Synthetic Fuels
Technoeconomic Analysis
and Life Cycle Analysis

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Overview

Timeline
• Start: October 2019
• End: Determined by DOE
• % complete (FY20): 80%

Barriers to Address
A: Future Market Behavior
  ➢ Potential market for low value energy and potential hydrogen markets beyond transportation

D: Insufficient Suite of Models & Tools

E: Unplanned Studies and Analysis
  ➢ H2@Scale is a new concept and requires analysis of its potential impacts

Budget
• Funding for FY20: $150K

Partners/Collaborators
• NREL and INL
• DOE NE Office
Synthetic fuels production can contribute to large scale hydrogen demand.

Need to evaluate potential hydrogen demand and associated cost.
EVALUATE ECONOMIC AND ENVIRONMENTAL IMPACTS OF PRODUCING SYNTHETIC FUELS FROM ZERO-CARBON HYDROGEN – Approach

Data
Performance, Energy and Market data

Analysis Framework
Energy and Market

Models & Tools
ASPen, GREET

Studies & Analysis
Evaluate potential hydrogen use, environmental benefits and economics of synthetic fuel production

Outputs & Deliverables
Hydrogen consumption potential by synthetic fuel production, and coast and environmental impacts

DOE’s Fuel Cell Technologies Office (FCTO), Program Plan and Multi-Year RD&D Plan

GREET, H2A
Electrofuels or “e-fuels” encompass energy carriers and their intermediates synthesized primarily using a carbon source and electricity (for hydrogen).
MAJOR CO$_2$ AND ZERO–CARBON ELECTRICITY SOURCES TO CONSIDER – Approach

Carbon Sources

- Bio-derived CO$_2$
  - Ethanol plants
  - Waste streams (MSW, residues, etc.)

- Fossil-derived CO$_2$
  - Ammonia plants
  - NG processing plants
  - NG SMR plants
  - Cement plants
  - Iron & Steel mills
  - Fossil power plants

Zero-Carbon Electricity Sources

- Wind
- Solar
- Nuclear
LARGE NUMBER OF SYNTHETIC CHEMICALS AND FUELS PATHWAYS ARE POSSIBLE – Approach
LCA of CO₂–BASED FUELS: SYSTEM BOUNDARY – Approach

**CO₂ source**

- Biomass- and waste-derived CO₂
  - Ethanol plants
  - Biomass gasification Plants
  - Waste streams (MSW, residues, waste plastics)

- Fossil-derived CO₂
  - NG processing plants
  - NG SMR plants
  - NG Ammonia plants
  - Cement plants
  - Steel mills
  - Fossil power plants

**Capture, Purification, Compression, and Transportation**

- Capture
- Clean-up
- Compression / Transportation

**Conversion**

**Use**

Fuel production
HIGH-CONCENTRATION CO$_2$ SOURCES – Accomplishment

- Corn ethanol plant CO$_2$: 87-98% purity, 44 MMT/year
- Ammonia plant CO$_2$: >98% purity, 19 MMT/year
- NG processing plant CO$_2$: >96% purity, 17 MMT/year
OTHER LOWER-CONCENTRATION CO₂ SOURCES – Accomplishment

- H₂ SMR plant CO₂: 28% purity, 44 MMT/year
- Cement plant CO₂: 14-33% purity, 65 MMT/year
POTENTIAL H₂ DEMAND FOR SYNTHETIC HYDROCARBON PRODUCTION FROM CONCENTRATED CO₂ SOURCES – Accomplishment

- ~100 MMT of concentrated CO₂ sources are considered (out of total ~ 5 GT CO₂)
  - 44 million MT from ethanol plants
  - Current CO₂ supply capacity of 14 MMT, and market demand of 11 MMT
  - Remainder from hydrogen SMR (refineries) and ammonia plants

Source: Supekar and Skerlos, ES&T (2014)
14 MMT POTENTIAL H₂ DEMAND WITH 100MMT CONCENTRATED CO₂ ANNULAY – Accomplishment

*Assumption: CO₂/H₂ mole ratio 1:3 for synthetic hydrocarbon production

Recovered CO₂ from
- Ethanol plants
- H₂ plants
- Ammonia plants

H₂ demand
for synfuel using CO₂
- 0.1
- 0.3
- 0.5

Preliminary

Wind electricity potential
Solar electricity potential

Installed nuclear plants

U.S. Operating Commercial Nuclear Power Reactors

As of May 2012
MODELED H₂ DEMAND FOR SYNTHETIC FISCHER-TROPSCH (FT) HYDROCARBON PRODUCTION – Accomplishment

Preliminary

Well to wheel (WTW) boundary of FT fuel production from electrolysis hydrogen and ethanol plant by-product CO₂

(Forthcoming by Zang et al.)
**FT FUEL PROCESS SIMULATION USING ASPEN PLUS – Accomplishment**

- Six process areas were simulated
- Two systems were evaluated:
  - with $\text{H}_2$ recycle
  - without $\text{H}_2$ recycle (with electricity export)
INTEGRATED ETHANOL AND FT FUEL MASS CONVERSION – Accomplishment

- FT fuel production is integrated with the dry milling corn ethanol production via 154 kg CO₂
- 479 kg corn and 17 kg H₂ are converted into 161 kg ethanol, 138 kg DGS, and 23 kg FT fuel

- CO₂/H₂ mole ratio 1:2.4 for synthetic FT fuel production
- Carbon conversion efficiency ~ 46%
CARBON-NEUTRAL HYDROGEN PRODUCES NET ZERO CARBON FT FUELS – Accomplishment

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>GHG Emissions (g CO2-eq./MJ)</th>
</tr>
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<tbody>
<tr>
<td>FT diesel from NG</td>
<td>103</td>
</tr>
<tr>
<td>Gasoline BOB from petroleum</td>
<td>94</td>
</tr>
<tr>
<td>Diesel from petroleum</td>
<td>92</td>
</tr>
<tr>
<td>Gasoline E10 from petroleum</td>
<td>91</td>
</tr>
<tr>
<td>Ethanol-com grain dry milling</td>
<td>53</td>
</tr>
<tr>
<td>Ethanol-nuclear with H₂ recycle (Integrated)</td>
<td>47</td>
</tr>
<tr>
<td>Ethanol-wind/solar with H₂ recycle (Integrated)</td>
<td>46</td>
</tr>
<tr>
<td>Ethanol-nuclear without H₂ recycle (Integrated)</td>
<td>45</td>
</tr>
<tr>
<td>Ethanol-wind/solar without H₂ recycle (Integrated)</td>
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<tr>
<td>Ethanol-nuclear with H₂ recycle (Integrated)</td>
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<td>Ethanol-wind/solar with H₂ recycle (Integrated)</td>
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<td>Ethanol-nuclear without H₂ recycle (Integrated)</td>
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<tr>
<td>Ethanol-wind/solar without H₂ recycle (Integrated)</td>
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<tr>
<td>Ethanol-corn stover (Stand-alone)</td>
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<tr>
<td>FT-nuclear with H₂ recycle (Stand-alone)</td>
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<td>FT-nuclear without H₂ recycle (Stand-alone)</td>
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<td>FT-wind/solar with H₂ recycle (Stand-alone)</td>
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<tr>
<td>FT-wind/solar without H₂ recycle (Stand-alone)</td>
<td>-9</td>
</tr>
</tbody>
</table>

(GHG emissions from land use change)
(GHG emissions reference)
(GHG emissions from nuclear hydrogen)
(GHG emissions from wind/solar hydrogen)

(Forthcoming by Zang et al.)
HYDROGEN COST < $1/kg FOR FT FUEL TO BREAKEVEN WITH $3.6/gal DIESEL – Accomplishment

(Forthcoming by Zang et al.)
SUMMARY – Accomplishment

- Modeled hydrogen demand and product yield for synthetic FT production
- Simulated two FT plant designs, with and without recycling of hydrogen, using Aspen Plus
- Conducted life cycle analysis with GREET® model
  - Evaluated two co-product allocation methods
  - More than 90% CO$_2$e emission reduction compared to petroleum fuels
- Conducted techno-economic analysis using H2A framework to determine cost of hydrogen for FT fuels to breakeven with petroleum fuels
  - Hydrogen cost < $1/kg for FT to breakeven with $3.6/gal Diesel
- Documented data sources, modeling approach and analysis in two papers
  - Currently under review
  - Publication pending
Collaborations and Acknowledgments

H2@Scale is a multi-national laboratory effort with collaboration across DOE national lab complex

– Mark Ruth and Paige Jadun: NREL
– Richard Boardman: INL
Future Work

- Consider additional CO₂ sources for synthetic hydrocarbon production
  - e.g., natural gas processing plants, cement plants, power plants and direct air capture

- Conduct economic and environmental analysis of other synthetic fuels and chemicals
  - e.g., methanol and methanol-to-gasoline, etc.
  - Determine potential CO₂ reduction for each fuel and chemical pathway compared to baseline current technologies
  - Determine H₂ cost for synthetic hydrocarbon to breakeven with baseline technology pathway

- Conduct regional analysis considering proximity of CO₂ and H₂ supplies
  - Evaluate economics of delivered H₂ vs. onsite production
  - Evaluate economics of CO₂ capture and transportation
Project Summary

- **Relevance**: Hydrogen from clean energy sources can be used with available CO₂ sources to produce near zero-carbon synthetic hydrocarbon chemicals and fuels.

- **Approach**: Evaluate economic and environmental impacts of synthetic fuel production using Aspen, H2A framework and GREET models.

- **Collaborations**: H2@Scale is a multi-national laboratory effort with collaboration across DOE national lab complex.

- **Technical accomplishments and progress**:
  - Modeled hydrogen demand and product yield for synthetic FT production.
  - Evaluated two FT plant designs, with and without recycling of hydrogen.
  - Conducted life cycle analysis with GREET® model.
    - Evaluated two co-product allocation methods.
    - More than 90% CO₂e emission reduction compared to petroleum fuels.
  - Conducted techno-economic analysis to determine cost of hydrogen for FT fuels to breakeven with petroleum fuels.
    - Hydrogen cost < $1/kg for FT to breakeven with $3.6/gal Diesel.
  - Documented data sources, modeling approach and analysis in two papers.

- **Future Research**:
  - Consider additional CO₂ sources for synthetic hydrocarbon production.
  - Conduct economic and environmental analysis of other synthetic fuels and chemicals.
  - Conduct regional analysis considering proximity of CO₂ and H₂ supplies.
  - Evaluate economics of delivered H₂ vs. onsite production.
  - Evaluate economics of CO₂ capture and transportation.

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