Wood-To-Oil

KiOR, Inc. Biomass Process:

A Potential Answer to America's Energy Independence

An Interactive Qualifying Project Report

Submitted to the faculty of

Worcester Polytechnic Institute

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

Nyansafo Aye-Addo

André da Vitória

Josué Malaver

James O'Connor

Abstract

Wood–To–Oil project was an Interactive Qualifying project done by students at Worcester Polytechnic Institute to assess the impact of KiOR Inc.'s Wood Pyrolysis process in the transportation sector to reduce the United States' dependency on oil and to reduce the price of gasoline. Students calculated the ideal oil production for KiOR based on Wood pyrolysis estimation figures and compared it to U.S. consumption of petroleum in the transportation sector. As comparisons, other alternative means of solving the oil problem in the U.S., such as Hydrogen, Natural Gas, Electricity and Biomass, were researched. Other biomass companies were also used to compare KiOR's process and its output claims.

Authorship

Nyansafo Aye-Addo, André da Vitória, Josué Malaver, and James O'Connor were all involved in the authorship of this report. Each individual was responsible for certain sections: Nyansafo authored sections 2.2, and 3.3, 4.2; André wrote sections 2.4, 4.3, and 4.4; Josué was responsible for sections 2.1, 3.1, 3.2, 4.0, and 4.1; James authored sections 1.0, 1.1, 1.2, 1.3, 2.3, and Appendix A. All other sections of this report were written as joint efforts.

Acknowledgements

We would like to thank God for his sustaining love and power. With Him all things are possible. Also, we want to thank Professor Thompson for his continuous support and guidance, from the beginning to the very end of this project. His expertise in the area of alternative energy was an invaluable tool and resource. He, through this project, has helped all of us better understand the complexities of the United States' quest for alternative energy.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

1.1 Project Goals

The goal of this project was to examine the feasibility of KiOR, Inc., through its biomass-to-oil technology, replacing a significant portion of the United States' petroleum consumption. Researching KiOR's process, it was investigated whether or not it could be implemented across the United States to a degree that would make a significant impact on the county's petroleum needs for the transportation sector, and reduce America's dependence on foreign oil.

1.2 Petroleum Consumption in the United States

The first successful American built automobile was designed by Charles and Frank Durylea and made its début in Springfield Massachusetts in 1894.[1] That first test was the début of an invention that was to change the face of the nation and the world and would have a mammoth effect on the world's petroleum consumption. Automobile production increased so much and they were used so pervasively, that the auto industry became a symbol of the strength of America's industry. Simultaneous with the growth in the car industry, the need to fuel them increased as well. Petroleum, in the form of refined gasoline, has been the fuel used in the vast majority of vehicles, and still is today.

[1] Bottorff, William W. "What Was The First Car? A Quick History of the Automobile for Young People." The First Car. Web. 24 Apr. 2012. <http://www.ausbcomp.com/~bbott/cars/carhist.htm>.

Petroleum is not only used to fuel automobiles, in fact, almost every modern product requires petroleum. From plastics, rubbers, nylon ropes, to synthetic cloths, shampoos, and dentures, petroleum is in almost every product used today. Combining all of these uses, petroleum consumption is extremely high and it is not getting any lower in the foreseeable future. Figure 1[2] shows America's increasing petroleum consumption from 1949 to 2010.

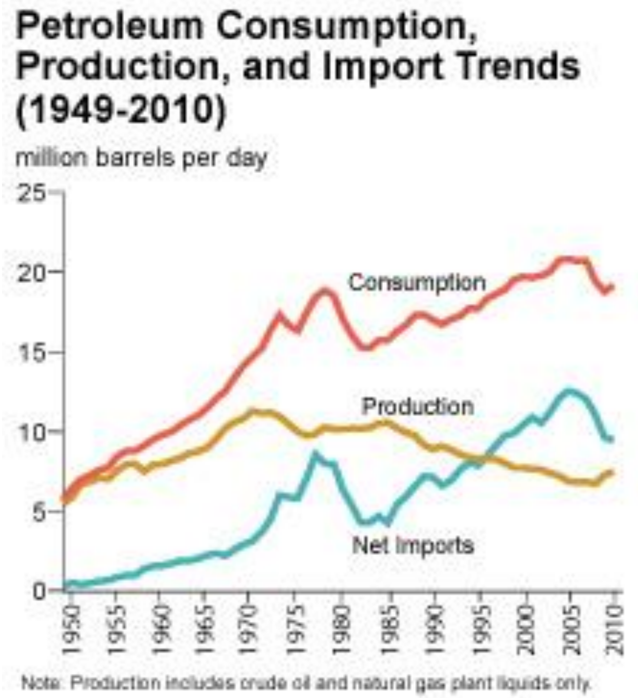

Figure 1 – Petroleum Consumption in the US.[2]

The figure shows that in 1949, America consumed just over 5 million barrels per day. Today, the United States consumes a massive 19.1 million barrels of petroleum a day. Of that 19.1 million, close to 11.8 million barrels are imported from other nations.[3] Figure 1[4] also shows a decline in domestic production. This trend forced the United States to be increasingly dependent on foreign resources for petroleum. Dependence on foreign oil, particularly resources from hostile or potentially hostile nations, is a major concern for America from both an economic and national security standpoint.

[2]"How Dependent Are We on Foreign Oil?" *EIA's Energy in Brief:*. U.S. Department of Energy, 24 June 2011. Web. 16 Mar. 2012. <http://www.eia.gov/energy_in_brief/foreign_oil_dependence.cfm>.
[3]*Ibid.*
[4] *Ibid.*

1.3 Energy Independence

As of April 2011, the United States of America imported nearly fifty percent of its petroleum, as shown in Figure 2[5]. In 2010, 11.8 million barrels were imported each day. The top five countries that are the largest suppliers are Canada, Saudi Arabia, Nigeria, Venezuela, and Mexico.[6]

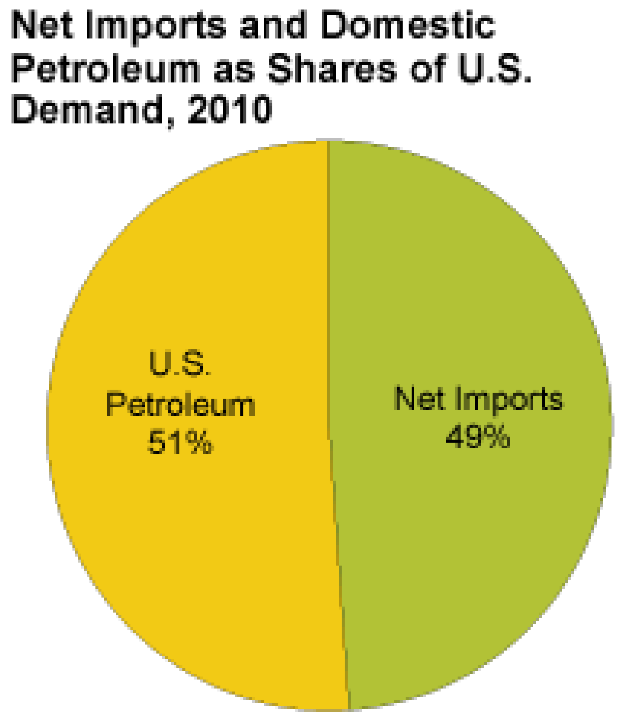

Figure 2 - Net Import and Domestic Petroleum as Shares of U.S. Demand, 2010.[5]

America's dependence on foreign oil is a major concern for the country. Militarily it puts the country at risk since it makes her reliant on countries that could be potential adversaries. Economically it creates uncertainty and roller-coaster markets because the country is susceptible to the whims of other nations and their pricing. Diplomatically it restricts the United States from acting against actions other countries may take, because these countries are able to threaten the US with price increases or supply decreases.

Because energy independence is so vital to the nation's wellbeing and safety, it is imperative that she become energy independent. There are two mainstream fields of thought on how to fix this issue. One way out of the problem is to drill more of our own petroleum. As of today, the United States is the third largest producer of oil, but with all of the natural resources available in America it is possible for the nation to be completely energy independent. With four

---

[5] "How Dependent Are We on Foreign Oil?" EIA's Energy in Brief:. U.S. Department of Energy, 27 Apr. 2012. Web. 27 Apr. 2012. <http://www.eia.gov/energy_in_brief/foreign_oil_dependence.cfm>.

[6] *Ibid.*

hundred billion barrels of underdeveloped technically recoverable oil reserves on U.S. land, some say that the route towards independence simply requires greater harvesting of domestic oil.[7]

The other stream of thought on this issue is one that supports “green,” “renewable” energy. As a result of environmentalist forces in this country, drilling for oil resources is increasingly difficult due to stringent regulations. The route to energy independence pushed by the environmentalists is “clean” and often “renewable” energy. A list of these resources with the most potential included is: hydrogen, electricity, natural gasses, and biofuels. All of these alternative fuels are competing for traction in the U.S. energy industry, as well as around the globe. All four of these alternatives to petroleum can be used to fuel automobiles, but they are competing against each other to be the most economical and plentiful alternative to petroleum. Each claims that it can provide the answer to America’s fuel consumption needs. But can they really? Because each one has pros and cons, a closer look at each one is required.

[7]U.S. Department of Energy. "Recovery of Undeveloped Domestic Oil Resources Can Provide the Foundation for Increasing U.S. Oil Production." (2006): 1-3. Print.

2.0 Alternatives to Petroleum

2.1 Hydrogen

Hydrogen is the most abundant element in the universe. Contrary to common thought, hydrogen is not an energy source, it is an energy carrier that stores and delivers usable energy, produced from compounds that contain it[8].

There are several processes used to produce hydrogen: natural gas reforming, electrolysis, gasification, liquid reforming, nuclear high-temperature electrolysis, high-temperature thermo-chemical water-splitting, and photo-biological and photo-electrochemical. We will discuss the first three of these because they are the ones that could most realistically be implemented in a near future.

Natural Gas Reforming uses the process of steam methane reforming (SMR). This method is the most common (95%) and cost efficient method used to produce hydrogen in large quantities today[9]. The process uses a metal-based catalyst such as nickel, in temperatures of 700 to 1000 degrees Celsius, where steam reacts with methane to produce carbon monoxide[10]. There are currently plants that generate over 480,000kg of hydrogen per day, or about 200 million cubic feet, providing 48% of the world's hydrogen. These plants are always situated very close to the consumers, since transportation and storage of the hydrogen would be more costly than the manufacturing process.

---

[8] "Hydrogen Production." *Hydrogen.energy.gov*. U.S. Department of Energy. Web. <http://www.hydrogen.energy.gov/pdfs/doe_h2_production.pdf>.
[9] "Hydrogen Prdocution." *Hydrogen.energy.gov*. U.S. Department of Energy. Web. <http://www.hydrogen.energy.gov/pdfs/doe_h2_production.pdf>.
[10] "Natural Gas Reforming." *FCT Hydrogen Production:*. U.S. Department of Energy. Web. <http://www1.eere.energy.gov/hydrogenandfuelcells/production/natural_gas.html>.

	Installed	Engineering	Contingency	Total Cost
Steam Methane	109,458,536	10,945,854	21,672,790	142,077,180
Water Gas Shift	2,922,779	292,278	578,710	3,793,767
PSA System	28,030,028	2,803,003	5,549,946	36,382,976
Cooling Towers	6,557,229	655,723	1,298,331	8,511,283
Water Systems	10,434,769	1,043,477	2,066,084	13,544,330
Piping	10,434,769	1,043,477	2,066,084	13,544,330
I&C	3,821,183	382,118	756,594	4,959,895
Electrical Systems	11,757,486	1,175,749	2,327,982	15,261,217
Building and	13,521,109	1,1352,111	2,677,180	17,550,399
Total Capital Investment: 255,625,376				

Table 1 - Total capital investment for an SMR plant producing 130 MMSCFD.[11]

This would mean that to use hydrogen as an alternative to petroleum, hydrogen production plants would have to be built all over cities to supply local fueling stations. It requires an unpractical situation. Table 1[11] shows the total capital investment for conventional SMR plant producing 130 million standard cubic feet per day of hydrogen; equivalent to 308,045 gallons of gasoline[12] (the U.S. consumes 378 million gallons per day[13].) Thus today's best method of producing hydrogen is still not a good enough alternative for petroleum.

[11] "Natural Gas Reforming." *FCT Hydrogen Production:*. U.S. Department of Energy. Web. <http://www1.eere.energy.gov/hydrogenandfuelcells/production/natural_gas.html>.

[12] "Fuel Properties Comparison Chart." *Alternative Fuels & Advanced Vehicles Data Center*. U.S. Department of Energy. Web. <http://www.afdc.energy.gov/afdc/progs/fuel_compare.php>.

[13] "Oil: Crude and Petroleum Products - Energy Explained, Your Guide To Understanding Energy." *U.S. Energy Information Administration (EIA)*. U.S. Energy Information Administration. Web. <http://www.eia.gov/energyexplained/index.cfm?page=oil_home>.

Gasification converts organic, or fossil based, materials that contain carbon into hydrogen. This process, similar to the SMR process, requires a high temperature reaction at

Process	Total Plant Cost ($ x 1000)
Coal & sorbent handling	26,188
Coal & sorbent prep & feed	62,420
Feedwater & misc. bop systems	14,263
Gasifier & accessories	188,828
Gas cleanup & piping	103,747
CO2 drying & compression	41,645
SOFC power island	338,966
HRSG, Ducting & stack	22,493
Steam power system	12,810
Cooling water system	17,078
Ash/spent sorbend handling system	38,868
Accessory electric plant	52,605
Instrumentation & control	27,743
Improvements to site	14,378
Building & structures	13,302
Total plant cost ($1000)	**975,335**

Table 2 - Capital cost breakdowns for a gasification plant.[14]

temperatures of over 700 degrees Celsius. The carbonaceous material then reacts with oxygen and steam. The result is a synthetic gas which then reacts with steam to produce hydrogen. Lastly, the hydrogen is separated and purified. Before this technology can be implemented on a large scale for the transportation sector, a way to stabilize and reduce costs must be created. Table 2[14] shows estimated costs for a gasification plant.

[14] "Analysis of Integrated Gasification Fuel Cell Plant Configurations." *Netl.doe.gov*. U.S. Department of Energy. Web. <http://www.netl.doe.gov/energy-analyses/pubs/IGFC_FR_20110225.pdf>.

Electrolysis uses a simpler process than gasification. Essentially, electric current splits water into hydrogen and oxygen. The major factor impeding this technology is the cost for electricity. The cost of the electricity required to use this process is about 80% of the resulting hydrogen selling price. The electricity could also be generated using renewable sources such a wind or solar. However, electricity itself could be an alternative source to the main problem being addressed, making electrolysis not a negative alternative. Figure 3[15] shows the cost of hydrogen breakdown. A table is difficult to generate because electricity, the main source of cost, is such a variable factor making it hard to approximate costs.

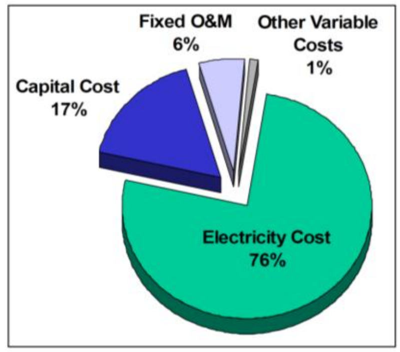

Figure 3 - Hydrogen Production Cost Breakdown.[15]

Creating the infrastructure necessary for large scale use of hydrogen as a transportation fuel would require simultaneous development of supply and transportation, which would prove an arduous challenge. The main issue we would be faced with would not be the use of the hydrogen itself, as we have seen plants already exist which use hydrogen as a source of energy, and the technology to use hydrogen as a source of fuel for in the auto industry exists as well. Instead the difficult task would be the supply and transportation of the hydrogen. These plants would need to be distributed all over the nation to be able to supply the amount of hydrogen required. Figure 4[16] shows a map of the limited number of hydrogen facilities in the United States in 2006.

[15]"Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis." *Hydrogen.energy.gov*. U.S. Department of Energy. Web. <http://hydrogen.energy.gov/pdfs/46676.pdf>.
[16]"EIA - Appendix C. Existing Hydrogen Production Capacity." *U.S. Energy Information Administration (EIA)*. U.S. Energy Information Administration. Web. <http://www.eia.gov/oiaf/servicerpt/hydro/appendixc.html>.

Figure 4 - Hydrogen Production Facilities in 2006.[16]

This number of plants is miniscule compared to the number needed. If we calculate the costs for building these plants all over the nation from the prices above, we would come up with an unrealistic number. Then we would need to add the transportation of the hydrogen to "stations," which is a huge challenge due to the corrosive nature of hydrogen. Due to the extremely small size of hydrogen atoms it is nearly impossible to contain without having any leakage which adds another dimension to the challenge of transportation. This data proves hydrogen, although an alternate source to replace petroleum is evidently not a viable source until we can significantly reduce the costs of production and transportation.

2.2 Electricity

There are three main types of electric vehicles: Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Battery Electric Vehicles (BEVs). The Hybrid Electric Vehicle has two sources of power: 1) An internal combustion engine that uses conventional and alternative fuel; and 2) an electric motor connected to a battery pack. HEVs charge their internal battery through the process called regenerative braking.[17] When the car's brake is applied, the vehicle using the electric motor as a generator captures the energy lost and stores it in the battery.[18] Benefits of HEVs include high fuel economy and low emissions despite the low driving range obtained from a fully charged battery. "The actual 100 percent electric range obtained from a fully charged battery in an HEV is very small, approximately 10 to 20 miles."[19]

With the exception of a larger battery pack PHEVs are similar to HEVs. They still have an internal electric motor and a combustion engine. However, its internal combustion engine, designed as an additional drive motor, extends the driving range when the battery is drained. The electric motor can be used for short distances of about ten to sixty miles for a one day round trip.[20]When the battery is drained, some PHEVs have a downsized gas engine to recharge the battery as the car moves or as a primary source of propulsion until the car can be charged with electricity from the grid. Other PHEV's use gasoline engines exclusively for recharging batteries.[21] "A typical fuel mileage cannot be calculated for PHEVs because the ratio of an electric motor to internal combustion engine drive times varies on driving applications."[22]

---

[17]U.S. Department of Energy."Hybrid Electric Vehicle Basics."*Alternative Fuels and Advanced Vehicles Data Center:* USA.gov, 22 Sept. 2011. Web. 13 Mar. 2012<http://www.afdc.energy.gov/afdc/vehicles/electric_basics_hev.html>.
[18]*Ibid.*
[19]UniStar Nuclear Energy. "Replacing Foreign Oil With Electric Vehicles." *A UniStar Issue Brief* (2011). Web. 11 Mar. 2012. <unistarnuclear.com/IB/IB_electric_vehicles.pdf>.
[20]*Ibid.*
[21]Berman, Bradley. "A Comprehensive Guide to Plug-in Hybrids."*Plug-in Hybrid Cars*. Hybridcars.com, 11 Aug. 2011. Web. 13 Mar. 2012. <http://www.hybridcars.com/plug-in-hybrid-cars>.
[22]UniStar Nuclear Energy. "Replacing Foreign Oil With Electric Vehicles." *A UniStar Issue Brief* (2011). Web. 11 Mar. 2012. <unistarnuclear.com/IB/IB_electric_vehicles.pdf>.

Battery electric vehicles (BEVs) are all-electric vehicles run solely on electricity. Most BEVs are manufactured with a target range of sixty to one hundred miles.[23]Because the battery of a BEV is charged using an electric power source, for longer trips, it is essential to charge the

Region	Coal	Oil	Natural Gas	Nuclear	Other
1. East Central Area Reliability Coordination Agreement (ECAR)	83.9	0.5	5.7	9.0	0.9
2. Electric Reliability Council of Texas (ERCOT)	45.2	0.5	37.3	11.9	5.1
3. Mid-Atlantic Area Council (MAAC)	44.1	1.2	5.5	34.2	15.0
4. Mid-America Interconnected Network (MAIN)	52.9	0.3	4.2	31.8	10.8
5. Mid-Continent Area Power Pool (MAPP)	73.1	0.4	1.8	12.3	12.4
6. Northeast Power Coordinating Council / NY (NPCC-NY)	12.3	5.6	33.9	29.3	18.9
7. Northeast Power Coordinating Council / NE (NPCC-NE)	17.5	1.8	43.0	21.9	15.8
8. Florida Reliability Coordinating Council (FRCC)	53.9	5.5	26.3	11.9	2.4
9. Southeastern Electric Reliability Corporation (SERC)	49.9	0.6	11.9	33.0	4.6
10. Southwest Power Pool (SPP)	74.1	0.6	15.9	4.3	5.1
11. Western Electricity Coordinating Council / Northwest Power Pool Area (WECC-NW)	28.8	0.1	6.4	3.2	61.5
12. Western Electricity Coordinating Council / Rocky Mountain and AZ-NM-Southern NV Power Area (WECC-RMP/ANM)	60.8	0.4	21.2	8.0	9.6
13. Western Electricity Coordinating Council / California (WECC-CA)	13.0	0.0	40.4	17.3	29.3

Table 3 - Power Generation Mix of U.S. Regions.[24]

battery or swap en route.

BEVs are categorized as zero-emission vehicles because their electric motors produce no exhaust. Although these cars produce no pollution, the electricity used to run them is often produced from coal power plants that do contribute to pollution. As shown in Table 3[24], power generation mix varies from region to region. It shows the projection for 2020 average mix based on EIAs Annual Energy Outlook (AEO) 2008.

A few regions in the United States have a significant percentage of power generation from other types of energy sources such as the Western Electricity Coordinating

[23]UniStar Nuclear Energy. "Replacing Foreign Oil With Electric Vehicles." *A UniStar Issue Brief* (2011). Web. 11 Mar. 2012. <unistarnuclear.com/IB/IB_electric_vehicles.pdf>.

[24]A. Elgowainy, A. Burnham, M. Wang, J. Molburg, and A. Rousseau. “Well-to Wheels Energy Use and Greenhouse Gas Emissions”: *Analysis of Plug-In Hybrid Electric Vehicles:* Energy Systems Division, Argonne National Laboratory, Feb. 2009. Web. 13 Mar. 2012.

Council/Northwest Power Pool Area (WECC-NW), but U.S. regions mainly produce electricity through coal, which is burned as a fossil fuel. Consequently, BEVs offer the best environmental benefits when their battery is recharged by renewable energy sources such as solar, wind, and hydropower or a mix of alternative fuels for PHEVs and HEVs. Researchers at Argonne National Laboratory reported that, in comparison to an internal combustion engine vehicle that uses gasoline, PHEVs with an all-electric range between 10 miles and 40 miles that use petroleum fuels (gasoline and diesel), a blend of (85% Ethanol and 15% Gasoline – E85), and hydrogen, offer a 40 - 60%, 70 – 90%, and more than 90% reduction in petroleum energy, and a 30 – 60%, 40 – 80%, and 10 – 100% reduction in Greenhouse Gases, respectively.[25] According to a report by the U.S. Department of Transportation, National Household Travel Survey, a driving range of 100 miles is sufficient for more than 90% of household trips.[26] Figure 5[27] shows that if the battery of electric vehicles improves cost efficiently, it could satisfy all household trips to school and social events etc.

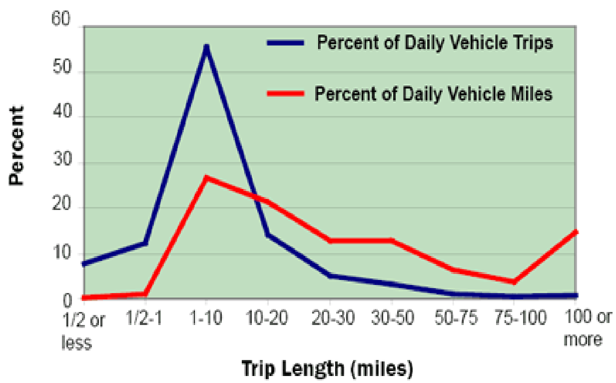

Figure 5 - Daily Vehicle Trip Lengths.[27]

[25]A. Elgowainy, A. Burnham, M. Wang, J. Molburg, and A. Rousseau. "Well-to Wheels Energy Use and Greenhouse Gas Emissions": *Analysis of Plug-In Hybrid Electric Vehicles:* Energy Systems Division, Argonne National Laboratory, Feb. 2009. Web. 13 Mar. 2012.
[26]U.S. Department of Energy."Hybrid Electric Vehicle Basics."*Alternative Fuels and Advanced Vehicles Data Center:* USA.gov, 22 Sept. 2011. Web. 13 Mar. 2012<http://www.afdc.energy.gov/afdc/vehicles/electric_basics_hev.html>.
[27]Tang, Tianjia. "Figure 4-5. Percent of Trips and Vehicle Miles: 2008 - Highway Finance Data & Information - Policy Information - FHWA." *Home*.U.S. Department of Transportation, National Household Travel Survey.Web. 14 Mar. 2012. <http://www.fhwa.dot.gov/policyinformation/pubs/pl08021/fig4_5.cfm>.

Although electric vehicles could potentially replace petroleum and reduce America's oil dependence, implementing an electric transportation system in the United States would require new infrastructure production of advanced batteries for grid vehicle technology and substantial electricity output for the transportation sector. Table 4[28]shows that Petroleum accounts for 96% of the energy source consumed by the transportation sector in the U.S. Also, the demand for transportation energy is almost equivalent to that of residential, commercial, and electricity combined. Therefore, if electricity is to become a substantial energy source for the transportation sector, a significant increase in generation capacity will be required.

Energy Source	Transportation	Industrial	Residential and Commercial	Electricity
Petroleum	27.8	9.5	2.0	0.8
Natural gas	0.6	8.0	8.0	7.0
Coal	0.0	1.9	0.0	20.7
Renewable	0.6	2.0	0.6	3.7
Nuclear	0.0	0.0	0.0	8.4

Table 4 - Distribution of U.S. Energy Consumption (Quads).[28]

One large deterrent that keeps this technology from becoming wide spread is its cost. In fact, "the only BEV available for sale in the U.S. prior to 2010 was the Tesla Sportster, which has a range of more than 200 miles, but sells for over $100,000 and it costs $40,000 to replace the battery."[29]Although, the problem with price and technology persists, manufacturers aim to increase production in the near future. Table 4[30] below shows an increase in manufacturing plants for electric vehicles. For BEVs alone the United States Department of Energy (DOE) estimates 46 manufactures in 2015 that will rely considerably on improvements in battery technology, public and home charging infrastructure, and consumer interest.

[28]A. Elgowainy, A. Burnham, M. Wang, J. Molburg, and A. Rousseau. "Well-to Wheels Energy Use and Greenhouse Gas Emissions": *Analysis of Plug-In Hybrid Electric Vehicles:* Energy Systems Division, Argonne National Laboratory, Feb. 2009. Web. 13 Mar. 2012.
[29]UniStar Nuclear Energy. "Replacing Foreign Oil With Electric Vehicles. "*A UniStar Issue Brief":* UniStar Nuclear Energy, Jan. 2011. Web. 13 Mar. 2012.
[30]*Ibid.*

EV/PHEV/BEV Offerings in the U.S.

Number of Manufacturers		
YEAR	HEV/PHEV	BEV
2010[1]	12	1
2011[1]	14	3
2015[2]	20	46

[1] U.S. DOE Alternative Fuels Data Center
[2] Plug-In America Vehicle Tracker Projection (not all may be offered in the U.S.)

Table 5 - Manufactures of EV (Electric Vehicles) in U.S.[30]

Another issue involves the energy density of battery, which is less than that of gasoline. Yet, electric vehicles convert energy into mechanical work more efficiently than internal combustion engine vehicles. Harmut Michel in, "The Nonsense of Biofuels," in the Angewandte Editorial makes the case that the combination of photovoltaic cells and electric engines uses available land 600 times better than the combination of biomass/biofuels/combustion engine.[31] The reason is that photovoltaic cells have a 15% conversion efficiency; that is 150 times better than storage of energy from sunlight in biofuels. Also, 80% of energy stored in battery is used for car propulsion, compared to 20% of energy for gasoline-run vehicle.[32]

The high cost and short lifetime of batteries are due to high material costs which prohibit commercial production. "A range of generic estimates for current battery costs centers on $600 per kWh."[33] Other problems include, homes not having parking space to charge their vehicles, and the time it takes to charge at refueling stations. The number of public charging outlets is also far from sufficient to fuel a large electric car fleet. In the Electrification Coalition Report, the cost per charging unit for a Level II charger is $2000. The report states that "even for fleets that

[31]Harmut, Michel "The Nonsense of Biofuels"Angew. Chem. Int. Ed. 2012.
[32]*Ibid.*
[33]"Electrification Roadmap: Revolutionizing Transportation And Achieving Energy Security." (2009): 1-91. Web. 11 Mar. 2011. <http://www.prtm.com/uploadedFiles/Thought_Leadership/Articles/External_Articles/EC-Fleet-Roadmap-print.pdf>.

centrally park, the cost of installing charging infrastructure may be significant. With Level II charger costs averaging $2,000 per unit, the cost of installing enough chargers to support a fleet of several dozen EVs or PHEVs could be challenging."[34] A rough calculation estimates that Worcester Polytechnic Institute (WPI) would spend $1.2 million to install 600 level II charging units for its employees. The daily cost of recharging employees' batteries would likely be prohibitive. Even if they don't provide separate charging units for employees other problems could arise such as crowded stations. Therefore WPI and other companies will not likely be able to give free charging. Also, charging spaces that host a fleet of electric vehicles might need to upgrade local electricity generation capacity and distribution networks. This shows that the current automotive infrastructure cannot support wide-scale electric vehicle technology.

2.3 Natural Gases

Natural gas is not a single gas, but is a mixture of multiple gases, most of them hydrocarbons. Some gases that commonly comprise natural gas are methane, propane, butane, ethane, pentane, nitrogen, oxygen, carbon dioxide, and organic-sulfur compounds. Methane is most often the largest component, often comprising between 87% and 97% of the mixture. Like petroleum, natural gas is found deep below the ground and must be drilled for. For nearly a century, natural gas has been used as a fuel to power automobiles, but not until recently have

[34] "Electrification Roadmap: Revolutionizing Transportation And Achieving Energy Security." (2009): 1-91. Web. 11 Mar. 2011. <http://www.prtm.com/uploadedFiles/Thought_Leadership/Articles/External_Articles/EC-Fleet-Roadmap-print.pdf>.

governments, corporations, and the general public woken to the positive affect natural gas can have towards energy independence.[35]

Hundreds of years ago, the Chinese discovered that natural gas was useful in heating source.[36] It was later used to fuel street lamps. It was not until the 1930's that natural gas vehicles became available. Today, natural gas is being used in numerous sectors of the economy, for example, heating buildings, and fueling stoves in residential as well as commercial locations. Not until after WWII, with advances in metal working, was there adequate means of transportation for the fuel. It could not travel in other fuel pipeline, such as oil, because of its small size and its ability to diffuse, it would easily escape. Without means of transportation, the fuel was economically useless and when found was normally burned or simply let loose into the atmosphere. With improvements in welding techniques, pipe rolling, and metallurgical advances developed during WWII, efficient pipelines were designed and created. After the war, pipelines

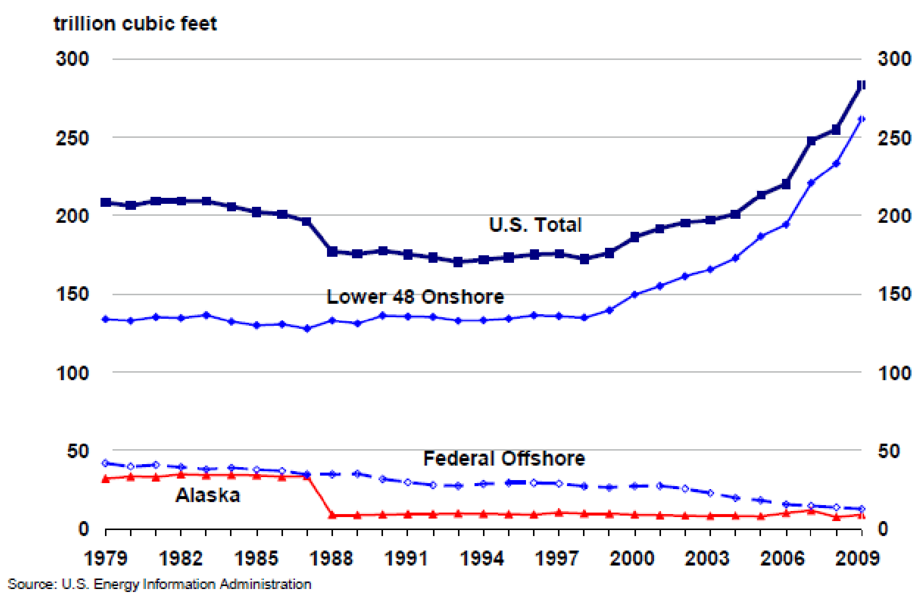

Figure 6 Gas Proved Reserves.[38]

[35]"NaturalGas.org." *NaturalGas.org*. NaturlGas.org, 2004. Web. 23 Apr. 2012. <http://naturalgas.org/overview/uses_transportation.asp>.
[36] "Computersmiths - History of Chinese Invention - The Discovery of Natural Gas." *Computersmiths*. Web. 24 Apr. 2012. <http://www.computersmiths.com/chineseinvention/natgas.htm>.

were quickly built across the country, providing the needed transportation.[37]

Natural gas reserves are not easy to calculate while still in the ground. For this reason, the estimates of total compressed natural gas CNG reserves in the United States are in continuous flux. However, as technology improves, the accuracy of these estimates increases and more natural gas is found

Figure 6[38] shows an estimate of the amount of proven gas reserves calculated to be in the United States. In 2008, the estimate for provable volume of natural gas was around 225 trillion cubic feet (tcf). By 2009, that number was approaching 300 tcf which translates to roughly 50 billion barrels of oil.[39] But this is only the amount that can be 100% proven to exist. Experts estimate that the combination of unproved, undiscovered and unconventional natural gas as high as 2,543 tcf, which translates to around 400 billion barrels of oil.[40]

Today, natural gas is considered a large part of the country's goal of reducing our dependence on foreign oil. Today, the United States has over 150,000 natural gas vehicles on the road, and worldwide there are over five million.[41] The majority of these vehicles are comprised of bus fleets, and other vehicle fleets of companies that are hard hit by high petroleum prices. Speaking to a United Parcel Service (UPS) facility in Maryland, President Barack Obama said,

---

[37]"NaturalGas.org." *NaturalGas.org*. NaturalGas.org, 2004. Web. 23 Apr. 2012. <http://naturalgas.org/overview/history.asp>.

[38]"U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves." *U.S. Energy Information Administration (EIA)*. U.S. Department of Energy, 30 Nov. 2010. Web. 23 Apr. 2012. <http://www.eia.gov/oil_gas/natural_gas/data_publications/crude_oil_natural_gas_reserves/cr.html>.

[39]"NaturalGas.org." *NaturalGas.org*. NaturalGas.org, 2004. Web. 23 Apr. 2012. <http://naturalgas.org/overview/history.asp>.

[40] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Total Energy. U.S. Department of Energy, 19 Oct. 2011. Web. 24 Apr. 2012. <http://205.254.135.24/totalenergy/data/annual/showtext.cfm?t=ptb0401>.

[41]"NaturalGas.org." *NaturalGas.org*. NaturlGas.org, 2004. Web. 23 Apr. 2012. <http://naturalgas.org/overview/uses_transportation.asp>.

"If you're a business that needs to transport goods, I'm challenging you to replace your old fleet with a clean energy fleet that's not only good for your bottom line, but good for our economy, good for our country and good for our planet." Many companies have taken this step by converting their fleets from petroleum fueled to natural gas fueled.

The UPS now drives over one thousand trucks that run on natural gas. Dallas Airport has a fleet of almost five hundred natural gas-driven maintenance vehicles, and Verizon has a fleet of five hundred and one CNG vehicles crisscrossing the country. Many companies are in the process of taking the same steps. AT&T is poised to purchase eight thousand CNG vehicles for its fleet. [42]Although it had a slow start, CNG is becoming a large energy source in the United States' fuel options and although it is not a renewable resource it is very plentiful[43]

Although many companies now own natural gas vehicles, most individuals have opted to stick with the norm and buy petroleum vehicles. As stated earlier, there are only 150,000 natural gas vehicles in the United States and only 5 million worldwide.[44] Thus, just as it is clear that the United States is not leading the way on pursuing natural gas vehicles. It also seems that consumers have yet to be persuaded that natural gas is the fuel of the future.

Considering both that natural gas automobiles have existed for over eighty years and the considerably small impact they have made, one must wonder what has held this fuel back. When seeking to calculate how well a certain alternative fuel will do in the open market, it must be compared to petroleum vehicles, point for point. One of the major advantages of natural gas is that is it very much like petroleum in form and application. It is stored in a fuel tank similar to a

[42]"NGVA." *NGVA*. Natural Gas Vehicles for America, 2011. Web. 23 Apr. 2012. <http://www.ngvc.org/forfleets/commercial/index.html>.
[43]*Ibid.*
[44]"NaturalGas.org." *NaturalGas.org*. NaturlGas.org, 2004. Web. 23 Apr. 2012. <http://naturalgas.org/overview/uses_transportation.asp>.

gas tank, and a tank that's filled in the same way as a gas tank, at a fueling station almost identical to a gas station. In the event of a vehicle collision, since natural gas is lighter than air it would simply evaporate into the air. And the storage tanks in natural gas vehicles (NGV) are much stronger than those of their gasoline counterparts.[45]The tanks are also pressurize. But is has disadvantages as well. Compared to petroleum automobiles, natural gas vehicles have a higher initial price, and the comparative scarcity of refueling stations make natural gas a hard sell for consumers.[46]

2.4 Biomass

Biomass derived fuels can be made from a large variety of feed stocks. Because biomass can be obtained through cultivation, or through natural means, only using readily available resources such as sunlight, air and water it is considered renewable. This makes it a very attractive option for lessening our dependence on fossil fuels, and within that, foreign oil. As with any other kind of technology before it, biofuels must undergo some degree of development before becoming a reality as a part of a commercially profitable industry.

Biomass is a broad term used to describe any kind of matter from a living organism, whether it is a functional piece of an organism, the entire organism, or even refuse excreted by the organism. An organism is everything from a single celled organism to multi-celled animals and plants.[47]Sometimes however, the definition may vary, becoming narrower depending on the application or context. Quantifications of biomass also vary. For example, the water content is a variable that is used to qualify different types of biomass. Furthermore, biomass may be

---

[45] "NaturalGas.org." *NaturalGas.org*. NaturlGas.org, 2004. Web. 23 Apr. 2012. <http://naturalgas.org/overview/uses_transportation.asp>.

[46] *Ibid.*

[47] "Biomass."*IUPAC Gold Book*. IUPAC, 11 Aug. 2011. Web. 12 Dec. 2011. <http://goldbook.iupac.org/B00660.html>.

processed in a number of different manners, to many different ends. For example, every time we eat something animal or plant derived, it is some type of biomass that our bodies process for energy and nutrients.

Due to the breath of its definition, biomass fuel can be obtained from many sources. Some biomass can be grown in the form of edible crops some to be harvested as an energy source, while some is grown as sustenance. This brings up possibly the gravest drawback of using biomass as fuel—it can conflict with the food industry. While not an eminent threat to the food industry, this adds a bounding condition to the amount of fuel that can be made from crops that would primarily be grown for consumption. On the other hand, it proves to be a very useful resource from sources such as municipal or rural wastes. Municipal and rural wastes can have energy rich components, such as animal oils or cellulose and lignin. Although many of these resources, such as sugar cane, bagasse, and cow dung, could be used as fertilizer, the conflict with the fertilizer industry is not as great as with the food industry. Much of this category of biomass is simply discarded depending on whether or not there is local demand for it. With biofuels technology, these sources could become a great resource.

For centuries mankind has used biomass as a source of energy. Wood and animal oil has been burned since the beginning of time. Plant matter is a good example. Charcoal, a form of plant matter, has been produced by man for millennia. It is a biomass fuel that is simple to produce and can be made almost anywhere due to the abundance of materials required for its production. Charcoal is simply wood, pyrolyzed in a controlled environment in which the more volatile chemicals within the wood are vaporized and the more stable components are prepared for easier consumption. The process through which charcoal is made is called Pyrolysis.[48] Pyrolysis for fuel creation however, is not limited to only producing charcoal. In recent decades, this process has been used to harvest energy from many different types of biomass, such as almonds, sugar cane, switch-grass, peanuts and even some varieties of micro algae.[49]

Pyrolysis is a process in which biomass, sometimes treated beforehand, is fed into a reactor and is then subjected to large amounts of energy, usually in the form of heat. This process breaks down long hydrocarbon chains to make it easier to harvest energy form the material or to vaporize more volatile substances within the matter being processed. As with most parts of the process, the reactor can vary in size and sophistication. Older processes involved piling wood around a central pit, in which the only surface contacting the air was aimed to be the central "flue".[50] As the process evolved, the wood was buried under dirt and later fed into furnaces made of clay or stone to slow down the reaction and preserve some of the stored energy within the wood.[51] Processes today revolve around the same principles but are much more highly controlled.

$$\text{Energy} + \text{Cellulose} + \text{Lignin} \rightarrow \text{Gas} + \text{Oil} + \text{Energy}$$

In a simplistic sense, the purpose of Wood Pyrolysis is primarily to cause the decomposition of long carbohydrate chains (all varieties of lignin and cellulose) composing wood, into some smaller molecular weight compounds , such as crude bio-oil to be converted

---

[48]Dinesh Mohan, Charles U. Pittman, Jr., and Philip H. Steele. "Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review." *Energy and Fuels* (2006): 848-89. Web. 27 Nov. 2011.
[49]Yanqun Li, Nathalie Dubois-Calero, Mark Horsman, Nan Wu, and Christopher Q. Lan. "Biofuels from Microalgae, ARTICLES: BIOCATALYSTS AND BIOREACTOR DESIGN." *Biotechnol.Prog.* (2008): 815-20.
[50]Mechanical Wood Products Branch."Simple Technologies for Charcoal Making."*FAO Home*.Forestry Department, 1987.Web. Dec. 2012. <http://www.fao.org/docrep/X5328E/x5328e00.htm>.

[51]*Ibid.*

into fuels. One important detail that must be highlighted is that the process does yield some energy. However this energy is not sufficient to eliminate the need for input.

The medium, in which the biomass being processed is carried out, may also vary. This medium may be anything from a solid, such as sand, to a variety of liquids, aqueous or otherwise. The carrier medium usually serves as more than just a physical means of transferring heat and moving the materials being processed. This medium can also be a substance that is miscible with the desired products of the reaction, making them easier to sort from the rest. Sometimes within the medium there may be some kind of catalyst or hydrolytic agent to quicken the reaction and lower the amount of energy used.[52]

The atmosphere in which the process takes place can vary, from unmodified air to a low oxygen atmosphere, or even atmospheres devoid of oxygen.[53] The reason to deprive the reagents of oxygen is that oxygen is a very powerful and reactive oxidizing agent and can very quickly release the energy within the material being processed. The pressure in these reactors may also vary from one, to hundreds of atmospheres.[54] Pressure like heat energy, can greatly affect the speed and efficiency of the reaction.

[52] "Process for Hydrolysis of Biomass." *United States Patent 4,556,430*. USPTO, December 3, 1985. Web.november 15, 2011. <http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PTO1&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=1&f=G&l=50&d=PALL&RefSrch=yes&Query=PN%2F4556430>.

[53] "Process for Converting Carbon-based Energy Carrier Material." *United States Patent: 7901568*. Kior Inc., 8 Mar. 2011. Web. Dec. 2011. <http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=6&f=G&l=50&co1=AND&d=PTXT&s1=kior&OS=kior&RS=kior>.

[54] "Catalytic Hydropyrolysis of Organophillic Biomass." *United States Patent: 8063258*. 15 Nov. 2011. Web. Dec. 2011. <http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=2&f=G&l=50&co1=AND&d=PTXT&s1=kior&OS=kior&RS=kior>.

Although all of the mentioned alternative fuels, hydrogen, electricity, natural gas, and biomass, provide key ingredients towards America becoming energy independent, the focus of this project is on biomass in particular. Many companies have sought to harness the potential energy stored in biomass. All attempts have met with varying success. The contexts for learning about KiOR Inc. lie partly in looking at other biomass companies. A few of the most prominent ventures are mentioned below.

3.0 Biomass Companies

3.1 Changing World Technologies:

Changing World Technologies (CWT) was founded in August 1997to explore energy alternatives.[55]Today, CWT is one of several companies that generate renewable biofuels. Using a patented thermal conversion process, CWT converts organic matter wastes into consumer products, i.e. electricity. This process is a renewable, eco-friendly means of producing renewable biofuels.

Through this thermal conversion process, the waste is: 1) prepared in a container with water, 2) put in a machine that applies heat under pressure of 400 degrees Celsius and is directed into a depolymerization reaction that separates the organic from the inorganic,3) the inorganic material is then put to storage, while the organic is sent into a hydrolysis reaction to separate complex molecules into simpler units, 4) the products from this step then need to be separated into the gases, renewable diesel, water and other remaining solids. This produces the final product.[56] This process is illustrated in the Figure 7[57] below.

[55]"Changing World Technologies, Inc." *Changing World Technologies, Inc.* Web. <http://www.changingworldtech.com/>.
[56]"Changing World Technologies, Inc. - What Solutions Does CWT Offer? - What Is Thermal Conversion Process (TCP)?" *Changing World Technologies, Inc.* Web. <http://www.changingworldtech.com/what/index.asp>.

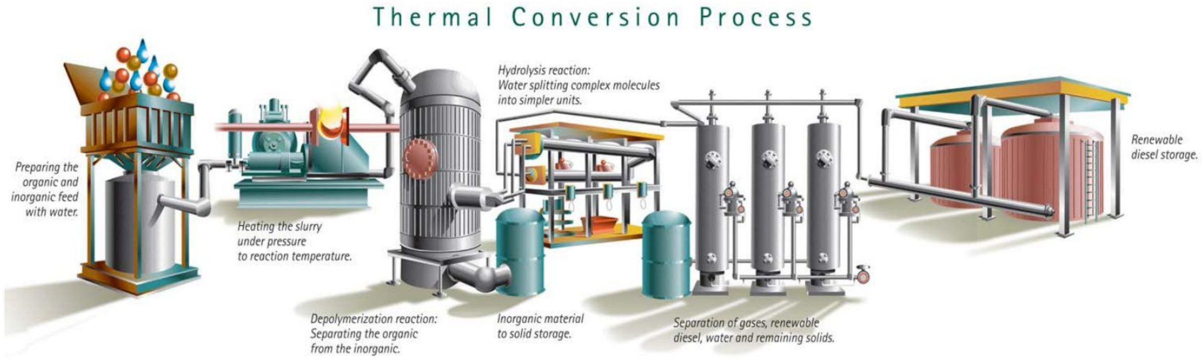

Figure 7 - Thermal conversion process used by Changing World Technologies[57]

Changing World Technologies reported that there are about 6 billion tons from agricultural waste per year in the U.S. that they could theoretically convert into 4 billion barrels of oil.[58] However the Environment Protection Agency reported 35 million tons for food scraps in 2010[59]that could also be used to convert to energy, yielding an even greater number of barrels of oil produced. Contrary to their claims, previous research shows that production from waste would only render about 3% of our petroleum need (about 160.7 million barrels).[60]

3.2 Primus Green Energy

Primus Green Energy is another company that converts biomass to fuel. Primus GE is a branch of Israel Corporation, with it being the majority shareholder. Israel Corporation is "one of the largest companies in Israel, with ownership in oil processing, distribution, alternative energy, fertilizers and special chemicals, shipping, and transportation companies." [61] Based in

[57]"Changing World Technologies, Inc. - What Solutions Does CWT Offer? - What Is Thermal Conversion Process (TCP)?" *Changing World Technologies, Inc.* Web. <http://www.changingworldtech.com/what/index.asp>.
[58]*Ibid.*
[59]"Municipal Solid Waste Generation, Recycling, and Disposal in the United States Tables and Figures for 2010." *U.S. Environment Protection Agency*. Web. <http://www.epa.gov/osw/nonhaz/municipal/pubs/msw_2010_data_tables.pdf>.
[60] Feasibility Study of Thermal Depolymerization Process, WPI
[61]"Investors." *Renewable Drop-in Fuel from Biomass*. Web. <http://www.primusge.com/about-us/investors/>.

Hillsborough, NJ, Primus GE is considered yet another leader in innovation of renewable energies.

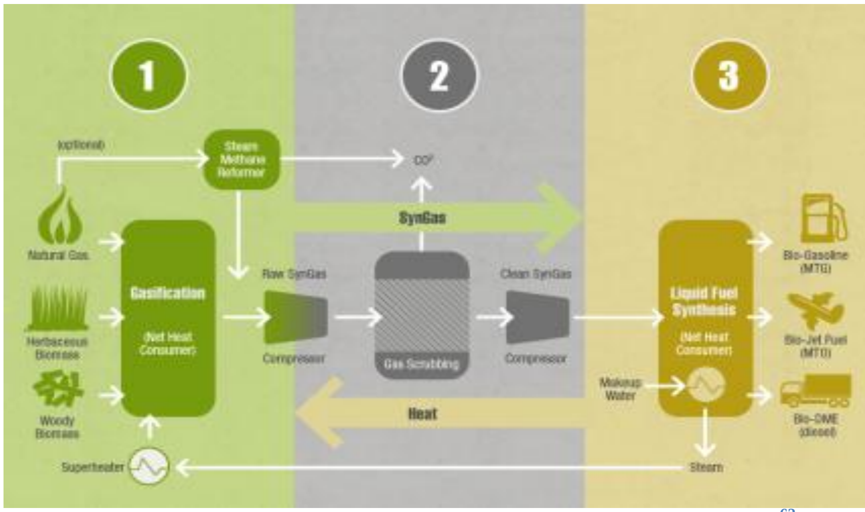

Figure 8 - Biomass to fuel conversion used by Primus Green Energy.[62]

The process used by Primus, can use a wide variety of fuels, from wood, to herbaceous material and agricultural residues. The process is illustrated in the Figure 8[62]. The wide variety of potential biomass inputs reduces the risk of running out of supply. The process is a thermal-chemical conversion process which uses proprietary technology, which yields "drop-in fuel" as the final product.[63] The process begins with taking the input biomass sending it through a gasification process to produces synthetic gas. The result is then put through a process called gas scrubbing where carbon dioxide is separated from the product—synthetic gas. Finally, the product enters a Liquid Fuel synthesis that uses a proprietary four-stage catalytic system that yields the final product of ready to drop in fuel.[64]Table 6[66] compares this final product with some of Primus GE's competitors' products.

[62]"How It Grows." *Renewable Drop-in Fuel from Biomass*. Web. <http://www.primusge.com/how-it-works/how-it-grows/>.
[63]"Biomass to Fuel Conversion." *Renewable Drop-in Fuel from Biomass*. Web. <http://www.primusge.com/how-it-works/biomass-to-fuel-conversion/>.
[64]"Biomass to Fuel Conversion." *Renewable Drop-in Fuel from Biomass*. Web. <http://www.primusge.com/how-it-works/biomass-to-fuel-conversion/>.

Mass production of the product is yet to begin. However, the company is in the process of building its first commercial facility in Pennsylvania, and "will have a processing capacity of 40,000 tons of biomass per year, generating 3.2 million gallons of high-octane gasoline each year."[65] Also, Primus has already established agreements with several partners to secure the supply, production, and distribution chain. Primus has the potential to become a great competitor in the renewable energy market, with the notion that the end product is ready to use fuel for vehicles. Table 6[66] compares the end product obtained from the primus process to other fuels.

	Fossil Fuel Gasoline	Ethanol	Bio-Diesel	Primus Bio-Gasoline
Uses	Drop-in	Fuel oxygenate	Substitute for diesel	Drop-in
Energy density (MJ/gallon)	132	89	126	132
Cost per gallon	$3.10	$2.23	$3.00	$1.69*
Displacement of food crops	None	High	Medium	None
Availability	Worldwide	US-Brazil	Europe	US and then worldwide
Lifecycle Carbon Dioxide Emissions	24.3 lbs/gallon	14.6 lbs/gallon	5.84 lbs/gallon	4.86 lbs/gallon

Table 6 - Comparison of Primus end product to other fuels[66]

[65] "Mass Production." *Renewable Drop-in Fuel from Biomass*. Web. <http://www.primusge.com/how-it-works/mass-production/>.
[66] "Bio-Gasoline vs. Ethanol / Bio-Diesel." *Renewable Drop-in Fuel from Biomass*. Web. <http://www.primusge.com/why-drop-in/bio-gasoline-vs-ethanol-bio-diesel/>.

3.3 Vegetable Green Energy, LLC (Vee-Go):

Vegetable Green Energy, LLC (Vee-Go) is a sustainable energy corporation. As a part of the E2M Ag – Energy Initiative of Western Massachusetts, Vee-Go Energy plans to establish a renewable fuel program that will mitigate the challenges the U.S. faces for its dependency, on oil in general, and provide a system that connects local farmers and communities as directly as possible and to produce non-food biofuels.[67]

Vee-Go's primary focus is on the production of energy pellets and BiocharXtra. Vee-Go's energy pellets are produced from a by-product of grain processing. One advantage of Vee-Go's energy pellets is its environmental impact. By using non-food biomass Vee-Go does not contribute to high food prices. Rather, as grain-processing increases so does the by-products. Additionally, Vee-Go makes the claim that their energy pellets have a carbon cycle of only three months, which is outstanding compared to wood pellets that have a twenty-year cycle.[68] The pellets can be used in a wood pellet stove.

The other main focus of Vee-Go is producing BiocharXtra, an organic 7-3-7 fertilizer (carbon content of 87% dry weight) by a pyrolysis process. Biochar is beneficial to agricultural sustainability. It can potentially reduce CO_2 and nitrogen global warming gases and increase the nitrogen uptake of plants.[69] It has also proven to absorb and neutralize toxic fungi that live on the soil. Although the intention of Vee-Go's sales is on energy pellets and BiocharXtra, it uses a similar process to produce "BiocharXtra". "Biochar is produced through pyrolysis or gasification

---

[67]Garjian, Michael. "E2M Ag-Energy Initiative of Western Massachusetts."1-4. Web. Feb.-Mar. 2012. <http://www.mass.gov/eea/docs/eea/biofuels/hearing2-e2m-agenergy-testimony.pdf>.
[68]Garjian, Michael. "Heating Pellets for Multi Fuel or Corn Stoves."*Heating Pellets for Multi Fuel or Corn Stoves*.Vee-Go Energy.Web. 18 Mar. 2012. <http://vee-goheatingpellets.com/>.
[69]*Ibid.*

– processes that heat biomass in the absence (or under reduction) of oxygen"[70] as shown in Figure 9[71] below.

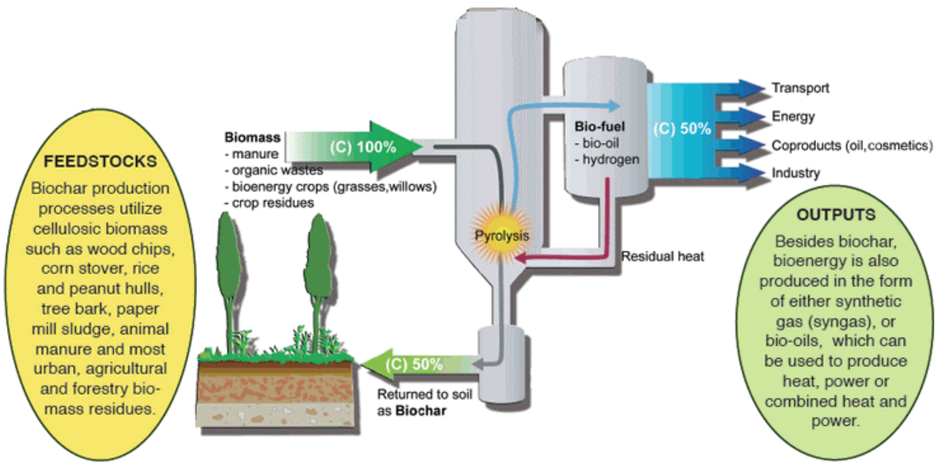

Figure 9 - Biochar Technology – Vacuum Pyrolysis.[71]

Biochar process generally includes the collection, transport and processing of biomass feedstock, the production and testing of Biochar, the production and utilization of energy co-products: gas, oil or heat, Biochar transport and handling for soil application, and monitoring of Biochar applications for carbon accounting or other purposes.[72] According to CEO, Michael Garjian, Vee-Go utilizes a much simpler process known as the "Rivera Process" developed by the late John Rivera. "Vee-go™ BiocharXtra™ is produced by a proprietary pyrolysis reaction within a vacuum at temperatures in the lower range typical of industrial pyrolysis reactions".[73] According to him, the proprietary catalyst will improve the Rivera process by the quality of the by-products. According to the International Biochar Initiative, small-scale pyrolysis systems use

[70] *What Is Biochar?* International Biochar Initiative, 2012. Web. 13 Feb. 2012. <http://www.biochar-international.org/biochar>.
[71] *Ibid*, Biochar Technology
[72] *What Is Biochar?* International Biochar Initiative, 2012. Web. 13 Feb. 2012. <http://www.biochar-international.org/biochar>.
[73] Garjian, Michael. "Heating Pellets for Multi Fuel or Corn Stoves."*Heating Pellets for Multi Fuel or Corn Stoves*.Vee-Go Energy.Web. 18 Mar. 2012. <http://vee-goheatingpellets.com/>.

biomass inputs of 50kg/hr. to 1,000kg/hr. Also, the average Biochar oven can produce 8 to 12 kg of Biochar in 1 to 4 hours.

Although Vee-Go claims to not use industrial or municipal waste, the vacuum pyrolysis process can be extended to feedstock including municipal wastes, Wastewater Treatment Plant Solids, and Grease. This describes phase one of the process: feedstock to fuel using a catalytic vacuum pyrolysis technology. Vee-Go's reactor output claims include: 55% Liquid Bio crude, 20% Solid Biochar, and 25% Gaseous.[74] Phase two describes the fuel to food stage. Vee-Go uses liquid biofuels and bio – gas products to power indoors city farms, enabling growth of organic, nutrients dense crops with the help of Biochar. From research and conversation with CEO (Michael Garjian), his company that produces liquid fuels and Biochar by-product just went private and plans to go public again with a renewed plan of producing more liquid fuels and Biochar. Because of this, no output results are available and the likely impact Vee-Go could have on the transportation sector or even U.S. dependence on oil remains unknown.

[74]Garjian, Michael. "E2M Ag-Energy Initiative of Western Massachusetts."1-4. Web. Feb.-Mar. 2012. <http://www.mass.gov/eea/docs/eea/biofuels/hearing2-e2m-agenergy-testimony.pdf>.

4.0 KiOR Inc.

4.1 Background

The focus of this paper, KiOR, a "next-generation renewable fuels company," was founded in 2007 by a conjuncture between Khosla Ventures and BIOeCON.[75]Khosla Ventures is a venture capital firm primarily focusing on funding businesses aspiring to find next-generation renewable energy sources[76]. BIOeCON on the other hand, focuses on developing technology to use biomass as a fuel source[77]. Sharing this common interest in energy, the two companies founded KiOR which would convert biomass into renewable crude oil. KiOR's main purpose is to significantly decrease the amount the United States needs to import to satisfy the demand in the transportation sector[78]. In doing so, the company claims not only to reduce the U.S. dependence on foreign oil for transportation gasoline, in addition, it would create thousands of jobs, having a double positive impact on our economy. But the company would not only have a positive effect on the United States, the whole world would benefit from the KiOR process. Besides the fact their process does not rely on depleting the world of its fossil fuels reserves, they claim to reduce direct lifecycle greenhouse gas emissions by over 80% with the product of their biomass fluid catalytic cracking compared to the petroleum-based fuels they aim to replace[79].

Initially, the company started with a pilot unit on the outskirts of Houston, Texas where research and experiments to further develop their technology took place. They have now moved on to a larger demonstration plant that is designed to process 10 Bone Dry Tons(BDT)per day—

[75]"About Us." *KiOR, Inc.* -. Web. 29 Oct. 2011. <http://www.kior.com/content/?s=2>.
[76]"Khosla Ventures - Venture Assistance, Strategic Advice, Venture Capital - Our People & Us." *Khosla Ventures*.Web. 12 Nov. 2011. <http://www.khoslaventures.com/our-firm.html>.
[77]"Welcome to BIOeCON." *Welcome to the Frontpage*. Web. 12 Nov. 2011. <http://www.bioecon.com/home.html>.
[78]"About Us." *KiOR, Inc.* -. Web. 29 Oct. 2011. <http://www.kior.com/content/?s=2>.
[79]"Sv1za." *U.S. Securities and Exchange Commission (Home Page)*.Web. 2 Nov. 2011. <http://www.sec.gov/Archives/edgar/data/1418862/000095012311060639/h80686a6sv1za.htm>.

representing a 400-times scale-up from the original pilot unit. The first commercial production facility, is set in Columbus, Mississippi, where construction began in the first quarter of 2011. To fund the construction of this facility, the company obtained $55 million of proceeds from the sale of their Series C convertible preferred stock in April 2011. However, at an estimated cost of $190 million this did not give them half of what they needed, hence they also sought an interest-free loan from the Mississippi Development Authority for $75 million. Existing company funds provided the rest of the funding. This new facility is designed to process 500 BDT per day, representing a 50-time scale up from the demonstration unit. KiOR's ambitions extend beyond building only one commercial unit, as they plan to expand to five more plants by obtaining a $1 billion loan guarantee from the U.S. Department of Energy[80].

4.2 Comparison to other Companies

The Biomass companies we researched are: KiOR, Primus GE, Changing World Technologies (CWT), and Vee-Go (Vegetable Green Energy). In comparing these companies, we have discovered one main issue that ties all these companies together with KiOR—the insignificant impact they could have on the transportation sector and more broadly the U.S. dependency on oil imports. According to our calculations in Appendix A, KiOR could potentially produce 83,750 barrels of oil per day in an estimated 40 plants based on surplus Southern Yellow Pine which is about 0.71% of U.S. Petroleum consumption per day. Primus GE plans to produce 3.2 million gallons of gasoline (~ 76,190.5 barrels of gasoline per year). This result is nowhere near KiOR's estimate and is much less than 1 % of U.S. Petroleum

[80]"Sv1za." *U.S. Securities and Exchange Commission (Home Page)*.Web. 2 Nov. 2011. <http://www.sec.gov/Archives/edgar/data/1418862/000095012311060639/h80686a6sv1za.htm>.

consumption per day. Vee-Go went private and did not disclose any information about their output results and Changing World Technology will offer the most advantage with 3% of U.S. petroleum consumption cited in the Changing World Technology section of the paper, based on the animal waste yield reported by the Environmental Agency, yet, it is also quite insignificant.[81]

With the exception of Vee-Go, the other three companies produce heavy and light liquid bio-fuels, biogas, and by-products (ash, fertilizer, etc.) through a catalytic vacuum pyrolysis process. A "proprietary" catalyst is essential to the process because it determines the quantity and quality of the products, as well as the required time for fast pyrolysis. Therefore, none of these companies are willing to disclose information about their catalyst.

The inconsistencies of some of the companies are indicative of their limited survivability, due to availability of biomass feedstock, energy efficiency of their process, and small-scale output results. For example, contrary to Changing World Technology's claim of high yield figures, previous research shows that production from waste would only produce about 3% of U.S. consumption of petroleum (about 160.7 million barrels).[82] Also Vee-Go's inconsistency in going private and public and even the failed works of John Rivera and his "Rivera Process" strongly suggests that biomass/liquid fuels method of producing liquid fuels, although a renewable alternative to the crude oil production and oil importation, has no foundational structure to support a commercially profitable enterprise.

Some slight differences are that Primus GE reports that their liquid fuel output can be fed directly into current automobiles in the market, whereas KiOR claims that their output needs to be refined before it can be used for automobiles. One main thing to keep in mind is that

---

[81] Feasibility Study of Thermal Depolymerization Process, WPI
[82] *Ibid.*

Changing World Technologies is not focused on replacing imported oil. Instead, their aim is to dispose of waste in a more efficient method.

Table 7 summarizes the output claims of the four companies described: Vee-Go, Changing World Technologies (CWT), Primus GE, and KiOR.

	KiOR Inc.	**Primus GE**	**CWT**	**Vee-Go**
Barrels of Oil / day	95,714	208.7	N/A	N/A
Percentage of U.S. Petroleum Consumption / day	0.71%	0.0015%	3%	N/A

Table 7 - Comparison of Biomass Companies

* Percentage is calculated based on 2010 U.S. Petroleum consumption per day in the Transportation sector (13.5 million barrels per day.)[83] As explained above, Vee-Go did not report any output results of their liquid fuel based on company going private. Changing World's Technology's estimate was quoted from a previous research project done by former Worcester Polytechnic Institute (WPI) students.[81]

4.3 Research Process

The idea for obtaining cost estimates for this project started simple. Obtain data about KiOR's process, obtain a yield report. Repeat the same for its competitors and calculate the company's viability. However, this process turned out to be anything but simple.

Sources on KiOR's process broke it down into steps expected of any pyrolysis process. First, the wood must be cut down and prepared physically. This would involve cutting the wood

[83] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *Total Energy*. U.S. Department of Energy, 19 Oct. 2011. Web. 23 Apr. 2012. <http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0513c>.

down and disposing of its undesirable natural form. Second, of the wood must be transported. Next, the costs of any other processing before the wood is processed in the reactor, such as drying and powdering the wood, must be considered. Lastly, we have the cost of sustaining the reaction atmosphere and temperature. We sought information about typical vehicles that move wood about these sites and came up with an estimate for how much energy would be required to transport the wood long and short ranges, and within an operation site to satisfy the magnitude of KiOR's necessary input. We also estimated the necessary input the cutting arms of one of these vehicles would require.

The drying of the wood: this could probably be somewhat avoided if sun drying were implemented but in some times of the year this would be prohibitively long without the proper facilities due to cold climates and precipitation. In southern states this would be less of a problem as the sun has much more of a presence.

From here we started looking into wood chippers. We looked for companies that make industrial wood chippers that match the criteria of being able to shred and powder the wood. We contacted two companies over the phone about relevant information pertaining to input and output of the chippers. Both times we were turned down due to the information being proprietary.

We then sought out information on the processes themselves. We looked for patents of Changing World Technology, KiOR, Vertroleum and Primus Green Energy. This yielded very little useful information. The only company that had patents available for browsing was KiOR. However, KiOR's patents were written in a very arcane manner as to likely prevent anyone from replicating their process. The ranges for possible operating temperatures in some of these patents spanned hundreds of degrees Centigrade, and conversely the range in pressure was also inconclusive. This implied the information was proprietary, or is being controlled closely.

The next step was to contact the companies directly. After several emails were sent and ignored, we called some of the companies directly to ask about the information. We were not able to find contact information for some of the companies and were turned down by others.

Without information on the processes themselves a proper estimation from that point of view of the process could not be obtained. From here we changed the scope of the analysis and based it on macroscopic values of the process previously obtained. Using values for density and volume of the wood and percent yield we obtained an estimate the potential output of KiOR's process in the magnitude of their operation.

4.4 Results:

As mentioned in the Research Process section of this report, we were unable to obtain specific data from KiOR about their process and products. Thus, we resorted to using data from a few years ago as the most relevant data. Furthermore, in this section, educated assumptions and approximations were made to obtain these results.

Properties of Wood-Derived Bio-Oil and Related Values

	Measure	**Unit**
Density	1.2	kg/L
(Potential) Oil Content of Wood	62	wt%
Water Content of Oil	25	wt%
Yellow Pine Density	0.42	1000kg/m^3
Energy Density	19.5	MJ/L

Table 8 - Properties of Wood-derived Bio-oil

The values listed above in Table 8 are estimations based on data from multiple sources.[84,85,86]

In this analysis we will consider the process on a macroscopic scale. Instead of using energy input and output, we will use data from Dinesh Mohan's *Pyrolysis of Wood/Biomass for Bio-oil* to estimate the viability of the process.[87] We will try to verify the numbers they claim for their output in gallons per year—3.8×10^9 (3.8 billion) gallons per year.

KiOR claims to have a surplus of 159,000 bone dry tons of Southern Yellow Pine as their initial material for one day.

$$159{,}000\,\frac{Ton}{day} * 2000\,\frac{lb}{Ton} * 365\,\frac{day}{year} = 1.16E11\,\frac{lb}{year}$$

Convert this mass into SI to make calculations for convenience.

$$1.16E11\,\frac{lb}{year} * \frac{kg}{2.2lb} = 5.28E10\,\frac{kg}{year}$$

Evaluating the oil content of the wood based on the previously assumed value of 62% per kilogram.

$$5.28E10\,\frac{kg}{year}\ Southern\,Yellow\,Pine * \frac{0.62\ Oil}{Southern\,Yellow\,Pine} = 3.27E10\,\frac{kg}{year}\,Oil$$

[84] Dinesh Mohan, Charles U. Pittman,, and Philip H. Steele. "Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review." *Energy & Fuels* 20.3 (2006): 848-89. Print.
[85]"Wood Densities."*Engineering ToolBox*.Web. 15 Jan. 2012. <http://www.engineeringtoolbox.com/wood-density-d_40.html>.
[86]Illston, J. M., and P. L. J. Domone.*Construction Materials: Their Nature and Behavior*. London: Spon, 1996. 410-23. Print.
[87]Dinesh Mohan, Charles U. Pittman, Jr., and Philip H. Steele. "Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review." *Energy and Fuels* (2006): 848-89. Web. 27 Nov. 2011.

However some water is still present after the drying process. This water is accurately called “chemically bound” as it cannot be removed by physical means. This water must be chemically removed from within the structure of the cellulose and lignin molecules. Accounting for the water content in the oil:[88]

$$(1.00_{oil} - 0.25_{water}) \times 3.27E10\frac{kg}{year} = 2.45E10\frac{kg}{year}$$

Since the listed output is reported in volume, we will convert our results accordingly.

$$2.45E10\frac{kg}{year} \times \frac{L}{1.2kg} = 2.04E10\frac{L}{year}$$

Lastly, convert to gallons.

$$2.04E10\frac{L}{year} \times \frac{gal}{3.7854L} = 5.4E9\frac{gal}{year}$$

Finally we make a percent comparison to the claims of KiOR.

$$\frac{3.8E9}{5.4E9} \times 100\% = 70.37\%$$

This indicates that the numbers KiOR claims are nearly 30% lower than the numbers obtained from these calculations. This discrepancy could be due to the crude nature of the estimation or it could be due to the differences in processes. While 30% is normally a large discrepancy it is, in this case, not undesirably large. This is supports KiOR’s claims about how much biomass fuel they can produce.

[88]Dinesh Mohan, Charles U. Pittman, Jr., and Philip H. Steele. "Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review." *Energy and Fuels* (2006): Page 9. Web. 27 Nov. 2011.

Conclusions

This project set out to investigate the legitimacy of the company KiOR Inc. and the potential impact that it could have on replacing petroleum in the United States. Due to the proprietary nature of the technology of KiOR's process, specific details on the efficiency and production rates of the process were unavailable. Using broad information and claims, available on KiOR's website, this project analyzes KiOR on a macroscopic level.

It was found that KiOR's numbers of how much they can produce are realistic and agree with calculations from a compared process. Although their numbers are correct they are also very small. It was calculated that the percent of the U.S.'s transportation petroleum need that KiOR could produce with 40 of their proposed 1500 BDT plants is approximately 0.71%. Also, in order to provide the nation with 25% and 50% of its needs, KiOR would need to build 1,411 and 2,821 production plants, respectively. Although there is more than enough potential biomass material available to produce the required amount, the number of plants necessary is impracticable.

Therefore, this report concludes that KiOR, although making innovative steps to answer U.S.'s problem with oil, couldn't make a substantial impact on the oil economy, either nationally or internationally.

Recommendations

As a result of conclusions made through this project, there are things that we would recommend for KiOR. To begin with, because of a low amount of oil produced, compared to national petroleum usage, KiOR should not focus on replacing petroleum and reducing America's reliance on foreign oil. Instead, they should narrow their focus to being an influential fuel source on a more regional scale. This technology has potential on a smaller scale.

KiOR production plants could be most practical in rural communities where they could be fueled by agricultural and municipal waste. These wastes could then be turned into fuel and fertilizers that would be sold to the surrounding community. This could produce a symbiotic relationship between KiOR and the communities. This would also reduce the cost of transporting fuel that KiOR would have to incur if its fuel sources and customers were not local. However, this would require an addition of a refinery process into KiOR's operation.

Appendix A:

Viability Calculations (A Southern Yellow Pine Case Study):

One of the main goals of this project was to evaluate whether or not KiOR's process, if implemented on a large scale, could fulfill one of KiOR's goals, namely lessening on the reliance the United States has on foreign oil. Below are calculations made using statistical information from both KiOR and government agencies. These calculations seek to combine claims and numbers espoused by KiOR with information and statistics supplied by the government to make accurate hypothetical calculations that illustrate KiOR's potential impact:

KiOR claims that the excess southern yellow pine biomass could fuel more than thirty-five of their 1500 BDT production plants. For these calculations, the number of plants will be estimated to be forty. The question to answer from this claim is how many gallons of oil could these forty plants produce at that nominal rate and would that number makes a significant difference to U.S. petroleum consumption?

67 gallon/BDT (Bone Dry Ton)[89]

1500 BDT/plant/day[90]

40 plants[91]

1 barrel = 42 gallon[92]

[89]"Frequently Asked Questions." *U.S. Energy Information Administration (EIA)*. U.S. Department of Energy, 30 Nov. 2010. Web. 23 Apr. 2012.
[90]"KiOR, Inc. - Home." *KiOR, Inc.* KiOR.com, 2012. Web. 23 Apr. 2012. <http://www.KiOR.com>.
[91]*Ibid.*
[92]"Frequently Asked Questions." *U.S. Energy Information Administration (EIA)*. U.S. Department of Energy, 30 Nov. 2010. Web. 23 Apr. 2012.

Using conversions of gallon to BTU and barrel to gallon obtained from government websites, shown above, the number of gallons possible is calculated as follows:

$$67\frac{gal}{BDT} \times 1500BDT \times 40\,plants \times \frac{1}{42}\frac{barrel}{gal} = 95{,}714\frac{barrel}{day}$$

In 2010, the total U.S. petroleum consumption was 19.1 million barrels per day.[93] Focusing more narrowly, 2010 statistics also show that 13.5 million barrels are consumed per day in the transportation sector alone.[94] What percent the total consumption and transportation consumption can KiOR produce?

$$What\%(total) = \frac{95{,}714 \times 100}{19.1E6} = 0.5\%$$

$$What\%(transportation) = \frac{95{,}714 \times 100}{13.5E6} = 0.71\%$$

Both of these numbers are very small. How many 1500 BDT plants would be needed to provide 10% of the Unites States' consumption? We will focus on the transportation sector only. By math, the number of gallons one 1500 BDT plant can produce is 2,392.857 barrels/day.

$$\#Plants = \frac{(0.10)(13.5E6)}{2392.857} = 565\,plants$$

Five hundred and sixty-five is a very large number. As a comparison, consider that throughout the entire United States there are only 104 operating nuclear reactors.[95] To build such

[93]"How Dependent Are We on Foreign Oil?" *EIA's Energy in Brief:*. U.S. Department of Energy. Web. 23 Apr. 2012. <http://www.eia.gov/cfapps/energy_in_brief/foreign_oil_dependence.cfm?featureclicked=3>.

[94]"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *Total Energy*. U.S. Department of Energy, 19 Oct. 2011. Web. 23 Apr. 2012. <http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0513c>.

[95]"NEI: Nuclear Energy Institute." *Nuclear Energy Institute*. 2012. Web. 23 Apr. 2012. <http://www.nei.org/keyissues/newnuclearplants/nuclear-supply-chain/>.

a large number of plants is impracticable. The amount of fuel required to operate this large number of plants is another important consideration. Five hundred and sixty-five plants would require:

$$\left(1500\frac{BDT}{day}\right)(565\ plants) = 847500\frac{BDT}{day} = 309{,}337{,}500\ \frac{BDT}{year}\ of\ Southern\ Yellow\ Pine$$

According to KiOR's website, the total excess Southern Yellow pine, only 52,500 BDT/year could be extracted. Thus, to produce 10% of the nation's petroleum needs, KiOR's process must be expanded to using other raw materials. According to a study done by the U.S. Departments of Energy and Agriculture, the United States has 1.3 billion dry tons per year of forestry and agriculture biomass potential. Three hundred and sixty-eight million dry tons of sustainably removable biomass could be produced on forestlands, and about 998 million dry tons could come from agricultural lands.[96]Therefore, there is potential for KiOR and other similar companies to take advantage of this biomass. The question is: can it be done in a realistic and profitable manner?

For example, from our previous calculation of the number of 1500 BDT plants it would take to produce ten percent of the United States' petroleum consumption, we can extrapolate and calculate how many plants would be necessary for any percentage.

$$\#Plants\ (25\%) = \frac{(0.25)(13.5E6)}{2392.857} = 1411\ plants$$

$$\#Plants\ (50\%) = \frac{(0.5)(13.5E6)}{2392.857} = 2821 plants$$

[96]"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *U.S. Energy Information Administration (EIA)*. U.S. Department of Energy, 2005. Web. 23 Apr. 2012. <http://www.eia.gov/>.

These numbers show that building enough 1500 DBT plants to replace even 25% of the United States' petroleum needs is impractical.