# Annual Report for the Fischer-Tropsch Fuels Production and Demonstration Project

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## Disclaimer

## Abstract


This project has two primary purposes: 1) Build a small-footprint (SFP) fuel production plant to prove the feasibility of this relatively transportable technology on an intermediate scale (i.e. between laboratory-bench and commercial capacity) and produce as much as 150,000 gallons of hydrogen-saturated Fischer-Tropsch (FT) diesel fuel; and 2) Use the virtually sulfur-free fuel produced to demonstrate (over a period of at least six months) that it can not only be used in existing diesel engines, but that it also can enable significantly increased effectiveness and life of the next-generation exhaust-aftertreatment emission control systems that are currently under development and that will be required for future diesel engines. Furthermore, a well-to-wheels economic analysis will be performed to characterize the overall costs and benefits that would be associated with the actual commercial production, distribution and use of such FT diesel fuel made by the process under consideration, from the currently underutilized (or entirely un-used) energy resources targeted, primarily natural gas that is stranded, sub-quality, off-shore, etc.

During the first year of the project, which is the subject of this report, there have been two significant areas of progress: 1) Most of the preparatory work required to build the SFP fuel-production plant has been completed, and 2) Relationships have been established, and necessary project coordination has been started, with the half dozen project-partner organizations that will have a role in the fuel demonstration and evaluation phase of the project.

Additional project tasks directly related to the State of Alaska have also been added to the project. These include: A study of underutilized potential Alaska energy resources that could contribute to domestic diesel and distillate fuel production by providing input energy for future commercial-size SFP fuel production plants; Demonstration of the use of the product fuel in a heavy-duty diesel vehicle during the Alaska winter; a comparative study of the cold-starting characteristics of FT and conventional diesel fuel; and demonstration of the use of the fuel to generate electricity for rural Alaskan villages using both a diesel generator set, and a reformer-equipped fuel cell.

# Introduction

## I. Rationale for the Overall FT Fuels Production and Demonstration Project

This section describes how the several Tasks (Reference 1) and Partners of this project fit together to make a cohesive whole. This section will show that the driving force for this overall Fischer-Tropsch (FT) Fuel Production and Demonstration Program is indeed a coherent and feasible future path that can progressively, over a period measured in decades, increase both the quantity and quality of liquid fuels available for transportation, and help reduce exhaust emissions at the same time.

The overall scenario can be described as a series of steps that can interact to increase progressively the quantity and quality of liquid transportation fuels over time. The envisioned overall scenario can be stated as follows: Transportable FT plants, in increasing numbers over time, can go to where the remote resources are located; There are many of these resources; The high-quality FT fuels produced can find niche markets now, and contribute to the diesel-fuel sulfur-reduction mandate in the years ahead; Larger quantities of unblended FT fuels over time can enable, 1) next-generation diesel emission control systems, 2) greatly improved diesel engines, and 3) mobile fuel cells; Each step along the path will need to make economic sense to be viable.

To understand how the pieces of this project fit together, some description of each piece is needed first. The pieces described below are: Small Footprint Plant (SFP) Fuel Production Technology; The Potential SFP Feedstock Resource Base; Initial and Longer-Term Commercial Uses of SFP Fuel; SFP Fuel as a Enabler for Improved Diesel Engine Design; The Reformer and SFP Fuels as Enablers for Mobile Fuel Cells; and finally, Will Economics Allow a Journey Along the Foregoing Path?

## II. Small Footprint Plant (SFP) Fuel Production Technology

The Syntroleum fuel production technology to be demonstrated in this project has several features that can contribute to the overall goal of increasing both the quantity and quality of liquid fuels available for future transportation. First, the technology uses air rather than oxygen in the process of making Fischer-Tropsch fuels. This means that a plant using this technology can be less expensive and more transportable than a plant that must include air-separation capability to make oxygen for its process. Furthermore, this project's technology can be made modular, which also improves transportability. These features will enable transportation of modules, and assembly of a production plant from them, at the source of otherwise un-usable feedstock (such as stranded or associated gas, for example) in a remote area, or even offshore. These features are also the reason that the plant to be built in this project is referred to as a Small Footprint Plant (SFP). Since the primary product of such a plant is high quality finished liquid fuel, it can be transported to where it is needed relatively easily. In fact, it may be needed locally, and thus this scenario could also reduce the transportation cost of finished liquid fuels to some remote areas, prominently including Alaska.

Another feature of SFP technology is that the "air" that has flowed through the process, and become a stream consisting primarily of nitrogen and carbon dioxide, with a little oxygen remaining in it, is still a valuable resource. This gas is at elevated pressure and temperature, and the temperature can be raised further by burning an additional amount of fuel in it to consume the remaining oxygen. Then the gas can be expanded through a gas turbine to generate electricity, which is a long-standing commercial technology. This feature makes the plant self sufficient in electricity for both processing, and for the domestic needs of the people who operate the plant. It is even possible to configure the plant to export electricity, if this is desirable in a particular situation.

Even after passing through the gas turbine and producing power, the remaining stream of nitrogen and carbon dioxide from the SFP is still a potentially valuable resource. This gas can, for example, be injected into an oilfield to help maintain oil yield over time.

**III. The Potential SFP Feedstock Resource Base**

The purpose of this sub-section is to outline the large potential resource base that can provide feedstock at relatively low cost for many SFP's over time.

Oil is produced in an extremely large number of places around the world. In virtually every case, at least some, and often a great deal of gas, called associated gas, is produced along with it. In some cases, it is economically feasible to gather this gas by building a pipeline (or possibly by other means) so the gas can be transported to a market, such as through the gas transmission system of the US. Much of the cost of pipelined natural gas is attributable to the relatively high cost of its transportation system. However, in many cases the combination of the relatively small amount and/or poor quality of the associated gas being produced, the distance to a market, and other factors, make it prohibitively expensive to gather associated gas and transport it to a market. However, if oil is produced, something must be done with the associated gas. In many areas of the world, associated gas is flared, or even vented to the atmosphere, which poses obvious dangers. In others, such as the North Slope of Alaska, for example, the associated gas is pressurized using expensive machinery, and re-injected into the oilfield to help maintain oil yield over time.

Associated gas that is currently being vented, flared or re-injected is a prime, but only one, example of potential feedstock for SFP's. This high-energy gas is either wasted outright by venting and flaring, or contributes only marginally to future oil production if re-injected. Therefore, such gas has low (or even negative) value under present circumstances, but it could be ideal feedstock for

SFP's. The finished liquid fuel from SFP's could, in many cases, be transported by the same means as the crude oil being produced. In virtually all cases, the liquid SFP fuel can be transported to market much more economically than the original associated gas could have been, because the SFP fuel can be used within the existing liquid fuel infrastructure.

Other examples of potential SFP feedstocks include already known remote or offshore gas that was discovered when searching for oil far from any existing gas pipeline infrastructure. SFP technology could promote the active search for such gas resources. In summary, there is no shortage of ideally suited potential gas feedstocks, either at present or in the intermediate (several decade) term. In this project Tiax (formerly Arthur D. Little, Inc.), will quantify the costs, risks, opportunities and potential economic alternatives associated with these resources, and their exploitation by using SFPs.

Longer term, many other feedstocks, including coal and even biomass, can be gasified and converted to ultra-clean liquid transportation fuel using the same basic SFP technology, with some additional front-end processing. The decision of whether to move a particular feedstock to a plant (such as moving a small portion of the vast resource of remote Alaskan coal, for example, to distant conventional power plants), or to move SFPs to the feedstock source to make ultra-clean liquid transportation fuel, would depend upon the relative overall economics of such alternatives.

## IV. Initial and Longer-Term Commercial Uses of SFP Fuel

The purpose of this sub-section is to point out the present and likely future conditions that make it reasonable to expect that a ramp-up will occur over time in both the market for, and in the use of, SFP fuel.

Some diesel bus fleets have already started using low-sulfur conventional diesel fuels to reduce emissions, and would conceivably use SFP fuels to obtain even greater emission reductions if SFP fuels were generally available. Two such bus fleets have agreed to participate in this project by making available three buses from each of their fleets to demonstrate the use of, and measure exhaust emissions using, SFP fuel; the Washington DC Metro Area Transit Authority (WMATA), and the Denali National Park bus fleet. ICRC will conduct these bus fleet field tests, with support and assistance from the University of Alaska at Fairbanks for the Denali test.

One of the consequences of reducing fuel sulfur and aromatics to low levels, whether in conventional or SFP fuels, is a reduction in fuel lubricity. Experience has already shown that low sulfur diesel fuels need to be treated with appropriate lubricity additive technology to assure fuel injection system durability. Therefore, since relatively long-term bus fleet tests of the zero-sulfur SFP fuel are planned, 1500-hour dynamometer tests of fuel-system durability will be conducted by

ICRC and AVL Powertrain Engineering, using additive treated fuel and new engines of the type used by each bus fleet, to validate the effectiveness of the lubricity additive technology before running the fleet tests.

SFP fuels have zero sulfur, virtually zero aromatics, and are hydrogen saturated. Such materials are likely to be in great demand from the middle of the current decade onward, as Federal Requirements already in place call for the sulfur level of all on-road diesel fuel to be reduced from a typical level of ~400 ppm today to a maximum of 15 ppm by 2006. The initial uses of SFP fuel will almost certainly include it as a final-step blendstock to meet the sulfur level requirement for diesel fuel that is primarily petroleum derived, and that has undergone extreme (by today's standards) refinery processing to remove sulfur down to the minimum practical and economic level. Although no problems are expected to occur when SFP and petroleum-derived fuels (especially those that are highly processed to remove sulfur) are blended, this project is designed to obtain some data to support this expectation. If any problems do occur with such blending in this project, they will be investigated thoroughly by Syntroleum, and by both DaimlerChrysler and MIT.

The reason that the sulfur level of on-road diesel fuel is being reduced is to reduce overall diesel exhaust emissions. Sulfur level reduction contributes to this goal directly, especially for particulate emissions, and it enables the use of exhaust aftertreatment emission control devices, which could be quickly rendered ineffective by fuel sulfur levels above ~15 ppm. For reduction of diesel particulate emissions to virtually zero levels, catalyzed particulate traps or filters are fairly well developed, and are being retrofitted in a few fleet tests of current heavy-duty diesel vehicles. Exhaust aftertreatment devices for NOx emission reduction are not as well developed yet, and are not likely to provide the extremely high degree of NOx emission reduction that traps achieve for particulates, but they do show promise. One of the advantages of SFP fuel, with its near-zero aromatic level, is expected to be a significant reduction in engine-out NOx emission level, even when compared to low-sulfur conventional fuel. In this project, West Virginia University will determine the magnitude of such potential reduction in NOx emissions, and other emissions as well, using the two real-world bus fleets.

An area of concern with respect to prototype exhaust aftertreatment devices under development for both heavy-duty and light-duty diesel vehicles of the future is their long-term effectiveness in maintaining emissions at low levels. It is expected that ultra-clean SFP fuel will minimize deterioration in emission-control effectiveness and maximize the useful life of such devices. Project partners DaimlerChrysler and Volkswagen will compare the SFP fuel to other available low-sulfur diesel fuels in this respect, using both heavy-duty and light-duty prototype engines and their exhaust aftertreatment emission control systems, and measuring emissions over long enough intervals to observe any fuel effects on emission control system deterioration. A possible outcome from studies of this type could be a strategy of matching future diesel vehicles employing exhaust aftertreatment with ultra-clean SFP fuel, maintained separately from low-sulfur conventional fuel, to achieve the extremely low emission levels over extended time periods that will be required of new vehicles by future vehicle emission regulations.

Longer term, metro areas with severe air-pollution problems could elect to require the use of ultra-clean SFP diesel fuel by all the diesel vehicles based in the area. If this approach produced perceptible improvements, other metro areas with similar problems would likely adopt it, as a relatively inexpensive way to achieve immediate emission reductions.

## V. SFP Fuel as an Enabler for Improved Diesel Engine Design

The purpose of this sub-section is to show that when SFP fuels reach a sufficient total volume to become commercially available on a widespread basis, maintained separately from the rest of the diesel fuel supply, it will be possible to design and build future diesel engines to take advantage of their premium properties, and thus improve diesel engine performance and reduce emissions further.

Diesel engines rely upon their fuel to have sufficient ignition quality for the engines to start and run acceptably. Diesel fuel ignition quality is normally quantified as Cetane Number, and a specification of 40 Cetane, minimum, is typical for current diesel fuels. Virtually all aspects of both the performance and emissions of a given diesel engine design respond positively to an increase in the Cetane number of the fuel. In fact, compromises are made in the design of current diesel engines so that they will perform acceptably on the available 40 Cetane fuel.

An example of such a design compromise is the typically high diesel-engine compression ratio, which is dictated by the necessity that the engine must start, even at low ambient temperatures, on fuels with a Cetane Number of 40. Diesel compression ratios required for cold starting are higher than ideal for optimum running and low emissions, and are certainly higher than for optimum diesel engine power density. Basically, current diesel engines are built extremely heavy to prevent internal pressure and stresses (attributable to both their high compression ratio, and to the long ignition-delay associated with low-Cetane fuels) from destroying them. In an attempt to increase diesel engine power density (i.e. to make the engine smaller and lighter, but maintain its high power output) the US Army has worked for years on a relatively complex variable compression ratio (VCR) design for a relatively light diesel engine, that would start (on relatively low-Cetane petroleum derived fuel) at high compression ratio, but then run at much lower compression ratio. Much better ignition quality of the fuel could achieve the same result (i.e. higher engine power density), by greatly improving cold starting at a lower fixed compression ratio, thus avoiding the added complexity and weight penalty of VCR.

SFP fuels have a Cetane Number of 70, or higher. Although the effort to reduce the sulfur level of petroleum derived diesel fuels is likely to have some beneficial effect on their Cetane Numbers, values greater than about 50 are unlikely. Therefore, SFP fuels offer the promise of truly revolutionary advances in the design of future diesel engines to make them smaller and lighter, but still powerful, less-noisy, easier-starting and lower-emitting. These are the potential advantages of SFP fuels that will be investigated by the MIT Sloan Automotive Laboratory, in addition to their research on the effects on injection timing on NOx and particulate emissions.

**VI. The Reformer and SFP fuels as Enablers for Mobile Fuel Cells**

The purpose of this sub-section is to show that when SFP fuels become commercially available on a widespread basis, maintained separately from the rest of the diesel fuel supply, they can assist the development and commercialization of mobile fuel cells.

It is well known that fuel cells can be very efficient, and that they produce virtually zero emissions. Fuel cells are not limited by the thermodynamic constraints that put a cap on the maximum efficiency an engine can achieve. Therefore, it is anticipated that fuel cells could be efficient and environmentally friendly power sources for vehicles of the future. But fuel cells “convert” hydrogen directly into electricity, so the vehicle must either carry hydrogen on-board as fuel (challenging, but potentially achievable economically in the future), or produce hydrogen on demand from some other fuel or energy source that is carried on-board. Hydrogen-saturated SFP fuels, both naphtha and diesel fuel, are ideally suited both to be carried on-board a vehicle, and to be reformed on demand to produce the hydrogen needed by a fuel cell.

A reformer produces hydrogen from a hydrocarbon fuel by heating the fuel to a high enough temperature to cause dissociation of the hydrogen from the original fuel molecules. This is done in the presence of a limited amount of air, so that the carbon in the fuel reacts with oxygen to form CO. The hydrogen is separated from the mixture, and fed to the fuel cell. The CO can be reacted further with water to produce CO2, and even more hydrogen for the fuel cell (the water-gas shift reaction). The net effect is that even the carbon in the fuel can contribute hydrogen (from water) to power the fuel cell.

A major concern in the ongoing development of reformers for fuel cell applications is the impurities that are contained in current hydrocarbon fuels. Impurities such as sulfur and metals must be removed, either in advance, or on-board, or they can quickly disable the system. Even some hydrocarbons, such as heavy aromatics for example, can cause deposition and other problems in reformers over time. A major advantage of SFP fuels is that they contain virtually zero levels of all such impurities, greatly improving the long-term performance and reliability of fuel-cell reformers.

## VII. Will Economics Allow a Journey Along the Foregoing Path?

The purpose of this sub-section is to recognize that the overall feasibility of the scenario outlined above will depend almost entirely upon economics at each step.

The foregoing discussion is mostly concerned with technical issues, and relatively few references have been made to economics. However, none of the above will happen if it does not make sense economically. Therefore, Tiax (formerly Arthur D. Little, Inc.), will conduct an economic analysis in this project. The major thrust of this will be a well-to-wheels economic and market analysis of SFPs and their potential feedstock resources, and of the commercial applications in future transportation markets for ultra-clean liquid fuels from these plants.

## Executive Summary

The preparatory work required to enable the building of the SFP fuel production plant, using project-partner Syntroleum Corporation's process technology, included several primary tasks. First, a potential plant-site had to be selected that would meet a number of critical requirements. These included; reasonable proximity to existing Syntroleum research and pilot-plant facilities in Tulsa, appropriate heavy industrial zoning for petrochemical processing and fuel production, availability of sufficient natural gas feedstock, heavy-duty transportation infrastructure, etc. The site chosen was an undeveloped 10-acre tract within the Port of Catoosa. The Port Authority oversees a concentration of heavy industrial operations located in close proximity to the Verdigris River (which is navigable and connects to the Mississippi River), on the eastern outskirts of metropolitan Tulsa, OK. A lease agreement was negotiated and executed, and the process of obtaining all required permits from the state, county and other governmental units having jurisdiction was undertaken and completed. An Environmental Assessment also had to be made, evaluated by all stakeholders, and approved by DOE-NETL before the project could go forward.

Syntroleum made the following major in-kind contributions this project: The use of Syntroleum proprietary process technology as the basis for the plant; The specific process design for the actual plant to be built; and Some major pieces of processing equipment to be incorporated into the plant. The primary pieces of equipment are an auto-thermal reactor (ATR, which produces synthesis gas, a mixture of CO and hydrogen), and a Fischer-Tropsch reactor (FTR, which produces long-chain saturated hydrocarbons from the synthesis gas).

These two reactors had previously been installed and operated on a trial-run basis on the property of a petroleum refinery in Cherry Point, Washington. Although these units performed well and proved their feasibility on a unit by unit basis, they were dependent upon supporting utilities and services from the refinery in order to operate in the previous project. For example, the refinery provided power and feedstock to the ATR, and the refinery "accepted" much of the output of the FTR, which could not be used as a diesel fuel without significant product upgrading. Syntroleum has small-scale laboratory facilities that upgraded relatively small quantities (a few drums) of the FTR product to finished fuel, mostly to develop upgrading technology on a small scale and provide small samples of crystal-clear product. However, the throughput amounts of the two reactors during the Cherry Point trial run were so large that most of the FTR product was fed into the refinery as a means of disposal.

The Cherry Point refinery was owned by ARCO, a partner with Syntroleum in the previous two-unit trial-run project. Subsequently, ARCO and the Cherry Point refinery were acquired by BP (British Petroleum). BP allowed Syntroleum to remove the two process units from the Cherry Point refinery for the purpose of moving them to Tulsa for use in the current program. The actual removal of the

ATR and FTR from Cherry Point, and their transportation to Tulsa, were significant engineering challenges that have been accomplished. The plant being built in this project will be a stand-alone plant capable of producing finished fuels in quantities sufficient to support fuel demonstration and evaluation on a fairly large scale.

The fuel demonstration and evaluation portion of the project has several components, and several partners who will be responsible for the associated tasks. The scope of fuel evaluation ranges from demonstration of SFP Fischer-Tropsch diesel fuel in current diesel engines to provide an immediate reduction in emissions, through enabling the development of all the following: More effective diesel exhaust emission control systems; Advanced designs of diesel engines themselves; and even Mobile fuel cells. The well-to-wheels economic analysis will consider costs and benefits associated with such uses, as well as with the currently underutilized energy sources that could be the input for future SFPs.

Relationships have been established, and necessary project coordination has been started, with all the partners who will have a role in fuel demonstration and evaluation. Subcontracts have been issued by ICRC to those organizations that will be receiving NETL funding, including Syntroleum, MIT, WVU, UAF, the Arctic Energy Technology Development Laboratory (AETDL) at UAF, and Tiax. Memoranda of Understanding (MOUs) are in the process of being established between ICRC and the other partners such as Denali National Park, the WMATA and Denali bus fleet operators, and DaimlerChrysler and Volkswagen, who will contribute their in-kind equipment and emission data on engines and vehicles in return for use of the SFP fuel to obtain the data.

## Experimental

The fuel demonstration and evaluation experiments that will be conducted in this project will not be done until the fuel production plant is completed and fuel is produced.

## Results and Discussion

Since experiments have not yet been done, there are no results to report.

## Conclusion

Since there are no results yet, no conclusions can be drawn.

## References


1. “Statement of Project Objectives,” Attachment A to Cooperative Agreement DE-FC26-01NT41099, July 20, 2001.