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Advanced bio-fuels from pyrolysis oil: The impact of economies of scale and use of existing logistic and processing capabilities

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ABSTRACT

The process for producing advanced bio-fuels from woody biomass using fast pyrolysis technology is in an early stage of development. Whether it will offer favorable economics versus future petroleum-derived fuels or other advanced bio-fuels is not clear at this time; however, a study of the value chain from growth to final distribution of drop-in bio-fuels has highlighted several factors that will have major impact on ultimate economics. These factors include:

- the impact of economies of scale
- advantages from using existing logistic capabilities, especially for first commercial production
- existing refinery processing capabilities
- the ability to finance timely process development and commercial scale-up with its associated risks.

Most of the required facilities should be able to operate at scale comparable to that used in the current petroleum-based fuels industry, with substantial cost savings. Use of current refinery facilities and distribution networks for part of the process can add substantial additional savings. Using existing inland marine transportation capabilities will aid in achieving economic scale sooner as well as in reducing costs. Developing the technology to the point where a major scale-up is practical, including a relatively small demonstration of the commercial process is likely to be expensive. Value chains that are able to capture most of the potential economies of scale and compete with petroleum-derived fuels are likely to call for a billion dollars or more in initial investment.

1. Introduction

In a recently completed study for the National Renewable Energy Laboratory, the Global Energy Management Institute of the University of Houston (UH-GEMI) took an end-to-end look at specific alternative value chains for producing advanced bio-fuels using fast pyrolysis technology and drew conclusions about what would be a preferred approach.[1] This paper, which addresses economic aspects, is the first of two based on the study. The second paper will address research opportunities. Criteria for selection of the preferred approach were favorable gasoline and diesel fuel costs relative to crude oil-derived fuels, meaningful quantities and minimum time to commercialization. The study considered the economics of both the First Movers, who would pioneer the commercialization of the process, and the Mature Industry that would evolve later.

The study was based on the following starting assumptions:

- Woody biomass is the raw material.
- Biomass is converted to a liquid, “Raw Pyoil,” using a fast pyrolysis process.
- Oxygen is removed from the Raw Pyoil by means of catalytic hydrotreating.
- The final product is a direct replacement for gasoline and diesel fuel.

The parameters and economics for the pyrolysis and hydrotreating steps were derived from a recent design study made by the Pacific Northwest National Laboratory[2] for a standalone plant that would produce 73 million gal per year of deoxygenated pyrolysis oil, from 2000 metric tons per day of wood chips.

The UH-GEMI study relied on published data and non-proprietary information from a variety of companies currently active in the production and distribution of transportation fuels and woody biomass, with one exception. There was no available information on the composition of pyrolysis oil as a function of oxygen content. Such

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[1] Arbogast et al., “Preferred Paths for Commercializing Pyrolysis Oil at Conventional Refineries”, UH-GEMI, December 2010.

[2] Jones, S.,Valkenburg, C., Walton, C., Elliott, D., Holladay, J., Stevens, D., “Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking”, PNNL, Feb 2009.

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information is critical to understanding the value of the ultimate product and determining the processing steps needed. To obtain this information, pyrolysis oil was produced in laboratory scale equipment and hydrotreated to reduce the oxygen level.

Samples were taken at 8%, 5% and 0.4% oxygen content, split into typical refinery fractions, and within each fraction the composition was characterized using typical refining categories. Initial results suggested that there may be viable refining strategies using 5% Pyoil as a feedstock, but these results are very preliminary and need confirmation from further testing. Our test results and their future implications will be discussed in more detail in the forthcoming paper on research possibilities.

The most attractive geographical region for this process appears to be the South Central U. S. It has the greatest density of forest resources and the lowest costs. The region also contains most of the U. S. refining industry and has access to the country's existing fuel product distribution infrastructure. Specifically, the study focused on the states of Alabama, Arkansas, Louisiana, and Mississippi plus forested areas in eastern Texas, eastern Oklahoma, western Florida and western Tennessee. In addition to access to outbound product logistics, the region's refining clusters offer access to supplies of hydrogen, disposition of process byproducts, an appropriately skilled local workforce, and the possibility of savings from further integration with existing refining operations.

2. Evaluation of alternative value chains

The primary economic drivers in the analysis were:

- Likely cost and availability of raw materials
- Logistic costs through the value chain
- Economies and diseconomies of production scale
- Process integration credits

In comparing various potential value chains we considered the following main characteristics:

- Source of feedstock to be used; i.e., forest residues and trimmings, existing whole trees, purpose grown energy crops or a mixture thereof.
- Configuration of the facilities to produce and upgrade the pyrolysis oil. In all cases there was a pyrolysis unit, a hydroprocessing unit, and facilities to handle raw materials and waste streams. Other possible functions could be performed as part of the dedicated Pyoil plants or obtained from third parties. For example, the standalone design in the PNNL study included a small hydrocracker to upgrade the heaviest components of the upgraded Pyoil. The plant also produced its own hydrogen, which in turn could be made from byproduct streams or from natural gas.
- Scale of production of each component in the value chain.
- Location of each component in the value chain and the degree of integration among components. Pyrolysis and hydrotreating units could be integrated with each other, or not, and either or both could be located near raw material sources, perhaps at the site of existing pulp mills; near advantageous logistics points; near petroleum refineries; or someplace else.
- Oxygen content of the upgraded Pyoil. Most of the cost of converting biomass into a crude oil substitute in dedicated Pyoil plants is associated with removing oxygen. Costs can be reduced if some of the oxygen can be eliminated elsewhere in the value chain, especially in existing facilities, and/or tolerated in the finished product.

The likely most favorable choices for the above characteristics are different in some cases for First Movers and a later Mature Industry.

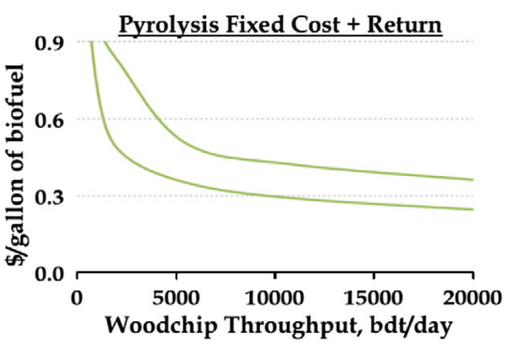

Fig. 1. Pyrolysis fixed cost + return. Woodchip throughput, bdt/day.

3. Feedstock source

Forest residues and trimmings appear to be the best raw material choice for First Movers due to the likely lower cost of these waste materials, as well as less chance of political barriers. This lower cost will be offset, to some degree, by likely lower yields in the process. Variations in quality of residue raw materials could also result in process difficulties, but this is yet to be determined. Small plants in select locations might find whole trees more convenient if potentially more expensive. Purpose grown energy crops are likely to be the preferred primary raw material for the Mature Industry due to greater availability, more concentrated production, and greater control over the whole process.

4. Configuration

There are many possible variations in pyrolysis and hydroprocessing design whose attractiveness will be determined by further research and development work. Some likely choices at this point that we included in our economic models were:

- For both First Movers and the Mature Industry it will be more economical to convert the heaviest upgraded Pyoil components in existing refinery equipment or blend it into fuel oil.
- With current technology it will be more attractive to produce hydrogen from natural gas than to make it from process byproducts.
- It will usually be more attractive to purchase hydrogen from existing suppliers and take advantage of existing distribution capabilities rather than making it, although investment in new hydrogen capacity by someone is likely to be required at some point.

5. Scale

Most of the equipment used in the pyrolysis and hydrotreating processes is similar to equipment long used successfully at large scale and low unit cost in the refining and chemical industries. As a result, substantial economies of scale are possible. Unit processing capacities at least up to the level of current fuel production facilities; i.e., tens of thousands of barrels per day, will be economically attractive for both First Movers and the Mature Industry. This economic advantage is offset to some degree, however, by greater technical and financial risk. These risks, and associated difficulty in obtaining financing, will be greater for First Movers. The cost impact of economies of scale is illustrated in Figs. 1 and 2 below.[3]

The greatest uncertainties with respect to economies of scale are the scalability of the pyrolysis reactors and whether the hydrotreating catalyst will need to be frequently or continuously regenerated. 200 bone dry metric tons/day (bdmt/d) was the largest demonstrated pyrolysis reactor capacity at the time the study was prepared. Designs with much larger capacity are claimed to be feasible.[4] The PNNL design study on which the GEMI study was based assumed reactor capacity of 2000 barrels per dry metric ton/day (bdmt/day) is attainable. The

[3] Data shown in Figs. 1 and 2 are based on the yield and cost structure of our First Mover models, which are described in more detail later.

[4] See www.envergenttech.com/rtp.php.

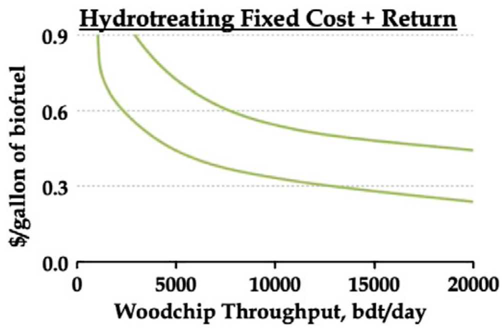

Fig. 2. Hydrotreating fixed cost + return. Woodchip throughput, bdt/day.

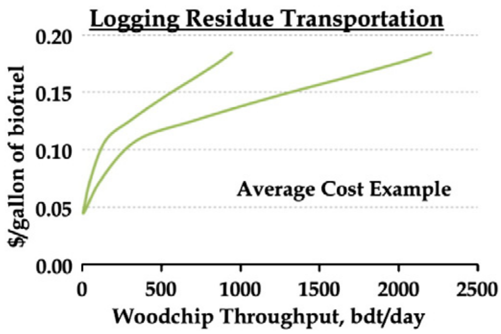

Fig. 3. Logging residue transportation. Woodchip throughput, bdt/day.

pyrolysis reactors and equipment that is limited in scale by the pyrolysis reactors account for 36% of the pyrolysis unit investment.

The range of costs shown is indicative of the current uncertainties associated with the technology but all cases indicate substantial economic incentives for large scale operations: ~0.23 $/gal of finished fuel for increasing pyrolysis reactor scale from 200 bdmt/day to 5000 bdmt/day, ~0.23/gal for increasing the rest of the pyrolysis plant from 2000 bdmt/day to 20,000 bdmt/day, ~0.24/gal for increasing the scale of the hydroprocessing plant by the same amount.

Pyrolysis unit savings will be offset to some degree by the higher cost of moving larger quantities of wood chips to the processing location. Figs. 3 and 4 show examples.[5] These cost relationships vary substantially among locations.

Similarly, if the pyrolysis unit and hydroprocessor are not in the same location, the savings from a larger scale hydroprocessor will be offset to some degree by additional transportation and handling costs.

6. Location

Upgraded Pyoil, even with all oxygen removed, is a crude oil substitute not a standalone fuel that would work well in existing vehicles. At a minimum, to meet current fuel specifications, it will be necessary to split it into its components and blend the components with crude oil-derived fuels.

This might be done by blending with crude oil derived products at fuel terminals, similar to what is done with ethanol today. It is more likely that at least some portion will need further refinery processing.

The main location choice is whether the pyrolysis and/or hydrotreating units are located close to raw material sources or close to existing refining and fuel distribution facilities. The former could provide lower raw material cost but limit potential scale. Centralized locations would allow much larger units but could involve higher logistic costs. Additional possibilities considered were repurposing existing pulp mill sites to produce pyrolysis oil and using existing refinery facilities for a portion of the Pyoil upgrading process.

Shipping raw Pyoil to a central hydroprocessor rather than fully upgraded Pyoil to a central refining location involves moving a greater quantity in more expensive corrosion resistant equipment. The additional cost, however, would be less than 5¢/gal of finished fuel, much less than potential economies of scale at a central location. As a result we did not assess the economics of small hydroprocessors located near raw material sources for commercial scale plants.

[5] The two curves shown on each chart reflect assumptions that 30% or 70% of the potential raw material availability can be accessed and purchased. Biomass resource data came primarily from the U.S. Forest Service's "Forest Inventory Analysis Timber Product Output Database", and "Forest Inventory Analysis Mapmaker 4.0".

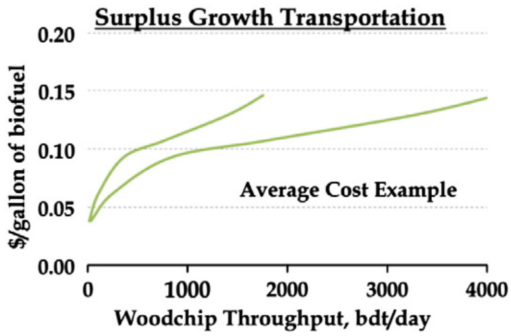

Fig. 4. Surplus growth transportation. Woodchip throughput, bdt/day.

7. Pyoil oxygen content

The cost of removing oxygen increases as the residual oxygen level decreases. Fig. 5 shows how upgrading cost varies depending on the final oxygen level of the Pyoil.

Significant savings in Pyoil hydroprocessing costs are possible if some portion of the oxygen is removed in existing refining equipment. These savings would be offset, to some degree, by additional costs required to process the partially upgraded Pyoil. Potential problems with corrosion and fouling may make such processing impractical. On the other hand, Pyoil with less than 10% oxygen content appears to be miscible with petroleum and initial tests suggest negligible total acid numbers for the heavy fractions (360 F+) of Pyoil upgraded to ~5% oxygen content.

8. "First Mover" value chains

By "First Mover" we refer to the first economically competitive commercial value chains. We assessed several different arrangements, varying the characteristics mentioned above and specific locations in the region.

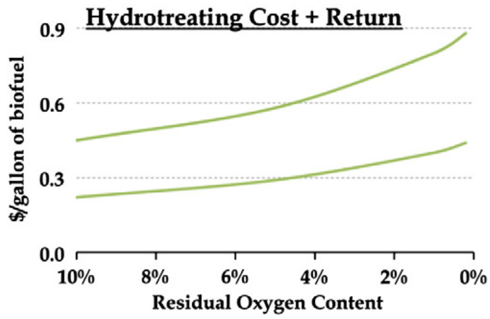

Fig. 5. Hydrotreating cost + return. Residual oxygen content.

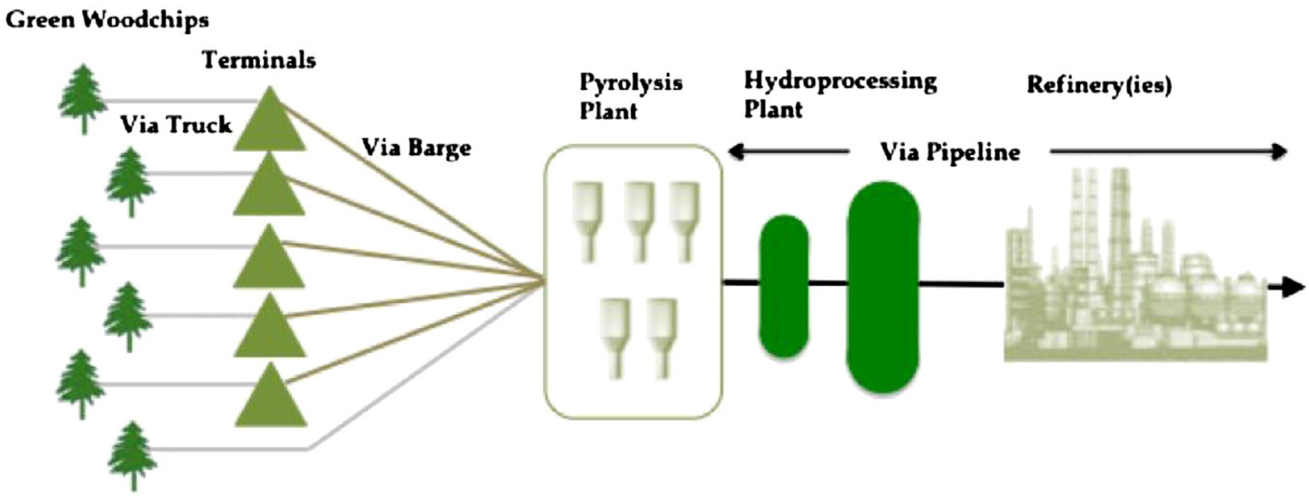

Fig. 6. First generation at-scale manufacturing.

Economic estimates assumed that several technology milestones were reached, and that the commercial process was successfully demonstrated in a small plant, with a capacity of about 7–10 million gal per year,[6] prior to design of the full scale First Mover plant. The demonstration plant can be expected to cost $100–200 million in initial investment.

Scale economies were the dominant economic factor. The most attractive value chain features a single, integrated pyrolysis and hydroprocessing unit, located near Baton Rouge, Louisiana, in the Lower Mississippi refining and petrochemical cluster, with the capacity to produce about 275 million gal per year of finished gasoline and diesel fuel. Fig. 6 illustrates the configuration of this value chain.

Feedstock is wood chips from logging residues and forest trimmings collected from the region shown in Fig. 7 and shipped to Baton Rouge primarily by water using conventional covered hopper barges. Truck shipments to transshipment points were limited to two hours elapsed time.[7] Fig. 8 shows an estimate of the maximum quantity of logging residues and trimmings potentially available at twenty-four transshipment points studied throughout the region. Our base case model assumed that no more than 50% of this maximum quantity would be available.

The relatively low cost of shipping large quantities of wood chips using existing marine transportation equipment allows the capture of processing economies of scale with a large scale centralized facility. The cost difference of shipping wood chips to the central integrated facility compared to shipping raw Pyoil to a central hydroprocessing facility was equivalent to 5 to 10¢/gal of finished fuel, depending mostly on the need for purpose-built equipment and handling facilities.[8] This is more than offset by the economies of scale and integration associated with one central facility. In addition, it avoids the operating risks associated with shipping a highly acidic and unstable liquid such as raw Pyoil and the commercial risks associated with relying on a more geographically limited local supply.

Hydrogen for hydroprocessing is purchased from third parties. This should be less expensive than a new, dedicated grass roots hydrogen plant, even though some new investment in hydrogen production is likely to be required due to the quantity used in the process. A small portion of the fully upgraded Pyoil will be too heavy to meet diesel specifications and, for cost and investment reasons, is processed in an existing refinery or sold for blending into fuel oil.

The scale of operation selection represents a tradeoff between lower potential costs and technical and commercial risks associated with a large scale up. A 10,000 bdmt/day capacity captures most of the scale economies. The model assumes demonstration of individual pyrolysis reactors capable of processing 2000 bdmt/day each and demonstration of a practical hydroprocessing catalyst with long enough life (a year) to use in a fixed bed hydroprocessor.

Risks associated with a slower First Mover scale up include investment in facilities with limited or no unsubsidized economic life and delay in replacement of petroleum-derived fuels, which can reduce the value of the technology substantially.

A location near an existing refinery cluster was selected due to potential benefits of integration, access to existing hydrogen supplies, a potential local market for the upgraded Pyoil and local availability of appropriate supporting services and human resources.

Such a location also offers economical access to existing fuel distribution systems. Repurposing an existing but no longer economically viable pulp plant was investigated. There are a limited number of interesting locations for this option, but we found little synergy between the existing facilities and what would be required for Pyoil production. Availability of low cost logging residues in the area also would be reduced if the pulp mill ceased operations. Also investigated were locations that were closer to raw material sources that had favorable access to existing water or pipeline transportation for moving the upgraded Pyoil. We did not find a First Mover economic advantage in such locations.

The Lower Mississippi refining cluster appears to be the best choice because of its relative proximity to abundant forest resources, access to the lowest cost marine and pipeline transportation infrastructure, and large refining capacity. A location near Baton Rouge, on the west side of the river, was selected as the best specific location because it is the farthest north and, therefore, closest to the raw material supply. Locations farther south would be more expensive, by 3–7¢/gal of finished fuel.

The First Mover is expected to produce a fully upgraded Pyoil which would be split into its main components and further processed by a refinery in the cluster, possibly one with an ownership interest in the First Mover facility. Based on initial limited test results, the composition and chemical components of fully upgraded Pyoil appear to be similar to those of a light, sweet conventional crude oil, as illustrated in Table 1, which compares fully upgraded Pyoil, with 0.4% oxygen, and West Texas Intermediate.

This suggests that co-processing in existing refineries would be practical; however, the feasibility and economics of co-processing still

[6] Considering only performance that had been demonstrated at the time of the study and with favorable assumptions about corrosivity of upgraded pyrolysis oil and successful development of an adequate catalyst system for deoxygenation, the cost range going into the existing fuel distribution system would be 3.75 to 5.25 $/gal.

[7] Biomass collection and truck transportation costs were estimated using the U.S. Forest Service's FoRTSVS and "Fuel Reduction Cost Simulator".

[8] Marine transportation and pipeline costs were based primarily on information from regional pipeline and barge operators and the U.S. Corps of Engineers Directorate of Civil Works' "Shallow Draft Vessels Operating Costs, Fiscal Year 2004".

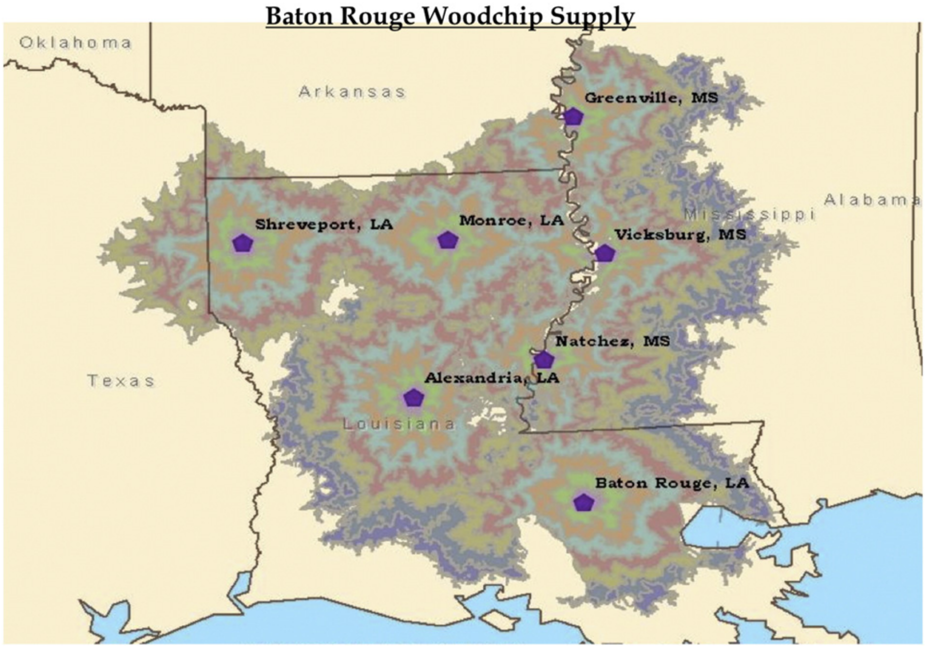

Fig. 7. Baton Rouge woodchip supply.

will depend on several factors that have yet to be demonstrated, including the corrosion characteristics of upgraded Pyoil, the absence of other adverse refining impacts such as fouling, whether the Pyoil components can be economically co-processed with crude oil-derived materials without adverse changes in process conditions, and the cost of any necessary refinery modifications.

As mentioned before, there is a very large potential for savings if a portion of the oxygen is removed in the refinery, but the practical feasibility of doing so requires substantial technical work to determine. This includes addressing questions concerning corrosion, fouling, how existing units would process the oxygen-containing product, if and how vulnerable catalytic refining operations can be protected, and what additional cost would be involved.

The choice of fully upgraded Pyoil for a First Mover reflects the caution we expect refiners to take, under the circumstances, in processing this new “bio crude”. If the feasibility of refining partially upgraded Pyoil were suitably demonstrated prior to designing the First Mover facilities that would likely be the best choice.

Cost estimates for initial commercial scale facilities covered a range of 1.75 to 2.90$/gal of gasoline and diesel fuel going into the existing fuel distribution system in the Gulf Coast, with an initial investment cost of $900 million to $1.2 billion. The range of costs quoted does not include the research and development cost to develop the commercial process. It does include adjustments to yields and costs reflecting typical challenges in building and operating first of its kind plants of this size.[9]

The assumption that a commercial process, similar to that in the PNNL design study used as a starting point in this analysis, has been successfully demonstrated prior to designing the First Mover facilities, is critical to the economic estimates. Considering only performance that had been demonstrated at the time of the study and with favorable assumptions about corrosivity of upgraded pyrolysis oil and successful development

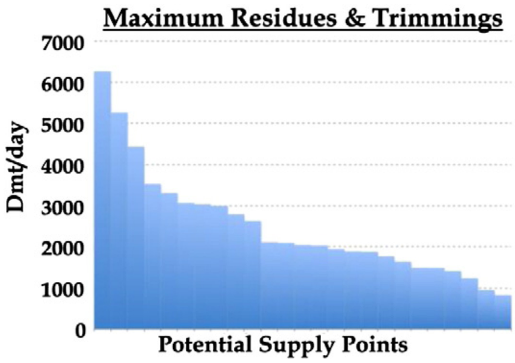

Fig. 8. Maximum residues and trimmings. Potential supply points.

Table 1
Upgraded Pyoil characteristics.

	Upgraded Pyoil	WTI
API	39	40
Sulfur, wt.%	0.01	0.38
CCR, wt.%	0.1	6
TAN	0.02	0.01
Composition, LV%		
C1–C4	0	3
Light naphtha	16	9
Heavy naphtha	33	26
Kerosene	21	15
Diesel	19	13
Heavy gas oil	11	26
Residual	0	9

[9] Estimates of investment and start up performance utilized parameters from the RAND Corporation study, “Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants”, 1981, and Horvath, R.E., “Pioneer Plant Study User Manual”, R-2569/1-DOE, RAND Corporation, June 1983, to reflect the current state of technology development and project definition.

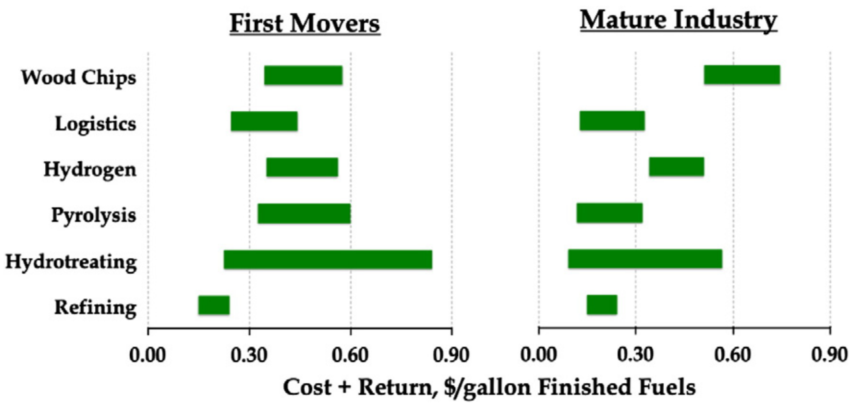

Fig. 9. Estimated cost of pyoil value chain components. Cost + return, $/gal finished fuels.

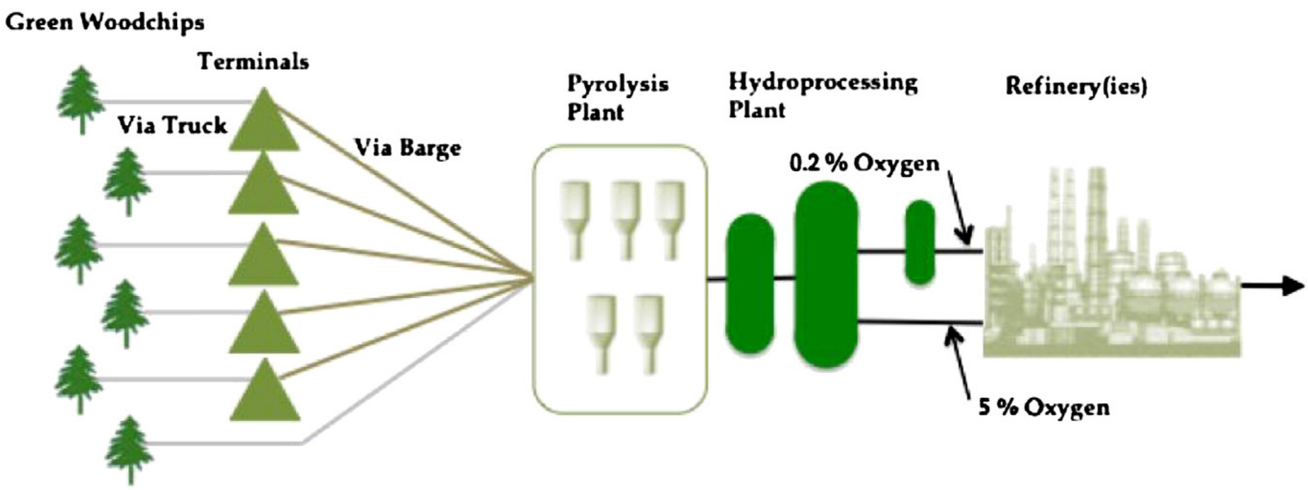

Fig. 10. Partially upgrading pyoil example.

of an adequate catalyst system for deoxygenation, the cost range going into the existing fuel distribution system would be 3.75 to 5.25 $/gal.

The pyrolysis oil process is one of the least developed of the advanced biofuel processes. Several links in the value chain are in early stages of technical or commercial development. Quantitative economic estimates are highly uncertain at this time. Fig. 9 shows estimated cost ranges for the various links in the First Mover value chain, as well as a potential Mature Industry value chain, which will be discussed next.

The large range of cost estimates for each link in the chain highlights the substantial research and development needs associated with the successful commercial development of this technology, identification of a stable hydrotreating catalyst in the upgrading step, improvement of oxygen removal in the pyrolysis step, scale-up of the pyrolysis reactors and definition of the maximum level of pyrolysis oil oxygen allowed into the existing refining infrastructure emerge as critical research areas, which we address in a separate paper.[10]

9. Mature industry changes

If the fast pyrolysis process proves to be successful and competitive with other advanced biofuel processes, it is expected that efficiency and yields will improve and capacities of individual plants will get larger.[11] In addition, it is very likely that the primary source of raw material will change and it is possible that different ways of dealing with Pyoil's oxygen content will evolve; i.e., some degree of refinery deoxygenation and/or residual oxygen in the finished product. These changes would have an impact on value chain economics.

Driven by sustainable raw material availability, the principal supply source for the industry is likely to shift to plantations growing fast rotation energy crops such as hybrid poplar or, in some locations, eucalyptus. Assuming access to 50% of recently generated residues and thinnings, the value chain could produce around 1.1 billion gal of gasoline and diesel fuel per year. The addition of energy crops can multiply that quantity several times. These crops are claimed to be capable of producing six or more dry tons per acre per year for energy uses in well run plantations and three dry tons per year when co-producing the energy crops with saw timber and pulp crops.[12] Research is under way to increase these yields.

Combining these yields with the target yields for converting wood chips to finished fuels (109 gal per dry metric ton of wood chips) results in biofuel production of 327 to 654 gal of biofuel per acre per year. Producing 1 billion gal per year of bio gasoline and diesel fuel

[10] Arbogast et al., "Advanced bio-fuels from pyrolysis oil: Opportunities for cost reduction".

[11] In our study, Mature Industry plants feed 20 k bdmt/day of wood chips and produce 54 kb/day of upgraded Pyoil.

[12] ArborGen LLC, "ArborGen: A Provider of Woody Biomass for Renewable Energy in the Southeast," commercial presentation, April 2010.

Table 2
Partially upgraded pyoil example.

	Fully upgraded	Partial upgraded	Mix
Oxygen, wt.%	0.2	0.4	5
Quantity to refinery			
Barrels/day	54,200	14,400	42,600
Tons/day	7900	1800	7400
Density	0.83	0.72	0.99
Output quantity, barrels/day			
Gasoline	28,600	22,800	
Diesel	24,000	30,500	
New investment, $ million			
Pyoil plant	940–1300	840–1150	
Refinery	??	??+	
Operating cost, $/barrel			
Pyoil plant	21–31	16–23	
Refinery	6.1+	6.5++	

would require 750,000 to 1,500,000 acres of forest land, or 3 to 6% of current managed plantation land or 0.8 to 1.6% of total private forest land in the region.

A shift to purpose-grown energy crops, in addition to forest residues, will result in higher raw material costs. On the other hand, more concentrated energy crop growth would make it possible at some locations to reap both the benefits of large scale pyrolysis operations and the logistic savings associated with proximity to the source. This, in turn, would improve the relative economics of refining clusters in the region, and elsewhere, that do not have access to low cost river transportation. Raw material prices for the mature industry are likely to vary geographically within the region, reflecting local supply and demand balances.

In our First Mover model all oxygen removal is done in the hydroprocessing unit. Oxygen removal should be managed over the entire value chain. If some portion of oxygen can be eliminated in the energy crop design, the pyrolysis unit, or the refinery, or if some amount of oxygen can remain in the finished fuel, substantial savings may be possible.

Since the last increments of residual oxygen are the most expensive to remove, the refining step is particularly interesting. These potential economic incentives come from two main sources:

- Using existing facilities to remove some of the oxygen reduces the needed investment in pyrolysis oil hydrotreating.
- Rather than subjecting all of the pyrolysis oil to the same processing conditions, the more diverse capabilities of modern complex refineries may be capable of producing higher yields of finished gasoline and diesel.

The potential benefits can be substantial. We created a strictly speculative economic case which illustrates the potential. In this case, a portion of the Pyoil stream believed to have very low acidity based on preliminary data, was removed from the hydroprocessor with 5% oxygen remaining and processing was completed in various refining units using a very simple refinery simulation.[13] The balance of the Pyoil was hydrotreated separately to reduce oxygen level and acidity. In this example the incentive for refinery processing was about 20¢/gal, or $130 million per year, which would be offset to some degree by the factors noted above. Fig. 10 illustrates this configuration. Table 2 illustrates the difference in material balance and associated costs.

The practicality of this approach will depend on the same factors noted earlier for refinery processing of Pyoil:

- The corrosion characteristics of the Pyoil,
- The absence of other adverse refining impacts, such as fouling,
- Whether the Pyoil components can be economically co-processed with crude oil-derived materials without adverse changes in process conditions.

With partially upgraded Pyoil these potential problems will be more severe and of much greater concern. The savings will be offset to some degree by any refinery modifications needed to accommodate the Pyoil processing.

10. Conclusion

Our economic study assessed the preferred path for commercializing advanced bio-fuels made using pyrolysis oil, once a practical commercial process has been demonstrated. While it is not clear today that this process will produce finished fuels at favorable cost relative to petroleum-based fuels or other advanced bio-fuels, it is clear that taking early advantage of potential economies of scale and integration with existing refining capabilities and infrastructure will greatly increase the chances of, and may be essential for, economic success of the technology.

Scale of production and the time scale within which large scale, competitive cost production can be attained dominate the economics of the value chain, its ability to contribute to national energy objectives, and the financial risk associated with initial individual investments.

Use of existing low cost inland marine transportation capabilities can significantly improve value chain economics, particularly for First Movers. Access to low cost inland marine transportation and proximity to forest resources suggest that the best initial location for commercial scale production is the Lower Mississippi River refining cluster. Lowest raw material cost is obtained by feeding the process with waste biomass such as logging residues. This is the best raw material source for early commercial production, but places an upper limit on potential fuel production. As the industry matures, the primary raw material source will shift to short rotation, woody energy crop plantations which will support much higher potential fuel production. While on-purpose production of energy crops can be expected to be more expensive than collection of waste material, the more concentrated production reduces logistics costs, and improves the relative economics of other refining clusters along the Gulf Coast.

It is likely that some pyrolysis oil components, upgraded to some degree, will be processed in existing refinery facilities and blended with petroleum-derived components to produce “drop-in” gasoline and diesel fuels. Large savings are possible if more of the Pyoil upgrading can be done in existing refining facilities, but physical and economic feasibility is not known at this point, in part due to a lack of understanding of Pyoil composition at various stages of deoxygenation.

[13] Key assumptions were that the oxygen was removed as water and the remaining hydrocarbon content behaved as would similar hydrocarbons in conventional refining.