Emerging Technologies to Support the SAF Grand Challenge 2050 Goal

Routes to achieving Net-Zero Fuels and e-fuels

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6/16/2023
Goals

• Overview and context

• Analysis for low carbon intensity fuels and efuels

• CO₂ Reduction and Upgrading for E-fuels (CO₂RUE) Consortium
In recognition of these myriad benefits, DOE, DOT, and USDA are launching a government-wide Sustainable Aviation Fuel Grand Challenge (the Grand Challenge) to reduce the cost, enhance the sustainability, and expand the production and use of Sustainable Aviation Fuel (SAF) that achieves a minimum of a 50% reduction in lifecycle greenhouse gas (GHG) compared to conventional fuel to meet a goal of supplying sufficient SAF to meet 100% of aviation fuel demand by 2050.

Through this MOU, the Parties intend to accelerate the research, development, demonstration, and deployment (RDD&D) needed for innovative solutions and technologies and the policy framework to enable an ambitious government-wide commitment to scale up the production of SAF to 35 billion gallons per year by 2050. A near-term goal of 3 billion gallons per year is established as a milestone for 2030.

1) The need to develop strategies that significantly reduce the carbon intensity of aviation fuels

2) The need to get enough renewable carbon to meet those demands
Reducing the carbon intensity of SAF pathways

While some of the approved SAF pathways hit the 50% threshold on paper, it's clear that:

- The large volume feedstocks and pathways in the US are still above that threshold and need further progress.
- Deep decarbonization (beyond 50%) will require more work.

Prussi, et al. CORSIA: The First Internationally Adopted Approach to Calculate Life-cycle GHG Emissions for Aviation Fuels
Acquiring enough renewable carbon to meet the demand

- 36B gallons of SAF = 600M tons of biomass
- ~9B gallons of marine fuel (EIA 2019) = 150M tons of biomass
- ~5B gal of diesel (~10% of today’s use) = 80M tons of biomass
- 100M tons of chemicals (~50% of today's market) = 400M tons of biomass
- ~ 500M tons of carbon removal via BECCS or BiCRS = 500M tons of biomass (assumes ~half of CDR uses biomass)
- **TOTAL = 1.8B tons of biomass**

The US has the potential to produce at least 1B tons of biomass (agricultural, forestry, waste, and algal materials) on an annual basis without adversely affecting the environment.
Enabling low CI Fuels in 2050 example: Corn ETJ

- Carbon from Corn Starch
- Starch
- Sugar

Sugar Biological Conversion → Ethanol Catalytic Upgrading

- Ethanol
- Captured CO₂
- CO₂ Derived Co-Products

- CCU
- CCS

Drying

- Gasoline
- Diesel
- Jet

Co-Products: Animal Feed & Corn Oil

Net Zero Carbon Tech Team - Us Drive (energy.gov)
Corn ETJ (with mitigation) Lifecycle assessment

1.1.0: Base (no mitigation)
- $H_2$ cost (NG SMR): $1.38 \text{ kg } H_2$
- $H_2$ base CI: 79 gCO$_2$/MJ
- Electricity: 6.8¢/kWh, 440 gCO$_2$/kWh
- NG: 69 gCO$_2$/MJ

1.1.1: **Renewable elec.** (per kWh)
- 2¢/6.8¢/10¢
- 0g CO$_2$/kWh

1.1.2: Using RNG for on-site heat
- Landfill gas ($7/$13/$19 per MMBTU)
- 11 gCO$_2$/MJ

1.1.3: **Renewable PEM H$_2$** (0g CO$_2$/kg)
- H$_2$ Cost assumptions (per kg): $1.38/$4.50/$6.35

1.1.4: **Renewable NH$_3$** on-field
- Made from renewable H$_2$
1.1.0: Base (no mitigation)
- $1.38 \text{ kg } H_2$
- $79 \text{ gCO}_2/\text{MJ}$
- Electricity: 6.8¢/kWh, 440 gCO$_2$/kWh
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- Landfill gas ($7/$13/$19 per MMBTU)
- 11 gCO$_2$/MJ

1.1.3: **Renewable PEM H$_2$ (0g CO$_2$/kg)**
- H2 Cost assumptions (per kg): $1.38/$4.50/$6.35

1.1.4: **Renewable NH$_3$ on-field**
- Made from renewable H$_2$
TEA and LCA of Corn ETJ + CCS

Takeaway: CCS cuts CI nearly in half and is lower cost (19¢/gal) than other mitigation strategies.

0 = Base  1 = RE  2 = RNG  3 = Clean H2  4 = Green NH3
CCU provides a route to increased volume of SAF (~50%) but is more expensive even with aggressive electricity price estimates AND requires significant amounts of renewable electricity and H2 to achieve attractive carbon intensities.
E-fuels

- Interchangeably called *synthetic fuels, power-to-liquids, power-to-gas or electrofuels*

- At its core, e-fuels are made by converting electricity into chemical bonds

- E-fuels provide an option for tapping into a vast renewable carbon resource

- E-fuels can have a very low carbon intensity IF they are made with renewable electricity

“Conventional biofuel”

“E-fuel”
Near term e-fuel pilot project

**Project Title:** Carbon Refining: Corn Ethanol 2.0

**Principal Investigator:** Jennifer Aurandt-Pilgrim

**Key Partners:** LanzaTech

**Proposed Total Project Cost:** $8.5M DOE funds

- Marquis will host, commission, and operate a LanzaTech skid-mounted gas fermentation pilot plant at their Hennepin, IL biorefinery

- CO₂ from fermentation off-gas will be combined with and low Cl H₂ and fed to the gas fermentation reactor

- Targets ethanol at 70% GHG reduction
Broad technology space of CO2 reduction

**H2-mediated Conversion Technologies**

\[ \text{CO}_2 + \text{H}_2 \rightarrow \text{CO} + \text{H}_2\text{O} \]
\[ \text{CO}_2 + 3\text{H}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O} \]

*Fischer-Tropsch*
*Reverse Water-gas Shift*
*Catalytic Hydrogenation to Methanol*
*Methanol to Olefins*
*Methanol to Gasoline*

↑Heat, ↑Pressure, ↑Scale, ↑TRL

**Electron-mediated Emerging Technologies**

\[ \text{CO}_2 + 2e^- + 2\text{H}^+ \rightarrow \text{CO} + \text{H}_2\text{O} \]
\[ 2\text{CO}_2 + 12e^- + 12\text{H}^+ \rightarrow \text{C}_2\text{H}_4 + 4\text{H}_2\text{O} \]

*Electrolysis*
*Non-thermal Plasma*
*Microbial Electrosynthesis*

↓Heat, ↓Pressure, ↓Scale, ↓TRL
Assessing the technology gaps that are good R&D targets

How to drive decarbonization of fuels and chemicals by 2050?

• Where is the “white space”?
• Where are the opportunities for applied R&D across low-to-moderate TRL?
• What are the economic and environmental targets that should be achieved?

• Availability of CO₂
• Identification of promising chemicals
• Strategic R&D needs
• Accelerated testing needs
• Commercialization timelines
• Technical targets
CO2-to-Fuels approach in EERE

Conventional biofuels

E-fuels

Engineered Carbon Reduction → Reduced Intermediate Conversion & Upgrading

Biomass Deconstruction, Conversion & Upgrading
Consortium R&D efforts

Identifying economic and environmental Drivers

Electrolyzer design

Reactor modeling

Metabolic engineering

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
In progress: setting near term targets for enabling e-fuels

- **Feedstocks** (siting, availability, cost)
  - Low Carbon Electricity
  - CO₂

- **Electrochemical**
  - Carbon efficiency
  - e⁻ efficiency
  - Scalability
  - Robustness

- **Fermentation**
  - T-R-Y
  - Carbon efficiency
  - Reactor design

Collaborative target setting with our Advisory Board:

Interested in participating in the Advisory Board? Contact us!
Final words

• E-fuels have solid potential for contributing to longer-term SAF goals

• There are almost as many e-fuels routes as there are biomass-derived fuel options. Some are theoretically ready for commercial scale, while many others are emerging

• E-fuels can be very low carbon intensity, however this relies heavily on access to massive amounts of dedicated renewable electricity deployment

• I welcome questions/comments!
Consortium R&D efforts

- Electricity Cost & Carbon Intensity
  - Zhou/Elgowainy (NREL/ANL)
  - TEA/LCA

- Energy Justice
  - Wang/Tao (ANL/NREL)
  - Zhou/Elgowainy (NREL/ANL)

- Market & Societal Impacts
  - Neyerlin (NREL/DOE)

- CO2
  - Formic Acid
    - Neyerlin (NREL/DOE)
  - NREL/DOE
  - Johnson (NREL/DOE)
  - Fatty Acids
    - NREL/DOE
  - Terpenes
    - Resch (NREL/DOE/DM/DTI)
    - Singer/Hahn (LBNL/LNL)
    - CO
    - H2

- SAF
  - Sitaraman (NREL/DOE)

- High Fidelity Reactor Models
  - Glusac (ANL/DOE)