Greenhouse Gas (GHG) Emissions Reductions Research and Development (R&D) Leading to Cost-Competitive Coal-to-Liquids (CTL) Based Jet Fuel Production

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ABSTRACT

The Department of Energy (DOE) supports R&D to convert the nation's abundant coal, natural gas, and biomass resources to power, fuels and chemicals thereby increasing energy security, reducing environmental impact, promoting economic development, and encouraging scientific discovery. Significant opportunities to reduce GHG emissions of CTL fuels include: increasing efficiencies of conversion technologies; supplementing coal with feedstocks that have lower lifecycle GHG emissions; and carbon capture, utilization, and storage (CCUS). In 2013, Congress appropriated $20 million to the Department of Defense (DoD) to advance technologies to enable CTL fuels to comply with EISA 2007 section 526. DoD in concert with the DOE conducted a solicitation (FOA DE-FOA-0000981) and awarded several R&D projects in the following CTL technology areas: Catalysts, Process efficiency, and Multiple or blended feedstocks. The CTL conversion processes included: Direct, Indirect, and Hybrid approaches.

Keywords: alternative fuels, gasoline, diesel, jet fuel, liquid fuels from coal, gas, and biomass, low-emission fuels

1 INTRODUCTION

The Department of Energy (DOE) supports R&D to convert the nation's abundant coal, natural gas, and biomass resources to power, fuels and chemicals thereby increasing energy security, reducing environmental impact, promoting economic development, and encouraging scientific discovery. Significant opportunities to reduce GHG emissions of CTL fuels include: increasing efficiencies of conversion technologies; supplementing coal with feedstocks that have lower lifecycle GHG emissions; and carbon capture, utilization, and storage (CCUS). In 2013, Congress appropriated $20 million to the Department of Defense (DoD) to advance technologies that will potentially enable CTL fuels to comply with the Energy Independence & Security Act (EISA) 2007 section 526.
DoD then teamed up with DOE in order to leverage DOE's technical expertise, capabilities, and complementary agency mission pertaining to secure, alternative fuels. DoD, by comparison, is a large fuel customer that evaluates fuels produced through new pathways that may be integrated into commercial-scale supplies of military fuels. The specific technology areas identified in the solicitation (Funding Opportunity Number DE-FOA-0000981) included: Catalysts (greater selectivity, increased production, durability, etc.), Process efficiency (process intensification, heat exchange/heat management, etc.), and Multiple or blended feedstocks (biomass, natural gas, etc.). The coal to liquids conversion processes included: Direct, Indirect, and Hybrid approaches.

1.1 Coal to Liquids Technologies

The Conversion Technologies considered were:

- Direct (Bergius Hydrocracking)
- Indirect (Gasification+[Fischer-Tropsch (FT) or Methanol])
- Hybrid (combination of direct and indirect)

Some characteristics of the conversion technologies include:

- **Indirect coal conversion technology –** High quality fuels produced, but lower process efficiency
- **Direct coal conversion technology –** High theoretical process efficiency but expensive upgrading required to meet fuel specifications
- **Hybrid Approaches -** Combination of aspects of both direct and indirect coal conversion technologies may strike a balance between process efficiency and final fuel quality by blending the indirect conversion (FT) fuels to reduce the amount of upgrading required for the DCL output, increasing "drop-in" fuels output
  - Using multiple or blended carbon feedstocks (biomass and natural gas with coal) may improve environmental performance
  - Combining aspects of syngas conversion or liquids processing (upgrading) technologies may generally improve process flexibility and maximize targeted product slate

The projects selected provide a diversity of technologies, as summarized below:

- Three Indirect Coal Conversion Processes: **RTI International, Southern Research Institute, and Ceramatec, Inc.**
- One Direct Conversion Process using Bio-Oils with Unique Hydrotreating: **Battelle.**
- One Hybrid Process Employing Fast Pyrolysis and Olefin Oligomerization: **Altex Technologies Corporation**

1.2 RTI International

Breakthrough Hybrid CTL Process Integrating Advanced Technologies for Coal Gasification, NG Partial Oxidation, Warm Syngas Cleanup, and Syngas-to-Jet Fuel

The hybrid CTL process integrates a number of emerging technologies anticipated to produce jet fuel that is cost competitive with that from petroleum with an equal or lower carbon footprint. The process technology components selected for the hybrid CTL process include Aerojet Rocketdyne's (AR) advanced compact gasifier with dry solids feed pump and natural gas partial oxidation (POX) technologies and RTI's warm syngas cleaning and novel syngas-to-liquids (STL) technologies. In Phase I, a bench-scale STL reactor system was used to provide liquid hydrocarbon samples suitable for upgrading to jet fuel. RTI worked with Axens to use the analysis of these samples to evaluate upgrading configurations and optimize the configuration of RTI's STL system for producing a jet fuel intermediate. In Phase II, the integrated 1 BPD pilot-scale test is used to produce approximately 1 barrel of intermediate product from syngas generated from coal, natural gas and combinations of coal and natural gas. The intermediate product from these pilot scale tests is upgraded by Axens into jet fuel. The preliminary techno-economic analysis completed in Phase I is updated with the experimental data obtained from the pilot scale testing and upgrading.

The Advanced Compact Gasifier, POX, Warm Syngas Cleaning, and STL technologies are anticipated to be advanced by the project development efforts utilizing blends of U.S. mined coal for the input feedstock and natural gas in the hybrid CTL process. Key aspects of the technology include:

- The proposed hybrid integrated process technology is projected to have the potential to reduce capital costs by up to 34% and be competitive with petroleum-based JP-8 production at oil prices at or above $70/bbl.
- Indirect FT (Traditional Fe & Co Based) conversion using coal & natural gas
- AR (Aerojet-Rocketdyne) compact entrained flow gasifier (lower capital cost) (EERC testing now)
- RTI warm gas cleanup (30% cost reduction) (Eastman and TECO tested)

1.3 Southern Research Institute

Indirect Liquefaction of Coal-Biomass Mixture for Production of Jet Fuel with High Productivity and Selectivity

Southern Research Institute is conducting a research and development project to provide innovative improvements to indirect coal liquefaction for conversion of coal or coal/biomass mixtures to jet fuel with high productivity and selectivity. This project includes the production of a hydrocarbon product from a coal/biomass blend. The hydrocarbon product is directly blended with petroleum-based jet fuel at approximately 50% by volume with the resulting mixture meeting JP-8 specifications. The project focus is to reduce the cost, increase process efficiency and improve the life-cycle for coal-to-liquids (CTL) production of jet fuel through process intensification design upgrades for the reactor, catalyst and catalyst bed configuration.

The Compact Autothermal Reactor, Hybrid FT Catalyst, and Efficient Heat Removal Incorporated Fixed-Bed Reactor technologies are anticipated to be advanced by the project development efforts utilizing Powder River Basin (PRB) sub-bituminous coal/wood pellet blends containing 55 to 75 % coal on a BTU basis in the coal/biomass to JP-8 jet fuel process. Key aspects of the technology include:

- Reducing the size of the CBTL facility contributes to commercialization and reduces cost.
- Indirect FT using coal, biomass & natural gas
- TRIG gasifier ([test at the National Carbon Capture Center (NCCC)])
- Improved PCI ATR reformer (a steam reformer will be used in the test) & conventional gas cleanup
- Microfibrous entrapped catalyst (MFEC) F-T reactor w/ Chevron hybrid F-T catalyst

1.4 Ceramatec, Inc.

Technology for GHG Emission Reduction and Cost Competitiveness of Mil-Spec Jet Fuel Production Using CTL

Ceramatec is demonstrating the production of jet fuel from a coal and glycerol or other biomass. The project integrates several unique technologies to produce a product that may be directly blended with jet fuel from petroleum based sources. The cost is anticipated to be competitive with jet fuel from petroleum, and generate approximately 30 percent less GHG emissions compared to conventional petroleum-based jet fuel. Process modeling is performed to determine the mix of coal and glycerol or other biomass to achieve the target emission reduction and cost. Successful completion of this project provides the data required for design of a commercial facility capable of providing jet fuel meeting specification and establishing the ability to produce jet fuel from coal with reduced GHG emissions.

The Energy & Environmental Research Center (EERC) at the University of North Dakota Transport Reactor Development Unit (TRDU) gasifier, sulfur removal system and hybrid catalyst technologies are anticipated to be advanced by the project development efforts utilizing U.S. mined coal blended with glycerol or other biomass in the hybrid CTL process. Key aspects of the process include:

- Economical process will demonstrate a 30% reduction in GHG and has the potential to achieve widespread commercial deployment.
- Indirect F-T conversion using coal (PRB) and biomass (glycerol)
- EERC TRDU gasifier with Ceramatec multi-tube fixed bed microfibrous entrapped catalyst (MFEC) F-T reactor and advanced Chevron FT catalyst.
- IntraMicron gas cleanup/desulfurization.

1.5 Battelle

Direct CTL for Jet Fuel Using Biomass-derived Solvents:

This project focuses on investigating a direct coal/ biomass to liquids (CBTL) process for producing jet fuel that uses novel biomass-derived solvents with excellent hydrogen-donor capability, eliminates molecular hydrogen (H2) required for producing syncrude, and operates under milder conditions (approx. 500 vs. 2,500 psi). All major process steps are explored and refined at bench-scale under continuous operating conditions, including (a) biomass conversion to high hydrogen-donor solvents; (b) coal dissolution in biomass-derived solvents to produce syncrude; and (c) two-stage catalytic hydrogenation/ hydrotreating of syncrude to jet fuel and other distillates. The process is scaled-up to continuous, pre-pilot scale. Project development efforts—utilizing domestic coal blended with biomass via the direct CBTL process—are expected to advance development of high-hydrogen donor bio-oil solvents and two-stage catalytic syncrude hydrogenation/hydrotreating technologies. Key aspects of this technology include:

- The combined coal and biomass direct liquefaction process would produce hydrogen-rich oils from biomass feedstock which is then combined with coal to conduct liquefaction without the need for gaseous H_2.
- The proposed process is expected to reduce CO_2 emissions for jet fuel production due to a ~40% reduction in H_2 requirements.

1.6 Altex Technologies Corporation

Green-House-Gas-Reduced Coal-and-Biomass-to-Liquid-Based Jet Fuel (GHGR-CBTL) Process:

Altex and its partners are designing, fabricating, testing, and assessing the performance of a greater than 1 barrel per day process to produce synthetic JP-8 jet fuel. The process combines lower temperature fast pyrolysis and the production of a targeted intermediate that can be converted to a liquid hydrocarbon fuel at a lower cost than gasification/FT methods. The system is tested utilizing low-rank U.S. mined coal (lignite and/or subbituminous) and lignocellulosic biomass in ratios between 51% and 85% coal by higher heating value (HHV). The product is sent to third parties for testing compliance with key military jet fuel specifications. Key aspects of this process include:

- Unique process reduces GHG by 31% and produces JP-8 spec fuel at <2$/gal
- Hybrid direct-indirect conversion process using lignite and biomass employing fast pyrolysis and olefin oligomerization w/ standard gas cleanup.

2 CONCLUSIONS

2.1 RTI International:

- Due to the reduced part count and complexity of Ceramatec's 4" modular reactor design, fabrication and maintenance (catalyst service) cost are significantly reduced compared to conventional small tube fixed-bed FT reactors, or the advanced micro-channel reactors.
- A simplified process flow-sheet made possible by advanced, wax free catalyst requires only modest upgrading or refining to produce a significant jet fuel fraction. Elimination of the wax hydrocracker and hydrogen plant is a major simplification and cost savings in construction and operation.
- A mass-produced, modular, road transportable plant design can achieve world scale economies of scale in small plants that can be sized and reconfigured to match the biomass resource.

2.2 Southern Research Institute

- Southern Research is leading a consortium to demonstrate key technologies to produce low cost jet fuel using CTL/CBTL
- Advanced process intensification approaches are being used to reduce cost
  - Compact ATR with contaminant tolerant metal-mesh catalyst to reform hydrocarbons and tar, and decompose ammonia in the presence of sulfur
  - Cobalt-zeolite wax-free jet selective catalyst with high productivity and selectivity
  - Heat exchange reactor technology to allow large diameter reactor to be used for exothermic FT reaction; to enable reduction in reactor tube height.
- The ultimate goal is to enable smaller plants to become cost effective

2.3 Ceramatec, Inc.

- Scale, Scope & Cost
  - Small 0.1% to 10% (150 to 15,000 bpd) of "World Scale (150,000 bpd)" GTL
  - Product syncrude with minimal upgrading
  - CAPEX << $100k/bbl/day
- Shop fabrication

- Reduce cost versus site built plants
  - Transportability to site (size limits on road transport)
  - Quality control and mass production vs. traditional economies of scale
- Catalyst loading and transport
  - Catalyst servicing done in shop
  - Replaceable reactor elements
  - Catalyst reduced and ready to operate
- Minimum infrastructure required
- Takes advantage of a variety of small distributed resources
  - Biomass, biogas, coal-biomass blend
  - Stranded gas, associated gas
  - CO_2 co-electrolysis as intermittent renewable energy storage

2.4 Battelle

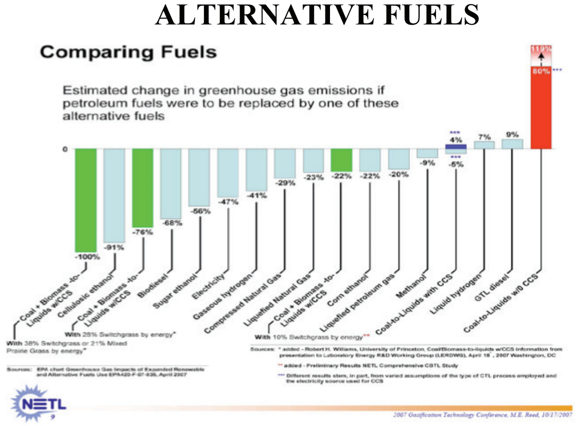
- Straightforward integration of proven subsystems with novel chemistry
- Significant reduction in the capital and operating costs due to mild operating conditions (500 vs. 2500 psi)
- Elimination of CCS at coal liquefaction site and minimization of CCS at the syncrude refining site reduces H2 demand
- Meets jet fuel specifications without blending with petroleum-based jet fuel

2.5 Altex Technologies Corporation

The JP-8 meets most of the JP-8 specs and gasoline properties can be tailored by the selection of catalyst. The experience to-date shows that the GHGR-CBTL is feed and product flexible.

ANL's GREET Model is used to update the preliminary LCA that showed inclusion of 11.2 wt% biomass in GHRG-CBTL leads to JP-8 with WTWa GHG emissions equivalent to petroleum-based JP-8 and inclusion of 49 wt% biomass leads to 31% less WTWa GHG emissions.

3 COMPARATIVE EMISSIONS FROM ALTERNATIVE FUELS



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