

DOE Final Scientific Technical Report

Project Title: Innovative Gasification to Produce Fischer-Tropsch Jet and Diesel Fuel

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Executive Summary

The primary objective of this project and the U.S. DOE's integrated biorefinery ("IBR") program was to demonstrate conversion of biomass and waste-derived feedstocks into military spec liquid fuels. Frontline's proposed integrated process was to incorporate several novel technologies and innovative applications of existing technologies that would serve both to increase plant efficiency and also to lower the cost of the produced biofuels. The project was intended to demonstrate Frontline Bioenergy's technologies for gasification and synthesis gas clean-up configuration to produce a syngas stream suitable for a proven Fischer-Tropsch ("F-T") unit that would produce F-T intermediate products. These F-T intermediate products were to be upgraded to military spec diesel and jet fuel, including F76, JP5, and JP8. Specifically, these technologies consisted of:

1. Frontline's PMFreeGas® ultra low particulate matter (PM) hot gas filtration technology
2. Application of Frontline's TarFreeGas® ultra low-tar gasification technology
3. Frontline's novel approach to syngas conditioning

The proposed gasifier system was to operate at 10 tpd capacity while the F-T plant was capable of approximately one barrel per day. Although the gasifier output would have been roughly ten times the F-T plant's required input, the 10 tpd capacity was chosen to enable scaling to commercial capacity.

Project partners included i) SGC Energia, owner of the F-T technology and owner of the proposed demonstration site in Pasadena, Texas; ii) Stanley Consultants, a reputable engineering company that provided detailed electrical engineering services; and iii) Delphi Engineering & Construction LLC, a consulting company that provided project management advisory services.

The integrated plant was never constructed due to lack of cost share funds. However, the commercialization plan and associated financial model suggested such a plant could be economically viable when the price of oil exceeds \$70 per barrel. The price of feedstock plays a significant role in the profitability of the plant for a given value of oil. An integrated biorefinery capable of producing liquid transportation fuels and other chemical feedstocks would benefit the public by providing a sustainable pathway to convert domestically available feedstocks into fuels that might otherwise be imported from countries or regions of the world that are typically hostile to the United States.

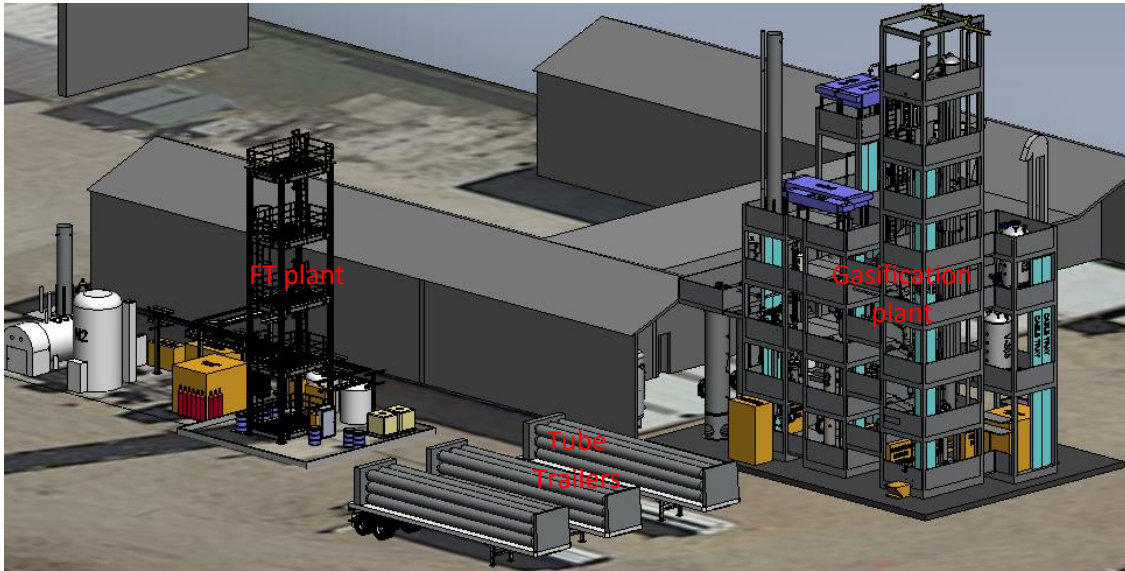
Accomplishments

The project was split into two budget periods ("BP"). BP-1a tasks included a preliminary technical and initial environmental review by the U.S. DOE staff. This goal was accomplished and the task completed. BP-1b tasks consisted of detailed environmental review, detailed engineering, and equipment costing, such that the project reached a shovel ready status. This task was also completed. BP-2 was to involve construction and testing, neither of which happened due to lack of cost share funds.

As mentioned above, the primary purpose of this project was to demonstrate conversion of biomass and waste-derived feedstocks into military spec liquid fuels. Although the plant was not constructed, detailed design of the plant was completed and budgetary pricing for the construction of the plant was obtained.

The plant was modeled in Solidworks™ such that assembly drawings would facilitate construction of the plant and dimensional drawings would enable fabrication of individual components. The site was also

modeled and is shown in the picture below. SGC Energia's FT pilot plant was already built and operated a bottled gas from the tube trailers. The gasifier plant was proposed, but never constructed.



SGC Energia's Technical Center in Pasadena, Texas with existing FT pilot plant and proposed gasifier pilot plant.

Detailed design was advanced to a point where bid packages were created and issued to contractors for fixed-price proposals. Seven packages were issued:

1. Site development and concrete
2. Equipment fabrication
3. Module assembly
4. Module transport and field mechanical
5. Field electrical
6. Field insulation and painting
7. Control system and panel fabrication

Frontline received proposals from multiple fabricators and contractors for the bid packages. There was substantial variance in the proposals for each bid package. In an attempt to evaluate and understand the variance in the proposals, Frontline staff visited with the fabrication and construction companies. Information gathered helped shed some light on the variability, but there was no specific item that clearly stood out to explain the differences/variability. Ultimately, Frontline determined that each company's bid reflected their particular interpretation of the project and, in almost every instance, either excluded certain aspects that would have been required if the plant were to be constructed, or included a substantial adder to cover the cost of items that were outside their scope of expertise. As such, it made interpretation of the quotes difficult and establishing a price for construction impossible

without substantially more work. If a decision had been made to proceed to construction, Frontline personnel would have spent additional time interacting with fabricators and contractors to address gaps left in the contractors' proposals and enter into definitive negotiations for fabrication and construction.

Factors that influenced project outcomes

Factors that influenced project outcomes include (in no particular order):

1. At the time of the award, oil prices were high and projects that produced alternatives were financially compelling. Declining and projected ongoing low price of crude reduced interest of investors or other strategic partners to invest in alternative energy projects. This was the primary contributing factor to Frontline's inability to identify funds to cover the non-DOE portion of the project costs. A long-term, guaranteed offtake could have shifted the project economics and therefore investor interest.
2. Due to the lower than anticipated product value, margins were further hampered by the relatively high cost of biomass feedstock result in operating costs that render the cost of a gallon of F-T produced fuel non-competitive. The team was not surprised by the biomass acquisition, logistics or processing costs. It was simply a matter of its increased importance as profit margins thinned due to other factors.
3. The number of unit operations resulted in a plant that would cost more than originally anticipated – if the plant had gone all the way to construction. As described in the next item, the primary learning was that Frontline's TarFreeGas[®] technology did not perform as well on low ash biomass feedstocks or MSW-derived feedstocks as it did for high ash biomass feedstocks. This learning indicated a requirement for an additional unit operation for further tar reduction.
4. Subsequent to receiving the grant award, additional laboratory testing of Frontline's TarFreeGas[®] technology on low ash biomass and MSW derived feedstocks, outside of and independent from DOE project funding, revealed the TarFreeGas[®] gasifier did not convert methane or other light hydrocarbons to syngas with certain feedstocks and under certain conditions. These subsequent results contributed to Frontline's understanding of the desired ash concentration and composition that enabled its TarFreeGas[®] reactor to produce a low-tar gas. Generally speaking, tar loadings can be reduced by higher operating temperatures in the case of MSW derived feedstocks, although higher operating temperatures are limited by agglomeration tendency of the ash, or higher alkali concentration in the case of biomass feedstocks, as the alkali helps promote carbon conversion. The operating temperature of Frontline's lab-scale TarFreeGas[®] reactor is limited due to its materials of construction, so the reactor could not be operated at the higher temperatures of interest. The low conversion efficiency for methane and other light hydrocarbons greatly reduced the theoretical yield for FT liquids. It was/is possible to include a thermal cracker to convert methane and other non-condensable hydrocarbons to syngas, but the additional unit operation would add to capital and operating expense to an already higher than expected price tag.

Lessons Learned

The project would have been an excellent demonstration of an integrated biorefinery. As previously mentioned, the project was not built because of lack of cost share, so the technical outcome is unknown. However, through the design process, Frontline had numerous learnings, the most important, of which, are enumerated here:

1. Modular construction is an attractive approach to minimize field costs and reduce construction expense compared to field, stick built methods.
2. As previously described, the quotes obtained from fabricators and contractors varied substantially, sometimes by as much as 3x difference between bids. To obtain more accurate pricing and a better understanding of the cost impacts of various project aspects, the project could have been subdivided into many more bid packages, such that differences in costs could be more readily evaluated and understood. Additionally, after receipt of the “free” cost estimates, which often came as lump sum proposals rather than the requested detailed, a la carte proposals, the project could have engaged the fabricators and contractors on a fee for service to refine and detail their proposals.
3. Conversion of methane as well as condensable and non-condensable hydrocarbons has a substantial impact on liquid yields in Fischer-Tropsch synthesis. For some feedstocks, reforming of methane and other hydrocarbons could result in a 2x increase in FT liquid yields. Feedstock composition and TarFreeGas[®] reactor operating conditions need to be tuned to maximize carbon conversion, thereby reducing the syngas concentration of methane and other hydrocarbons.

Products developed and technology transfer activities

1. **Publications (list journal name, volume, issue), conference papers, or other public releases of results.** No papers published.
2. **Web site or other Internet sites that reflect the results of this project.** No web site or other publicly available information for the project.
3. **Networks or collaborations fostered.** No new networks or collaborations formed.
4. **Technologies/Techniques.** All technologies considered for use in the project were originally conceived and reduced to practice by Frontline and SGC Energia.
5. **Inventions/Patent Applications, licensing agreements.** All technologies considered for use in the project were originally conceived and reduced to practice by Frontline and SGC Energia.
6. **Other products, such as data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments or equipment.** None.

Conclusions

The primary objective of this project and the U.S. DOE’s integrated biorefinery (“IBR”) program was to demonstrate conversion of biomass and waste-derived feedstocks into military spec liquid fuels. An

integrated biorefinery holds great potential and can benefit the public in many ways. In this project, although the project did not proceed to construction, the team learned many lessons and refined our knowledge of the technology and its market application.

- The complexity and costs associated with converting biomass or waste into FT intermediates and then into fungible transportation fuels requires an adequate margin between feedstock and oil prices. The analysis of this project suggests oil prices must be greater than \$70 per barrel to have a chance at a profitable commercial project.
- The substantial contribution of feedstock cost to plant operating expense suggests projects should be designed to consume a wide variety of feedstocks, whichever is available at the lowest cost at the time. However, the heterogeneous nature of feedstocks inevitably results in variable conversion parameters and changes in syngas composition. FT conversion requires very strict hydrogen-to-carbon monoxide ratios, which would require homogeneous feedstock.
- Conversion of methane and other hydrocarbons to hydrogen and carbon monoxide in the synthesis gas is crucial. Increased conversion to hydrogen and carbon monoxide improves FT liquid yield, which greatly enhances product revenue.
- Quotes provided by fabricators and contractors were highly variable. In retrospect, the team would have increased the number of bid packages by decreasing the scope of each bid package. This would have enabled a more granular view of project cost factors.
- Future work would include a thermal cracker, which would enable feedstock variability and greatly enhance syngas production, resulting in more FT liquids and therefore, more revenue.