 1200 MW power plant so the licensing process in the US would be long and contentious. With most of the new gas reserves required for feedstock in the US either far offshore or in relatively populated locations at least five additional years would be required for licensing to put “a Pearl” in service, taking the first replacement product out to the middle of the next decade

At this point in time GTL does not make it to a place on Table A1 that indicates it is or will be in the 2021 future a substitute in the mix of domestic liquid fuels

Electric Vehicle Technology To Reduce The Use of Crude Oil Based Diesel or Gasoline: A. Corridore

An electric automobile does not use a synthetic liquid fuel but does reduce the use of fossil-based fuels. We treat this reduction on the same basis as CTL, a “savings” of fossil fuels.

Hybrid Electric Vehicles (HEV) & Plug-In Hybrid Electric Vehicles (PHEV) are battery-powered electric vehicles which use only electric motors. PHEV vehicles are a combination of electric motors and internal combustion engines (ICE). Their batteries can be recharged by plugging a power cord into an electrical outlet. Current designs use battery power at the start of a trip, to drive the vehicle for some distance until a minimum level of battery power is reached (the “minimum state of charge”). When the vehicle has reached its minimum state of charge, it operates on a mixture of battery ICE power, similar to some hybrid electric vehicles currently in use. In charge-depleting operation, a PHEV is a fully functioning electric vehicle.”[8]

The well known Hybrid Electric Gasoline Vehicle on the road today is the Toyota Prius (with an estimated fuel economy rating of 51mpg in the city, 48mpg on the highway and a combined figure of 50mpg)[9] followed by the newly introduced Plug-In Hybrid Electric Vehicle the Chevrolet Volt (with a 93 mpg equivalent in all electric mode, 37/mpg in gasoline mode only, and a combined gas/electric rating of 60/mpg)[10]. As shown in **Table D1** below Ford, Volvo, Mitsubishi, and Volkswagen (among others) plan to introduce electric vehicles into the US market over the next 3 years.

Table D1: Current and Future PHEV / HEV Vehicles:

Current PHEV / HEV Vehicles:

Toyota Prius (HEV) US Sales - 2009: 140K units, 2010 Jan - Sept: 106K units[11]
Chevrolet Volt (PHEV) US Sales - 2011: 10K to 25K units, 2012: 60K to 120K units)[12]
Nissan Leaf (PHEV) US Sales – 2011: Unknown, 2012 Smyrna TN plant to produce 150K[13]
Tesla Roadster (HEV) – 2009: 937 Units, 2010 Jan – June: 1,063[14]

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[8] http://www.eia.doe.gov/oiaf/aeo/otheranalysis/aeo_2009analysispapers/ephev.html
[9] http://www.motorauthority.com/blog/1031631_toyota-revises-prius-mpg-rating-to-51-city-48-highway-and-50-combined
[10] http://www.chevroletvoltage.com/index.php/Volt/2011-chevrolet-volt-receives-new-fuel-economy-label-from-epa.html
[11] http://en.wikipedia.org/wiki/Toyota_Prius#cite_note-GCC100710-1
[12] http://www.egmcartech.com/2011/01/25/report-gm-to-double-chevrolet-volt-output-to-120000-in-2012/
[13] http://en.wikipedia.org/wiki/Nissan_Leaf
[14] http://www.fastcompany.com/1662643/tesla-sells-only-10-cars-a-week-but-has-plans-to-build-a-cabriolet-van-and-suv

Up & Coming PHEV / HEV Vehicles:[15]

Toyota Prius Plug-in Hybrid (PHEV) – Introduction to the US in 2012
Volvo C30 Plug In Hybrid (PHEV) - Introduction to the US in 2011/2012
Mitsubishi (HEV) - Introduction to the US in 2011/2012
Ford Focus EV (HEV) - Introduction to the US in 2011
Smart Fortwo EV (HEV) - Introduction to the US in 2012
Tesla Model S (HEV) - Introduction to the US in 2012
Toyota iQ - Introduction to the US in 2012
Toyota RAV4 EV (HEV) - Introduction to the US in 2012
Volkswagen E-UP! – Limited Production Available in US in 2013
Fisker Karma (PHEV) – Introduction 2011 (if introduction is in US)

Estimating the miles per gallon equivalent for a PHEV is dependent on the percentage of travel done in all-electric mode versus in charge-sustaining mode. In addition, it is also dependent on how long the car is driven between charges. For the 2011 Chevrolet Volt if the car is driven 30 miles between charges, the fuel economy is N/A as no gas would be used. If driven 45 miles between charges, the EPA has estimated 168 mpg, at 60 miles the estimate is 89 mpg, and at 75 miles between charging the estimate is 69 mpg. The DOE in the AEO2011 Early Release Overview[16] has estimated combined (electric/gas) miles per gallon equivalent for varied electric hybrid vehicles over the next 30 years as shown in **Table D2** below. Using today's technology (a 2011 PHEV Chevrolet Volt or a 2010 HEV Toyota Prius) saves between 188 to 240 gallons per year or 4.5 to 5.7 bbl of oil per year assuming the car is driven on average 15,000 miles per year as shown in **Table D3** below.

Table D2: DOE MPG Vehicle Estimate Forecast

Mile Per Gallon Equivalent	2011	2016	2021	2026	2030
Gasoline ICE Vehicles	31.65	34.82	36.87	36.94	37.13
100 Mile Electric Vehicle	146.2	169.2	168.0	177.1	179.5
200 Mile Electric Vehicle	71.8	92.4	121.1	139.6	142.4
Plug-in 10 Gasoline Hybrid	0.0	64.1	65.4	67.1	67.2
Plug-in 40 Gasoline Hybrid	64.3	70.2	72.4	73.1	73.4
Electric-Diesel Hybrid	0.0	61.2	61.1	60.8	61.1
Electric-Gasoline Hybrid	52.5	56.9	58.8	58.8	58.9

Table D3: PHEV and HEV Gas/Oil Savings per Year

	MPG	Gallons/Yr	Difference	BBL Oil Conv	Difference
Gasoline ICE Vehicles	31.7	474		11.3	
Plug-in 40 Gasoline Hybrid	64.3	233	241	5.6	5.7
Electric-Gasoline Hybrid	52.5	285	188	6.8	4.5
Based on	*15,000*	*miles driven per Year*			

To provide a US country scale estimate of gas/oil savings an estimate an electric vehicle adoption rate needs to be calculated as a first step. The adoption of the electric vehicle is difficult to estimate because there are multiple factors to take into consideration. The following factors provide a perspective on this challenge: percentage of consumers who have access to overnight charging,

15 http://fueleconomy.gov/feg/evnews.shtml
16 http://www.eia.doe.gov/forecasts/aeo/tables_ref.cfm

penetration rate/competition with other vehicle types, infrastructure, vehicle attributes, vehicle availability, price, fuel savings over a payback period at a discount rate versus upfront vehicle cost, etc. But the DOE in the AEO2011 Early Release Overview provides adoption rates (as shown in **Table D4** below) across cars and light duty trucks. The DOE has estimated adoption rates will grow from 3% to 7% from now through 2030 which translates into 400K to 1.3M electric vehicle units.

Table D4: DOE Electric Vehicle Adoption Forecast Rate

New Car Sales in the USA (in Millions)	2011	2016	2021	2026	2030
ICE Cars	5.36	7.19	7.74	8.53	9.12
Electric Vehicles	0.28	0.46	0.62	0.81	0.93
Other Alternative Vehicles	0.66	1.37	1.43	1.62	1.76
Total Cars	**6.30**	**9.03**	**9.78**	**10.96**	**11.81**
Electric Vehicle Adoption Rate	*4.5%*	*5.1%*	*6.3%*	*7.4%*	*7.8%*
Conventional Light Trucks	4.57	4.78	4.25	4.28	4.40
Electric Vehicles	0.12	0.23	0.24	0.33	0.40
Other Alternative Vehicles	1.61	2.15	1.89	1.88	1.89
Total Light Trucks	**6.30**	**7.16**	**6.38**	**6.50**	**6.69**
Electric Vehicle Adoption Rate	*1.9%*	*3.2%*	*3.8%*	*5.2%*	*6.0%*
Conventional Light Cars & Trucks	9.92	11.97	11.98	12.81	13.52
Electric Vehciles	0.40	0.69	0.86	1.14	1.33
Other Alternative Vehicles	2.28	3.53	3.32	3.50	3.65
Total Cars & Trucks	**12.60**	**16.19**	**16.17**	**17.46**	**18.50**
Electric Vehicle Adoption Rate	*3.2%*	*4.3%*	*5.3%*	*6.5%*	*7.2%*

Using these adoption rates we calculate weighted average mpg's for all electric vehicles; we also assume that their would be a cumulative effect in gas/oil yearly savings (i.e. the electric cars purchased the year before would be considered in addition to the new cars purchased in the current year so on and so forth). We estimate yearly savings to range up to 80M BBL or 200K BBL/day (~1% of total US Consumption) by 2030 as shown in **Table D5** below:

Table D5: Estimate of Gas/Oil Savings per Year [17]

	2010	2011	2012	2013	2014	2015	2016	2021	2026	2030
Figure in Millions										
Total New Car Sales*	5.3	6.3	7.4	8.4	8.5	8.8	9.0	9.8	11.0	11.8
*Adoption Rate**	*3.4%*	*4.5%*	*4.5%*	*4.5%*	*4.8%*	*4.8%*	*5.1%*	*6.3%*	*7.4%*	*7.8%*
Total Electric New Car Sales	0.179	0.284	0.338	0.377	0.407	0.428	0.460	0.618	0.808	0.927
W. Avg Electric Car MPG*	53.0	56.6	61.2	60.2	62.8	63.4	66.4	70.5	74.5	74.3
Car ICE MPG*	31.2	31.7	32.3	32.5	33.1	34.1	34.8	36.9	36.9	37.1
Million Gallons Saved per Year	35	95	169	249	336	423	517	1,042	1,772	2,497
Million BBL of Oil Saved per Year	0.8	2.3	4.0	5.9	8.0	10.1	12.3	24.8	42.2	59.5
Based on	*15,000*	*miles driven per Year*								
Figure in Millions										
Total New Truck Sales*	4.53	4.57	4.96	5.20	4.97	4.89	4.78	4.25	4.28	4.40
Adoption Rate	*1.8%*	*1.9%*	*2.4%*	*2.4%*	*2.5%*	*3.2%*	*3.2%*	*3.8%*	*5.2%*	*6.0%*
Total Electric New Truck Sales*	0.080	0.086	0.118	0.125	0.123	0.156	0.153	0.161	0.221	0.265
W. Avg Electric Truck MPG*	43.4	44.1	43.3	44.4	44.8	45.7	47.0	48.9	49.4	51.3
Truck ICE MPG*	23.94	24.23	24.72	24.94	25.30	25.91	26.53	28.58	28.66	28.89
Million Gallons Saved per Year	22.4	46.3	77.0	109.9	141.8	180.9	218.7	397.6	613.4	835.6
Million BBL of Oil Saved per Year	0.5	1.1	1.8	2.6	3.4	4.3	5.2	9.5	14.6	19.9
Based on	*15,000*	*miles driven per Year*								
Total Million BBLs Saved per Year	**1.38**	**3.36**	**5.85**	**8.54**	**11.37**	**14.37**	**17.52**	**34.28**	**56.81**	**79.36**
Total Million BBL/Day Saved	0.004	0.009	0.016	0.023	0.031	0.039	0.048	0.094	0.156	0.217
Total US Milion BBL/Day Consumed*	**18.98**	**19.10**	**19.99**	**20.30**	**20.36**	**20.45**	**20.54**	**20.74**	**21.03**	**21.39**
% of Total US Consumption Saved	**0.02%**	**0.05%**	**0.08%**	**0.12%**	**0.15%**	**0.19%**	**0.23%**	**0.45%**	**0.74%**	**1.02%**

* Taken directly from or cacluated using data from the DOE AEO2011 Early Release Overview - http://www.eia.doe.gov/forecasts/aeo/tables_ref.cfm

Making some basic sensitivity analyses on adoption rates provides a perspective on how significant the electric vehicle can have on impacting gas/oil savings as shown in **Table D6** below. Specifically, in order to get to 1MBBL's per year in savings by 2030 the USA would need to have a 30% adoption rate starting no later then the year 2015.

Table D6: Sensitivity on USA Estimate of Oil Savings per Year by HEV Vehicles

Million BBLs Saved per Day	2010	2016	2021	2025	2030
DOE Adoption Rate	0.004	0.05	0.09	0.14	0.22
Constant 10% Adoption Rate in 2015 Forward	0.004	0.07	0.16	0.24	0.35
Constant 20% Adoption Rate in 2015 Forward	0.004	0.11	0.29	0.45	0.66
Constant 30% Adoption Rate in 2015 Forward	0.004	0.15	0.42	0.66	0.98
Constant 40% Adoption Rate in 2015 Forward	0.004	0.19	0.55	0.86	1.29

As already mentioned the key factor in adoption rate is price parity between a Hybrid Electric Vehicles and a Conventional Internal Combustion Engine Vehicle. But it is not only the dealer prices that drive savings but also operating costs. There are three main factors that drive parity: Battery/System cost differences, electricity costs, and gasoline/oil prices.

The DOE states in a paper (Economics of Plug-In Hybrid Electric Vehicles)[18] that the combined costs of the PHEV battery and supporting systems (which together represents the total incremental costs of a PHEV compared to an ICE vehicle) are not expected to remain static. Successes in research and development are expected to improve battery characteristics that reduce costs over time. Specifically, for a PHEV – 40 (i.e. the Chevrolet Volt) the systems costs are estimated to be ~$14.5K more in 2010, ~$8.3K more in 2020, and ~$5.1K more in 2030 not accounting for any tax credits or government

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[17] Through the beginning of the paper we have used the year 2011 as the jumping off point. In this table and the proceedings ones we have changed the jumping point to 2010 because it's the first year that significant HEV sales occurred.
[18] http://www.eia.doe.gov/oiaf/aeo/otheranalysis/aeo_2009analysispapers/ephev.html

incentives. The average price of gasoline required for a PHEV – 40 to cancel out the cost difference between an ICE is $8.40/gallon in 2010 (or $215/bbl price) as shown in **Table D7 below**.

Table D7: Gas to Oil BBL Cost Equivalency Analysis

Assumptions:

WACC	8%
Life of the Car	7 years
Miles Driven per Year	15,000
% of gas price derived from the price of oil*	61%

* http://www.eia.doe.gov/energyexplained/index.cfm?page=gasoline_factors_affecting_prices

	2010	2020	2030
Incremental Cost PHEV - 40 Cost Vs. ICE	$14,500	$8,300	$5,100
PHEV - 40 MPG	64.3	70.9	73.4
Gallons of Gas Used	233.3	211.5	204.3
ICE MPG	31.2	36.7	37.1
Gallons of Gas Used	480.7	408.6	404.0
Gallons of Gas Saved with PHEV per Year	247.4	197.1	199.8
Discounted Equalizing Avg Gal of Gas over 7 Yr Period	$8.37	$6.02	$3.65
Discounted Equalizing $/BBL of Oil over 7 Yr Period	$214.50	$154.14	$93.44

While there has been a great fanfare associated with the introduction of electric vehicles, they are not expected to “flood” the market. According to the DOE forecast, between 2021 and 2026 yearly sales will amount to 860K to 1.3M electric vehicle unit sales respectively per year. This equates to ~30 to ~60 million barrels per year in oil savings respectively which is quite small when compared to the ~20 million barrels per day that the United States consumes. The analysis above shows that in order to achieve just 1 million barrels per day in oil reduction we would need to increase the DOE adoption rate of electric vehicles from the 5% to 7% range to between 30% and 40%. However, this is unlikely to happen unless there are substantially higher and more stable oil prices and or electric car systems/batteries costs come down significantly more than has been forecast. In the interim, the federal government and states (at a more local level) have provided tax credits, in the range of $2,500 to $7,500, to incentivize the purchase of electric vehicles.[19] Whether or not the credits will be sustainable (from a fiscal standpoint) and adequate to drive sufficient adoption to support competition and associated technological improvements is unclear.

[19] EIEA2008 grants a tax credit of $2,500 for PHEVs with at least 4 kilowatt hours of battery capacity (about the size of a PHEV-10 battery), with larger batteries earning an additional $417 per kilowatt hour up to a maximum of $7,500 for light-duty PHEVs, which would be reached at a battery size typical for a PHEV-40. The credit will apply until 250,000 eligible PHEVs are sold or until 2015, whichever comes first. ARRA2009, which was enacted in February 2009, modifies the PHEV tax credit so that the minimum battery size earning additional credits is 5 kilowatt hours and the maximum allowable credit based on battery size remains unchanged at $5,000. ARRA2009 also extends the number of eligible vehicles from a cumulative total of 250,000 for all manufacturers to more than 200,000 vehicles per manufacturer, with no expiration date on eligibility. After a manufacturer’s cumulative production of eligible PHEVs reaches 200,000 vehicles, the tax credits are reduced by 50 percent for the preceding 2 quarters and to 25 percent of the initial value for the preceding third and fourth quarters.

Bio-Fuels Technology To Reduce The Use of Crude Oil: R. Ames

Two different technological processes are in development to produce cellulosic ethanol, or ethanol from non starch (corn) sources including grasses such as switchgrass and fast growing woody biomass such as poplar. In biochemical conversion (as shown in **Figure E1** below), biomass is broken down to sugars using either enzymatic or chemical processes and then converted to ethanol via fermentation. In thermochemical conversion (as shown in **Figure E2** below) biomass is broken down to intermediates using heat and upgraded to fuels using a combination of heat and pressure in the presence of catalysts[20].

Figure E1: Biochemical conversion route for biomass to biofuels[21]

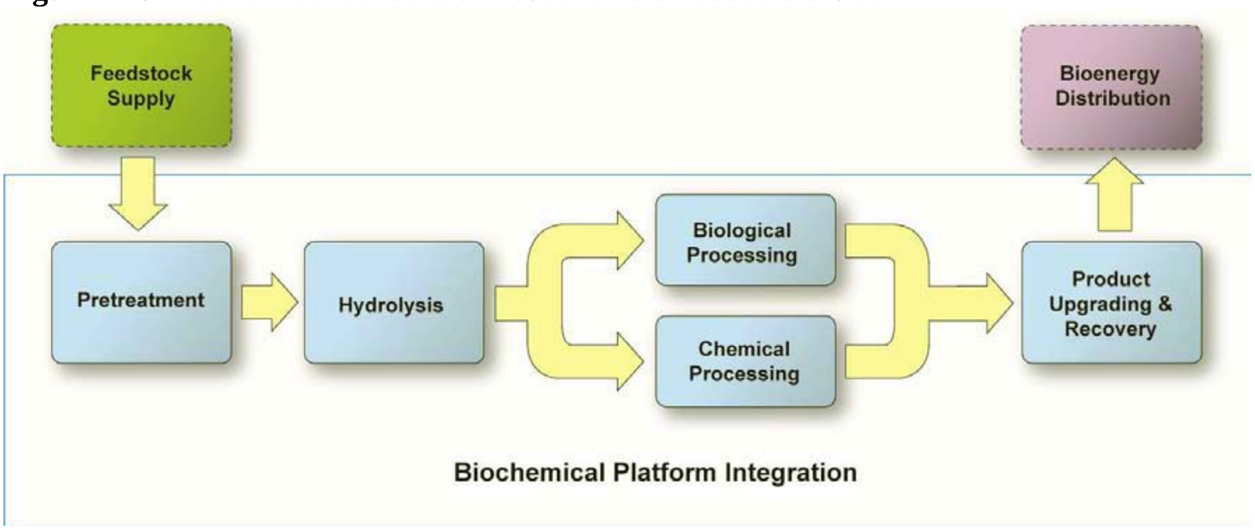
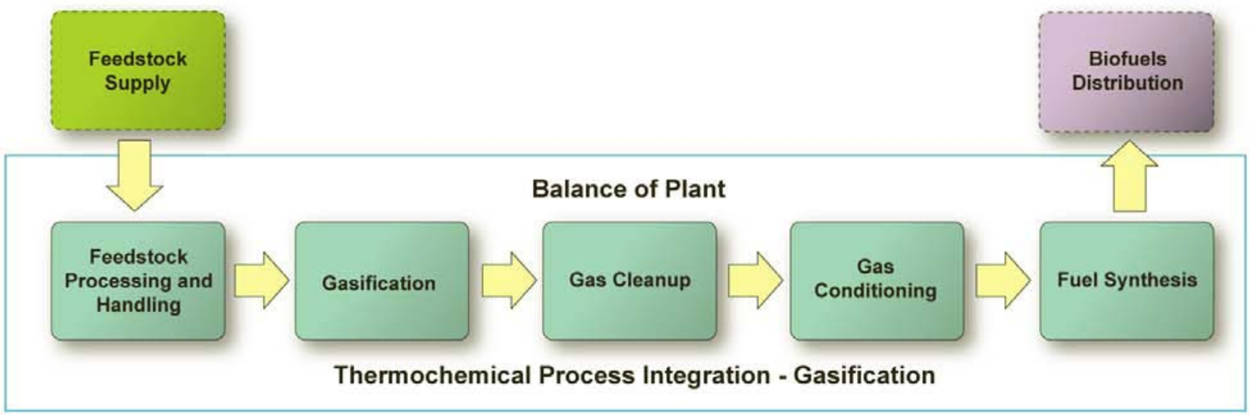


Table E2: Thermochemical conversion route for biomass to biofuels



Several cellulosic ethanol companies currently have operating demonstration plants employing both the biochemical and thermochemical conversion technologies, as shown below in **Table E3**, with annual output totaling 5.58 million gallons of cellulosic ethanol per year.

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20 http://www1.eere.energy.gov/biomass/processing_conversion.html
21 http://www1.eere.energy.gov/biomass/pdfs/biomass_mypp_november2010.pdf

Table E3: Cellulosic ethanol demonstration plants[22]

Currently Operating Cellulosic Ethanol Demonstration Plants					
Company	Location	Start Date	Process	Feedstock	Capacity [gal/yr]
Iogen	Canada	Apr 2004	Biochemical	Wheat straw	260,000
BioEthanol Japan	Japan	Jan 2007	Biochemical	Wood waste	370,000
KL Energy Corp	Wyoming	Jan 2008	Biochemical	Wood	1,500,000
Verenium	Louisiana	Mar 2008	Biochemical	Bagasse	1,400,000
AE Biofuels	Montana	Aug 2008	Biochemical	Various	150,000
Mascoma	New York	Feb 2009	Biochemical	Various	200,000
Coskata	Pennsylvania	Sep 2009	Thermochemical	Waste	50,000
Inbicon	Denmark	Nov 2009	Biochemical	Various	1,400,000
Dupont Danisco	Tennessee	Jan 2010	Biochemical	Corn cobs	250,000
				total	**5,580,000**

Source: Company Websites

More companies have plans to build cellulosic ethanol plants in the United States. The following companies have announced production that by 2015 will equal an additional 240.5 million gallons per year[23].

Table E4: Planned Cellulosic Ethanol Plant Capacity by 2015[24]

Company	State	Technology	Feedstock(s)	2015 Total (thous. bpd)
Coskata		Gasification	Multi-feedstock	3.59
BP Biofuels / Vercipia	Louisiana	Enzymatic hydrolysis	Bagasse	2.44
DDCE	Tennessee	Enzymatic hydrolysis	Corn cob	1.65
POET	Iowa	Enzymatic hydrolysis	Corn stover, switchgrass, MSW, wheat straw	1.63
DDCE	Iowa	Enzymatic hydrolysis	Corn cob	1.63
Range Fuels	Georgia	Gasification	Wood Waste	1.30
Abengoa	Kansas	Enzymatic hydrolysis	Corn stover	0.98
Fulcrum	California	Gasification		0.69
AE Biofuels	Montana	Enzymatic hydrolysis		0.66
IneosBIO	Florida	Gasification/fermentation		0.52
Trenton Fuel Works	New Jersey	Acid Hydrolysis	Mixed cellulose	0.25
KL Energy	Wyoming	Enzymatic hydrolysis	Stover	0.08
ADM	Illinois	Enzymatic hydrolysis	Stover	0.07
American Process	Wisconsin	Enzymatic hydrolysis		0.06
Haldor Topsoe		Enzymatic hydrolysis		0.05
Logos Technologies		Enzymatic hydrolysis		0.05
REII		Gasification		0.02
ZeaChem	Oregon	Gasification/fermentation	Poplar/energy woods	0.02
				15.69

Estimating the barrels of crude oil replaced by cellulosic ethanol is complicated by 2 key factors: ethanol has a lower energy density than gasoline, and gas-powered vehicles generally cannot interchangeably run either gasoline or straight ethanol.

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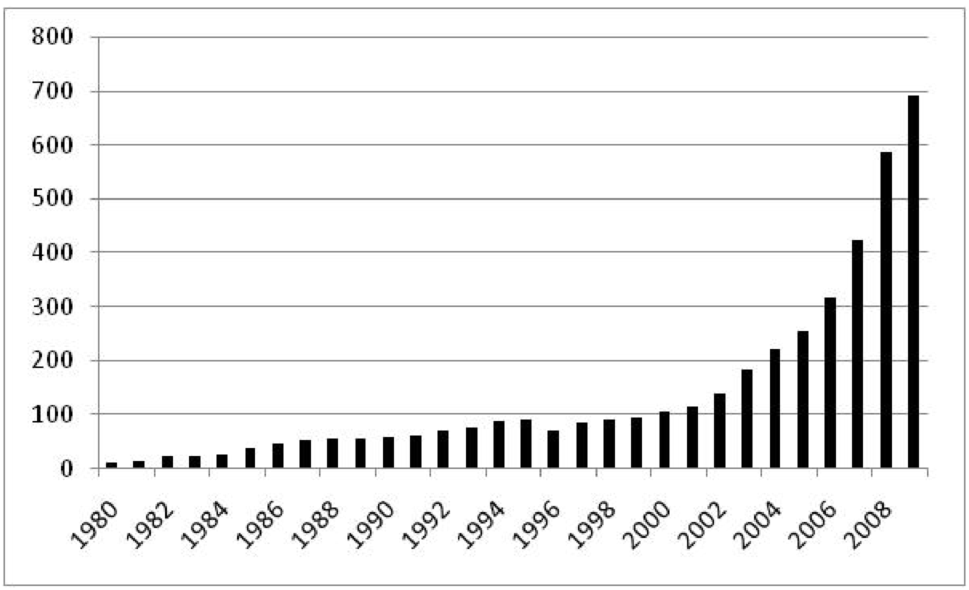
[22] http://www1.eere.energy.gov/biomass/pdfs/us_biofuels_industry_report.pdf
[23] http://biofuelsdigest.com/bdigest/free-industry-data/
[24] http://biofuelsdigest.com/bdigest/free-industry-data/

The energy density of ethanol is approximately 76,000 BTUs per gallon compared to 115,000 BTUs per gallon for gasoline. However, to a small degree this is offset by ethanol's higher octane rating (115 vs. 85-88). For purposes of determining ethanol's supply impact relative to gasoline we use DOE's estimate of 67%[25] that for every barrel of cellulosic ethanol produced the country saves 0.67 barrels of gasoline. More than 99% of the ethanol marketed in the U.S. is sold at E10 (10% ethanol, 90% conventional gasoline), and the rest is sold as E85[26].

All conventional highway vehicles manufactured since 1978 are certified to run on blends of ethanol up to E10. In contrast, only certified flex-fuel vehicles (FFVs) are designed to run on higher level ethanol blends, up to E85. At refueling stations, E10 is stored and dispensed in the same tanks and dispensers as gasoline. E85 requires a special dispenser and separate storage tank which together can cost over $60,000 to install at a refueling station. Currently, only around 8 million FFVs and fewer than 2,000 E85 retail stations are in use in the United States, located mostly in the Midwest.[27]

Over the past 10 years the market for ethanol in the U.S. has grown over seven fold as shown in **Figure E5** below, from approximately 1.5 billion gallons in 1999 (96 K bbls/day) to 10.6 billion gallons in 2009 (691 K bbls/day). Most of these barrels are produced from corn starch.

Figure E5: Historical U.S. ethanol production (thousands of bbls per day)*[28]*



Since 1978 ethanol has been statutorily limited to E10 blends (10% ethanol / 90% gasoline) except for use in flex fuel vehicles. This 10% cap creates a 'blend wall' that limits ethanol penetration to roughly 13 billion gallons, or 3.3 billion barrels, per year. Recently EPA approved E15 for use in 2007 and newer model year vehicles, and more recently for 2001 to 2006 model year vehicles. This increases

[25] http://www1.eere.energy.gov/biomass/pdfs/biomass_mypp_november2010.pdf
[26] http://www1.eere.energy.gov/biomass/pdfs/biomass_mypp_november2010.pdf
[27] http://www1.eere.energy.gov/biomass/pdfs/biomass_mypp_november2010.pdf
[28] http://www.ethanolrfa.org/pages/statistics

total penetration to approximately 17.5 billion gallons, or 0.4 billion barrels, per year. Approving E15 for all vehicles would further increase the blend wall to over 20 billion gallons, or 0.5 billion barrels, per year as shown in **Figure E6**.

Figure E6: E15 Blend Wall Under Various Scenarios (thousand bbls per day)[29]

Further approvals beyond E15 to E20 would increase the potential market penetration of ethanol. The Department of Energy's Biomass Program and Vehicle Technologies Programs are determining the extent to which these higher ethanol blends impact a range of issues including vehicle performance, materials compatibility, and exhaust emissions. Currently due to materials compatibility and handling issues ethanol relies on a redundant infrastructure system, including separate fuel storage tanks and retail pumps. Technological enhancements to existing corn ethanol processing methods, such as that marketed by Gevo, help alleviate these infrastructure challenges by changing the molecule produced from ethanol to biobutanol.

Penetration rates can also be increased through greater availability of E85 pumps. Eight million flex-fuel vehicles are on the roads today, but fewer than 2,000 retail outlets dispense E85. The limited availability, which may continue to be an impediment in the future, is the roughly $60,000 cost for a separate tank and pump.

The six factors that drive biochemical cellulosic ethanol cost include: feedstock cost, prehydrolysis/treatment, enzymes, saccharification & fermentation, distillation & solids recovery, and balance of the plant[30]. DOE expects future cost reductions in all 6 factors due to technological advancements and increases in crop yields per acre.

Based on the state of the biochemical conversion technology in 2008, the projected minimum selling price of cellulosic ethanol from corn stover is $2.61 / gallon ($110 / bbl), or in a gasoline equivalent

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[29] http://www.ethanolrfa.org/exchange/entry/e15-scenerios/#. Y-axis scale converted from millions of gallons per year to bbls per day

[30] http://www1.eere.energy.gov/biomass/pdfs/biomass_mypp_november2010.pdf

price $3.90 / gallon ($164 / bbl). The forecast selling price achieved in 2012 is $1.49 / gallon ($63 / bbl) or in a gasoline equivalent price $2.22 / gallon ($93 / bbl). Based on conversations with Dr. Robert Perlack[31], the biochemical cellulosic ethanol cost from cereal straw and switchgrass are expected to be in line with corn stover.

The seven factors that drive thermochemical cellulosic ethanol cost include: feedstock cost, feed handling & drying, gasification, synthesis gas cleanup & conditioning, fuels synthesis, product recovery & purification, and balance of the plant. DOE also expects future cost reductions due to technological advancements and increases in crop yields per acre across all of these factors. Based on the state of the thermochemical conversion technology in 2008, the projected minimum selling price of cellulosic ethanol from woody biomass is $2.40 / gallon ($101 / bbl), or in a gasoline equivalent energy per volume price of $3.58 / gallon ($150 / bbl).[32] The forecast selling price achieved in 2012 is $1.57 / gallon ($66 / bbl) or in a gasoline equivalent energy per volume price of $2.34 / gallon ($98 / bbl).

In an attempt to spur the growth of cellulosic ethanol, Congress has mandated that obligated parties (e.g., refiners, importers and blenders) purchase renewable fuels. The cellulosic biofuels mandate is 185K bbl/day in 2016 and 590K bbl/day in 2021[33].

However based on the DOE study "Biomass Multi-Year Program Plan"**[34]** given the state of technology in 2007, with oil at $169 / bbl, 45,000 bpd of cellulosic ethanol (gasoline equivalents) can be produced. By 2012 at $93 / bbl 476,000 bpd of ethanol (gasoline equivalents) can be produced. And by 2016 at the same $93 / bbl, the DOE projects 830,000 bpd of cellulosic ethanol (gasoline equivalents) can be produced. This is approximately 0.01% of the total U.S. demand for on-road gasoline. The DOE study does not provide an estimate beyond 2017 (which is 920,000 bpd) therefore we will use 2017 as our 2021 estimate.

Conclusion:

The United States energy policy for the replacement of crude oil as a transportation fuel has been ineffective. Various laws, mandates, and subsidized technologies over the past four decades have yet to make a dent in the use of gasoline and diesel for American transportation. Our analysis of the leading four alternatives is based on the forecast EIA price of crude oil and the continuation of current policy initiatives.

Of the alternatives, CTL has the promise for making a contribution of more than 100,000 bbls per day of crude oil equivalent by 2016 and 500,000 bbls per day by 2021. CTL requires significant capital investment for the new plants and facilities, but the fuel products slip directly into the US supply and

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[31] Employed by Oak Ridge National Laboratory, Dr. Robert D. Perlack works in the Environmental Sciences Division as senior Research Economist and Task Leader for Resource Analysis funded by the U.S. Department of Energy, Office of the Biomass Program. He was awarded the Oak Ridge National Laboratory Significant Event Award in 2005 as lead author of the study *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*

[32] Since ethanol has ~2/3 the energy per gallon as conventional gasoline, we also express price here in terms of the 'gasoline equivalent energy per volume'.

[33] http://www.epa.gov/otaq/renewablefuels/420f10007.pdf

[34] http://www1.eere.energy.gov/biomass/pdfs/biomass_mypp_november2010.pdf

Table A1 Synthetic Fuels, 2016 and 2021

		2016	2021
Crude Oil Prices (2009 dollars per barrel)			
Imported Crude Oil[1]		89.08	100.77
Prices of Crude ($/bbl) Required for Synfuels Cost Parity			
CTL	*$/BBL Equivalent*	$86	$86
GTL	*$/BBL Equivalent*	NA	NA
Electric Cars (based on DOE adoption rates)	*$/BBL Equivalent*	$178	$148
BioFuels	*$/BBL Equivalent*	$93	$93
US Supply (in million barrels per day)[1]:			
Domestic Crude Production 1/		5.83	6.03
Net Imports		8.73	8.39
Other Crude Supply 2/		0.00	0.00
Total Crude Supply		**14.56**	**14.42**
Natural Gas Plant Liquids		2.23	2.43
Net Product Imports		1.13	0.95
Refinery Processing Gain 4/		1.01	1.01
Product Stock Withdrawal		0.00	0.00
Other Petroleum Supply		**4.37**	**4.39**
Supply from Renewable Sources		1.16	1.42
Ethanol		1.04	1.25
Biodiesel		0.10	0.10
Other Biomass-derived Liquids 5/		0.02	0.06
Liquids from Gas		0.00	0.00
Liquids from Coal		0.05	0.07
Other 6/		0.27	0.34
Other Non-petroleum Supply		**1.48**	**1.83**
Total US Supply		**20.40**	**20.65**
Estimated Synfuels Supply Given Forecast Prices (in million barrels per day)			
CTL		0.10	0.50
GTL		0.00	0.00
Electric Cars (based on DOE adoption rates)		0.05	0.09
BioFuels		0.83	0.92
Total Synfuels Supply:		**0.98**	**1.51**
% Total Reduction:		**4.8%**	**7.3%**
Notes:			
1) DOE AEO2011 Early Release Overview - http://www.eia.doe.gov/forecasts/aeo/tables_ref.cfm			

distribution system for motor fuels. Even so, it continues as it has been for fifty years, a “promising” technology just emerging (always) on the horizon at a maximum of ½ million barrels per day.

Hybrid electric and electric vehicles provide incremental relief of approximately 48,000 bbl per day (a .23% reduction) and 94,000 bbls per day (a .45% reduction) in reduced use of petroleum fuels in 2016 and 2021 respectively. Technological breakthroughs in battery capacity are required to lower the effective cost of these vehicles. Until such breakthroughs are made, the deficit-ridden state and federal governments will determine the growth of the electric vehicle industry with each annual budget. We have not addressed any burden on the national grid that would come with a wholesale shift to electric vehicles because our forecast does not anticipate such a shift.

Biomass to fuel, whether ethanol or biodiesel, provides some measure of relief from petroleum based fuels. These fuels are also subject to annual subsidies and worldwide markets. We have not included ethanol from Brazil in our analysis because that would be an imported fuel source.

GTL fuels will face competition from the use of natural gas as a stationary fuel source for electric power generation and from foreign buyers who will buy natural gas at its oil equivalent energy content price when LNG liquefaction facilities for export go online in 2015. But more basic, the combination of the likely problems with a first domestic plant that in design has a gestation period of ten years, and is of a scale that requires many further years of licensing and permit grants puts GTL out in the time span beyond production of liquids comparable to those of other synfuels.

Our conclusion is found in **Table A1**, which indicates (1) actual prices and quantities for comparable crude mb/day (2) design drawing numbers (3) projections for actual plants (4) projections for planned plants (5) projections for non existent plants and for should be existent plants. As added together for a global (domestic) estimate of how much crude has been and will be replaced, the ability of synfuels (and crude replacement by electric motors) could extend by 2021 to 7.3% of the expected level of crude based liquid fuels. So much, then, for the R&D revolution in replacement of fossil based liquids.