US SAF Activities for Aviation Decarbonization

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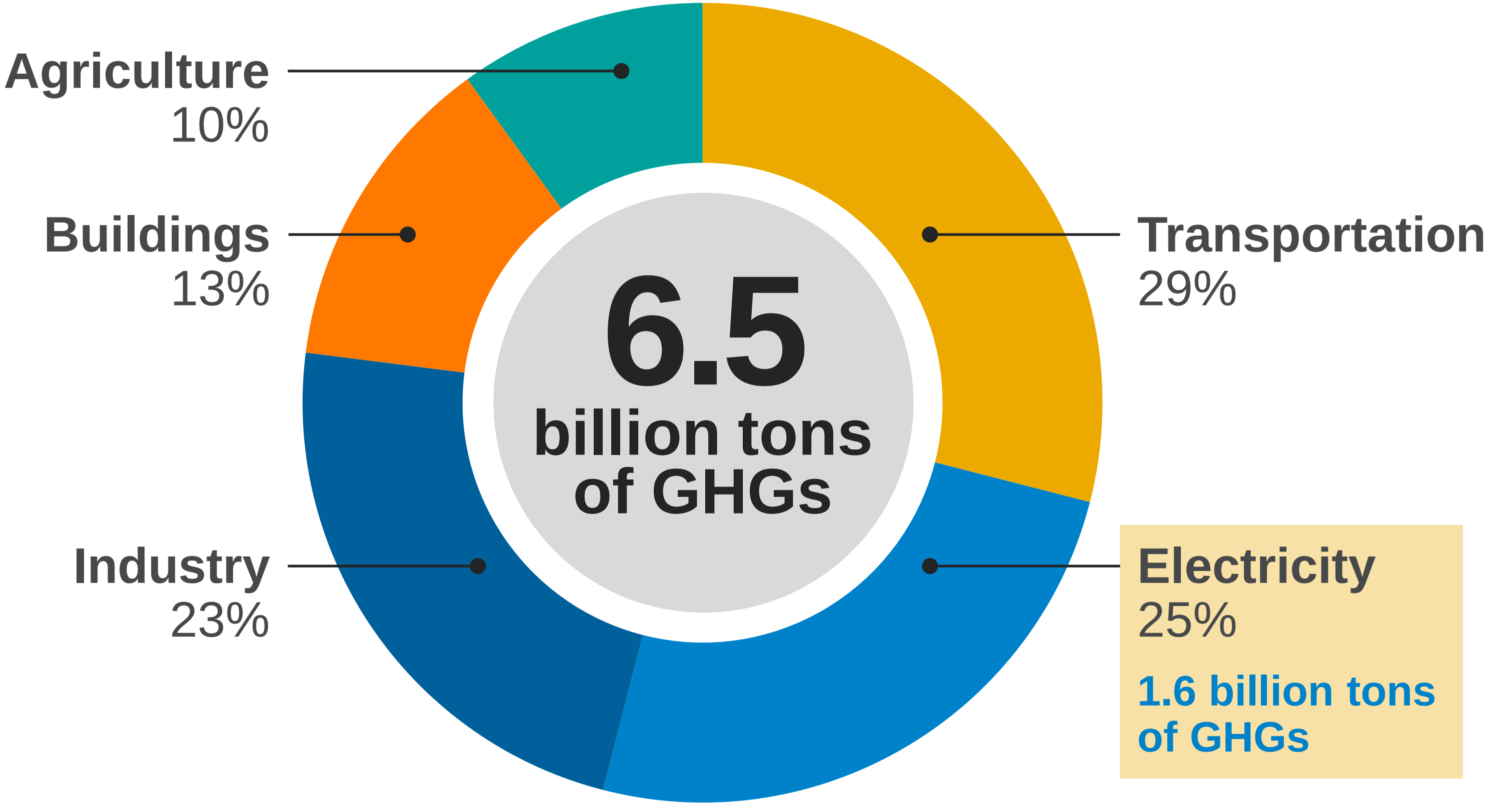
U.S. Greenhouse Gas Emissions Sources *2019*



UNITED STATES NET ZERO CARBON GOALS

2035

Electric Sector

2050

Entire Economy

Aviation sector accounts for 11% of US transportation GHGs

Share of US transportation GHG emissions; remaining 12% for US is from pipelines and offroad.

U.S. Aviation Climate Goal

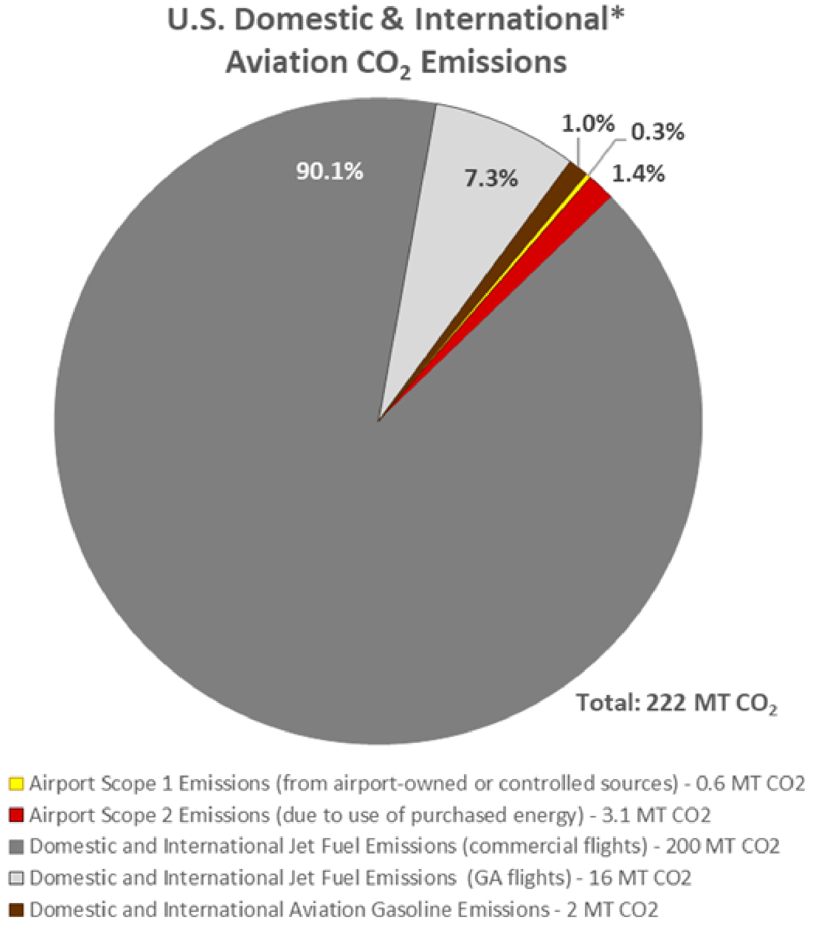
U.S. Aviation Climate Goal:

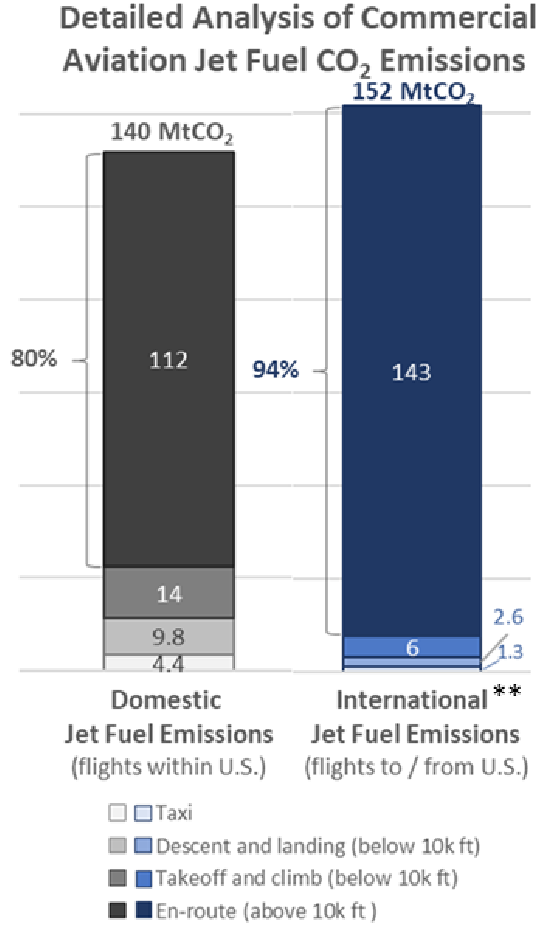
Net-Zero GHG Emissions* from U.S. Aviation Sector** by 2050

* Aviation GHG emissions include life cycle carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions. Aircraft engines produce negligible amounts of nitrous oxides and methane, so this plan has a focus on aviation combustion CO_2 emissions and well-to-tank life cycle GHG emissions (CO_2, N_2O, and CH_4). The U.S. Aviation 2050 Goal is based on emissions that are measurable and currently monitored. Research is ongoing into the climate impacts of aviation-induced cloudiness and the indirect climate impacts of aviation combustion emissions (see section 7 for details on the climate impacts of aviation non-CO_2 combustion emissions).

** This U.S. aviation goal encompasses CO_2 emissions from (1) domestic aviation (i.e., flights departing and arriving within the United States and its territories) from U.S. and foreign operators, (2) international aviation (i.e., flights between two different ICAO Member States) from U.S. operators, and (3) airports located in the United States.

Analysis of U.S. Aviation CO_2 Emissions in 2019

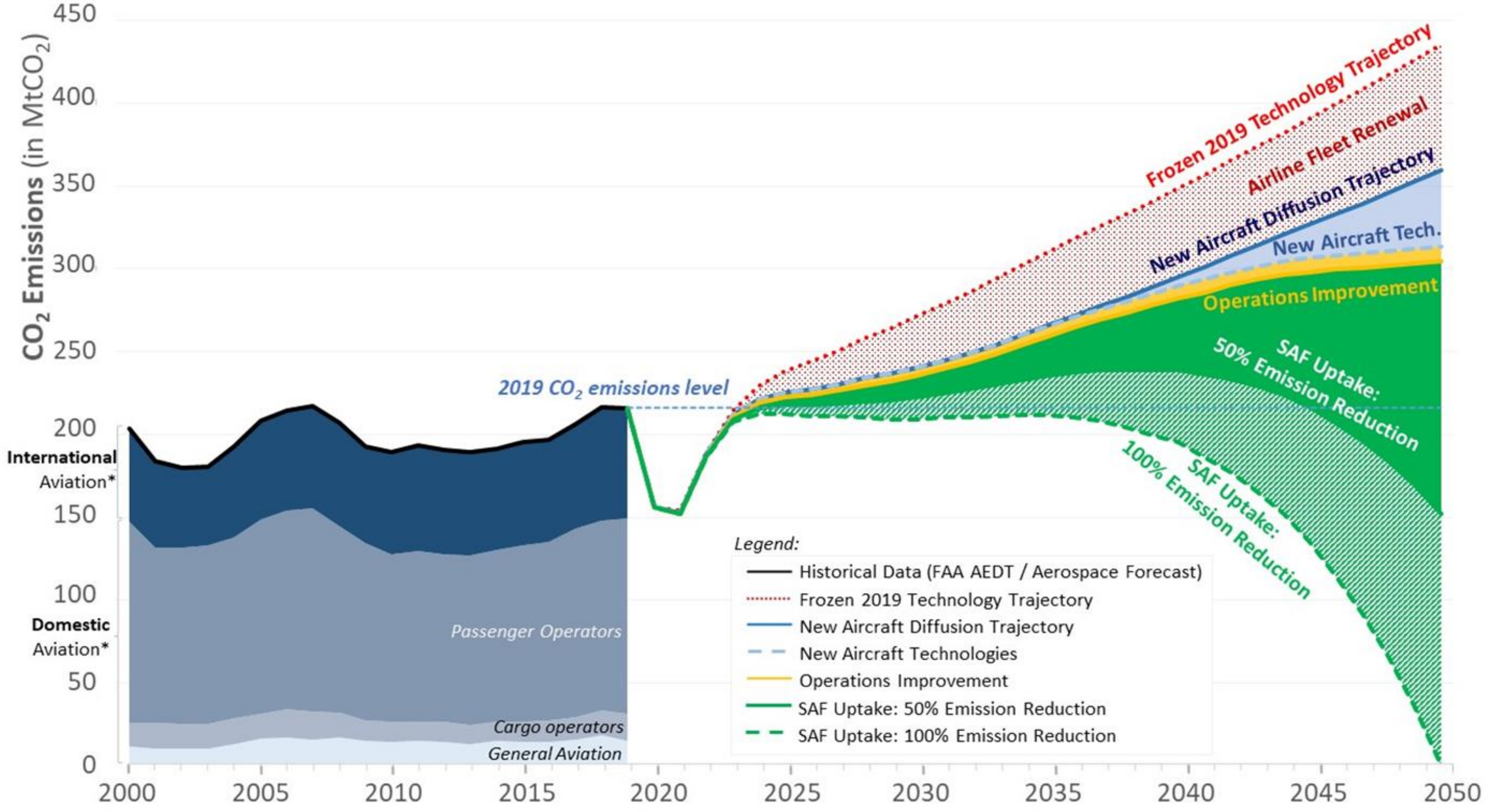




* CO_2 emissions from (1) domestic aviation (i.e., flights departing and arriving within the United States and its territories) from U.S. and foreign operators and (2) international aviation (i.e., flights between two different ICAO Member States) from U.S. operators (only). Airport scopes 1 and 2 added for this specific analysis (figure).

** International aviation to / from the United States, regardless of the operator of the flights i.e., including both U.S. and foreign operators.

Longer Term Analysis of Aviation CO_2 Emissions



* Note: Domestic aviation from U.S. and Foreign Carriers. International aviation from U.S. Carriers.

NOTE: Analysis conducted by BlueSky leveraging R&D efforts from the FAA Office of Environment & Energy (AEE) regarding CO_2 emissions contributions from aircraft technology, operational improvements, and SAF

U.S. Governmental SAF Grand Challenge

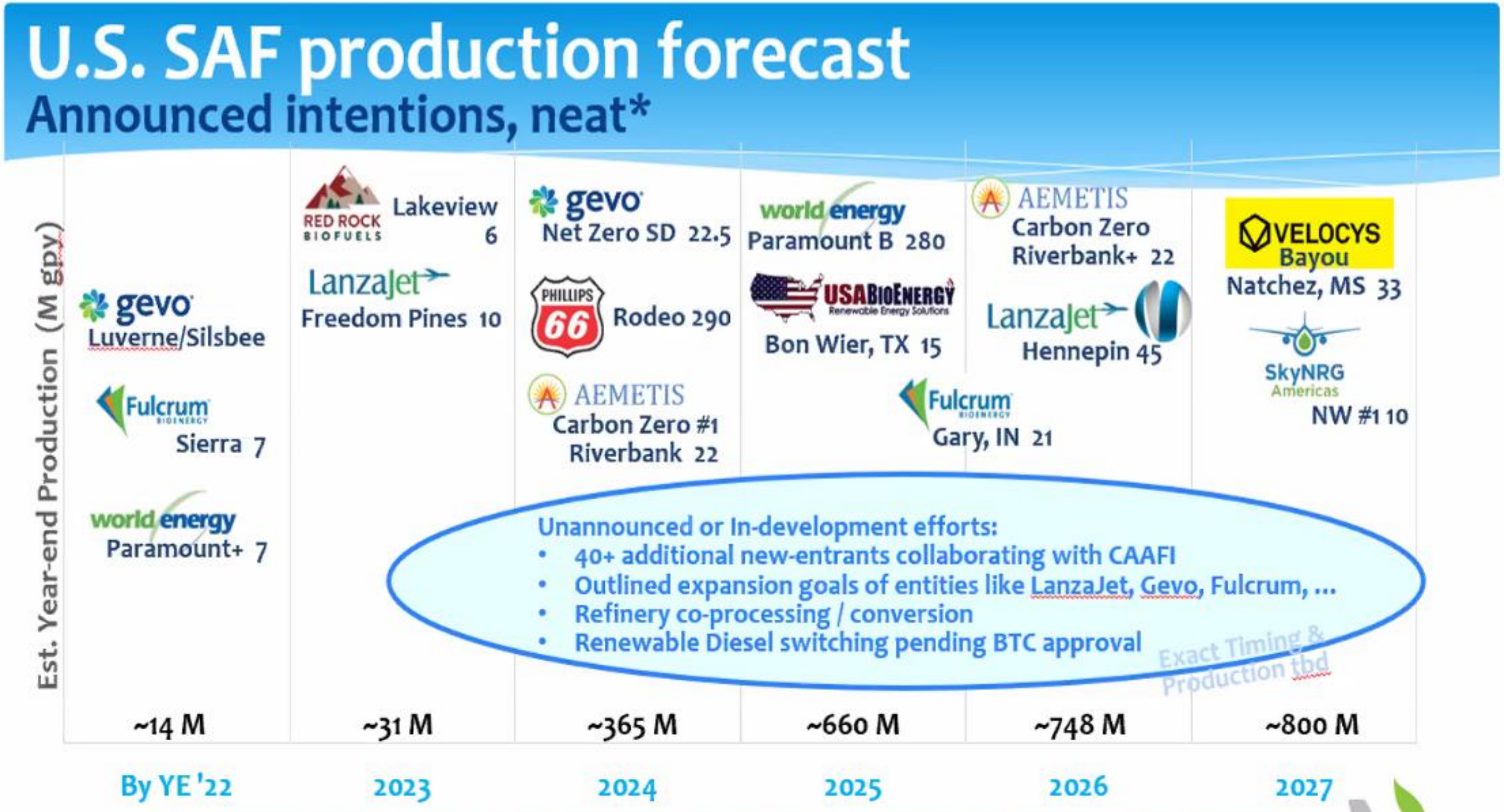
- Minimum 50% reduction in life-cycle GHG emissions

- Near term goal: 3 billion gallons in 2030 in 2030, minimum GHG reduction of 20%

- Long term goal: 35 billon gallons in 2050 (100% of US aviation fuels)

- Detailed roadmap document will be released in Mid-December 2022

State of Industry



- Not comprehensive; CAAFI estimates (based on technology used & public reports) where production slates are not specified. Does not include various small batches produced for testing technology and markets.
- Does not include fractions of substantial Renewable Diesel capacity (existing and in-development) that can be shunted to SAF based on policy support

2 March 2022

CAAFI
COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

URGENT expansion of emerging industry needed to meet:

- Government-Industry goal of 3B gal by 2030, doubling SAF production each year through 2030
- U.S. Government Sustainable Aviation Fuel Grand Challenge of 35B Gal by 2050, meeting 100% of aviation fuel demand
- Requires 400–500 refineries in the United States, more than double today's current fuel ethanol industry

SAF and other incentives in 2022 Inflation Reduction Act

- Section 13203: Sustainable Aviation Fuel Credit
  - Incentive for SAF (40B tax credit)
  - Incentive amount is based on LCA GHG results
  - LCA is based on CORSIA or RFS
  - Applies to SAF sold or used after December 31, 2022

SAF Provisions of the 2022 Inflation Reduction Act (IRA)

The Inflation Reduction Act of 2022, signed into law by President Biden on August 16, includes a two-year Tax Credit for those who blend SAF; a subsequent three-year Tax Credit for those who produce SAF; and a grant program of $290 million over four years to carry out projects that produce, transport, blend or store SAF or develop, demonstrate, or apply low-emission aviation technologies. To be eligible, the SAF must achieve, in general, at least a 50% improvement in greenhouse gas (GHG) emissions performance on a life-cycle basis as compared with conventional jet fuel.* The tax credit – which starts at $1.25/gallon of neat SAF – increases with every percentage point of improvement in lifecycle emissions performance up to $1.75/gallon.

- Section 13704: Clean Fuel Production Credit
  - Incentive for clean transportation fuels, including SAF (45Z tax credit)
  - Incentive amount is based on LCA GHG results
  - LCA is based on GREET (or as above for SAF)
  - Applies to fuels sold or used after December 31, 2024

- Section 13204: Clean Hydrogen
  - Incentive for clean hydrogen (45V tax credit)
  - Incentive amount is based on LCA GHG results
  - LCA is based on GREET
  - Need regulation/guidance by Aug. 16, 2023 (one year from enactment)

FAA - IRA Section 40007 Grant Opportunities

- **Fueling Aviation's Sustainable Transition through Sustainable Aviation Fuels (FAST-SAF) and Low Emissions Aviation Technology (FAST-Tech)**
  - To advance sustainable aviation fuels (SAF) and low emissions aviation technologies to reduce emissions from aviation and aid in addressing the climate crisis
    - $297 million

- **FAST-SAF Public Meeting**
  - Share information about the plans
  - Solicit interest from the public, and provide an opportunity for feedback
  - A venue for potential grant applicants to initiate discussions on teaming opportunities.
    - December 14, 2022, from 9am to 5pm Eastern
    - Department of Transportation Headquarters atrium
    - 1200 New Jersey Ave SE, Washington, D.C. 20590

SAF demand is also located/connected to high-potential e-kerosene

Figure 2. Major U.S. refined products pipelines carrying jet fuels (Airlines for America 2018) and the 10 largest airports by traffic volume

GREET LCA covers many groups of energy systems

Petroleum Sector:
- Conventional oil
- Shale oil
- Oil Sands

→

Gasoline
Diesel
Jet fuel
Liquefied petroleum gas
Naphtha
Residual oil

Natural Gas Sector:
- Conventional NG
- Shale gas

→

- NG end use in electric, industrial, and residential sectors
- Transportation sector: CNG, LNG
- Alternative fuels: LPG, methanol, DME, FT diesel, FT jet

Hydrogen Economy:
- Gaseous hydrogen
- Liquid hydrogen
- With CCS, if applicable

←

Natural gas
Biomass
Coal
Petroleum coke
Coke oven gas
Electrolysis with electricity
Nuclear energy

Electric Systems:
- Electricity generation at US plant level
- Aggregate to national, NERC, and state level
- With CCS, if applicable

←

Natural gas
Coal
Residual oil
Biomass
Nuclear
Hydro
Wind
Solar

Renewable Energy/Fuels:
- Ethanol
- Biodiesel
- Renewable diesel
- Renewable gasoline
- Renewable jet fuel
- Renewable natural gas

←

1st Gen Feedstocks:
- Corn
- Sorghum
- Soybeans
- Rapeseeds
- Sugarcane
- Palm

2nd Gen Feedstocks:
- Dedi. energy crops
- Crop residues
- Forest residues
- MSW
- Animal wastes

Algae

Renewable Hydrogen via electrolysis:
- Wind
- Solar
- Nuclear

→

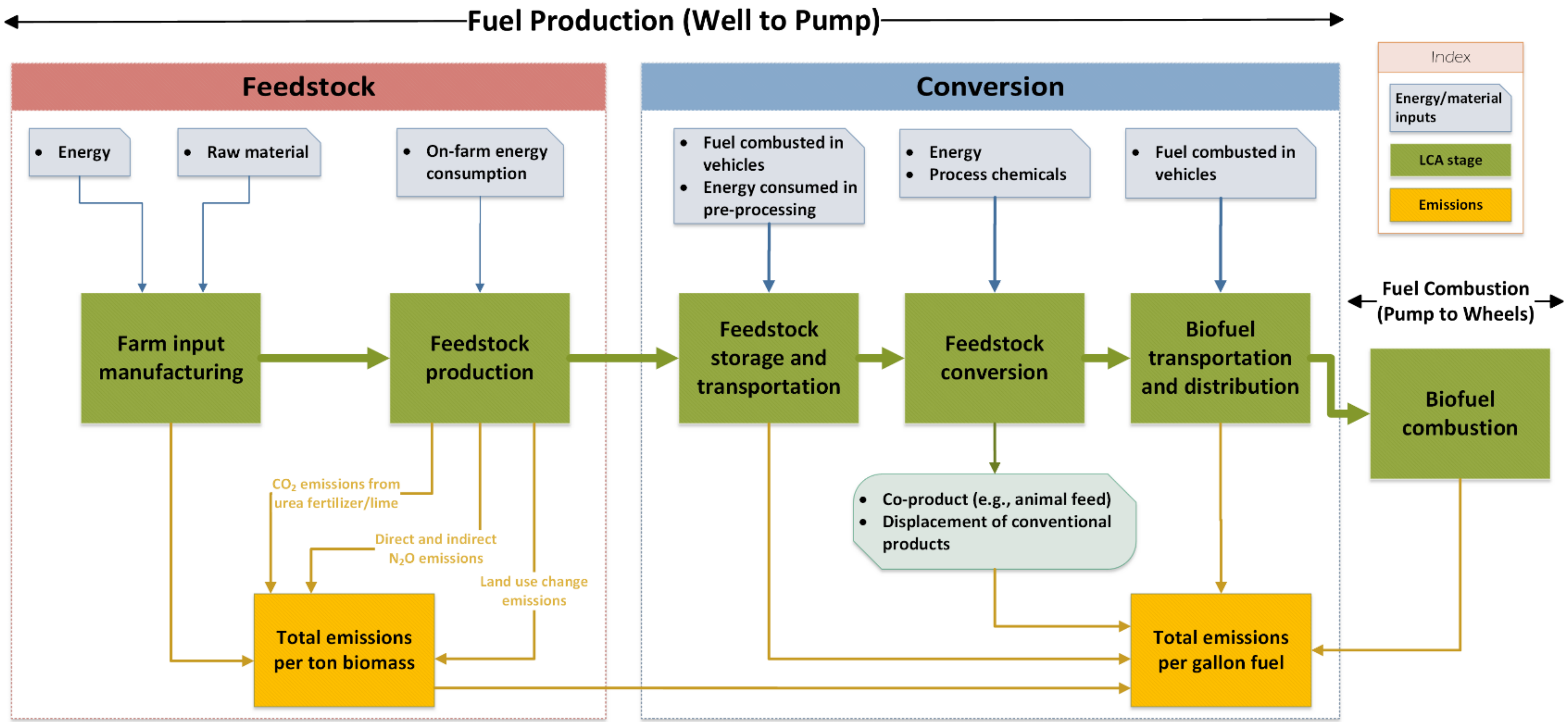
Electro-Fuels
- Gasoline
- Diesel
- Jet fuel
- Methanol

←

CO_2 Sources
- Ethanol plants
- NG SMR plants
- Cement plants
- Etc.

Besides energy systems, GREET also includes plastics and products.

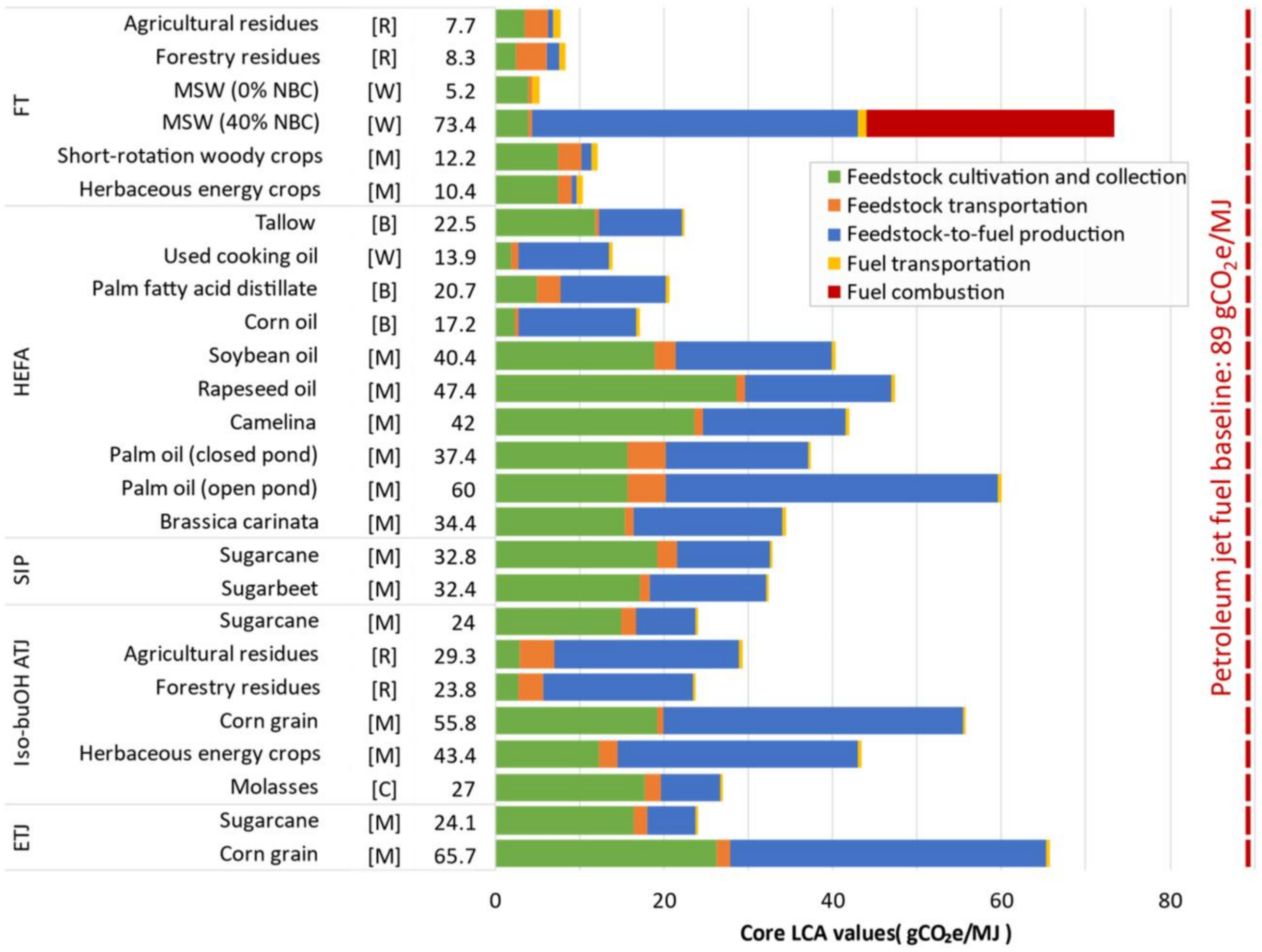
GREET includes details of both biofuel feedstock and conversion



- EU REDII, ICAO CORSIA, RenovaBio, and Canadian Clean Fuel Standard allow feedstock certification

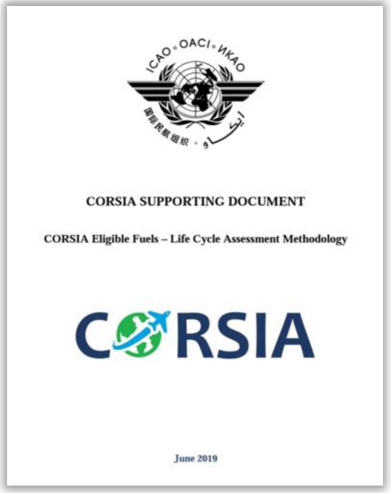
- All biofuel regulations/programs allow biofuel facility certification

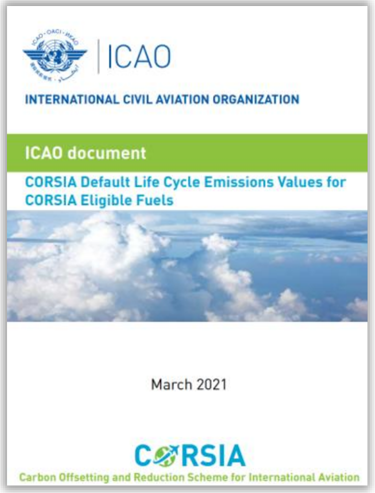
Argonne generated LCA values of SAF pathways using GREET



(Prussi et al. 2021)

- Argonne has been a member of ICAO's Fuels Task Group (FTG) since inception
- Argonne's GREET was used to calculate the core LCA values of SAFs for CORSIA
- Default LCA values available in CORSIA documents

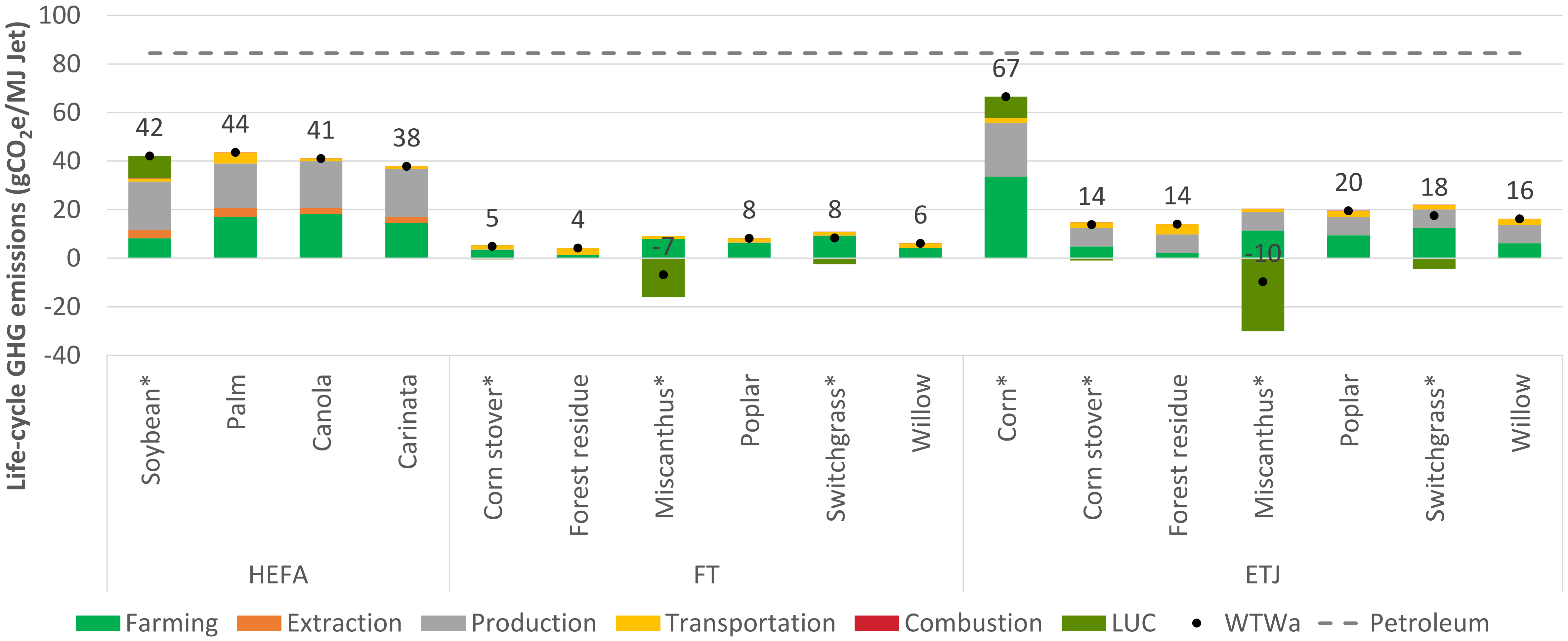




FT: Fischer-Tropsch | HEFA: hydroprocessed esters and fatty acids
SIP: Synthesized iso-paraffins | Iso-BuOH: Iso-butanol
ATJ: Alcohol-to-jet | ETJ: Ethanol-to-jet | NBC: non-biomass carbon

SAF LCA results presents significant emission reduction potential

Life-cycle GHG emission results of major SAF pathways using the GREET Aviation Module



* LUC included

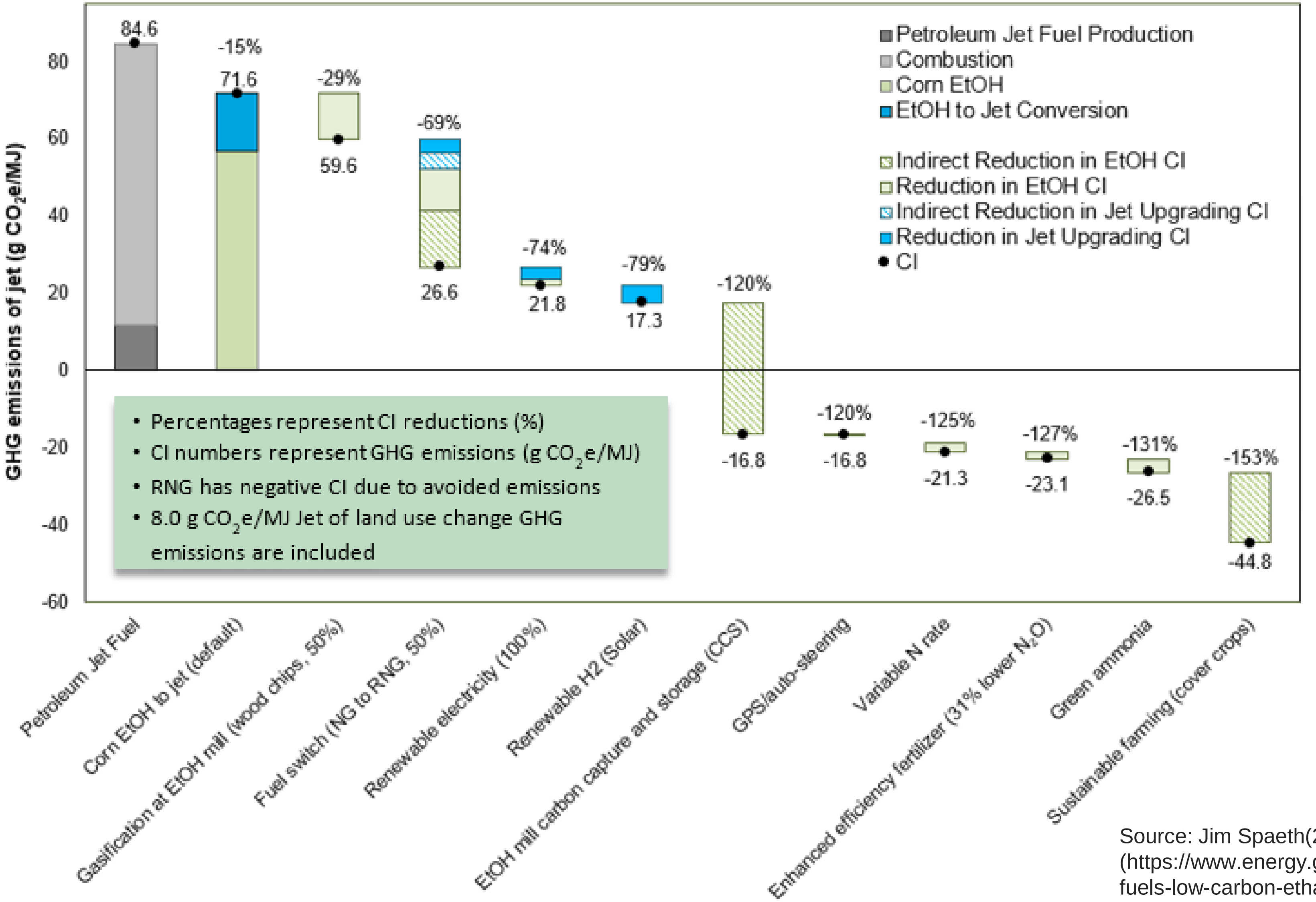
Key findings from LCA results of major pathways

- SAFs present **GHG emission reduction benefits** compared to petroleum jet fuels.
- Using **waste feedstocks** (agricultural residues, forest residues, tallow, used cooking oil, etc.) leads to less carbon intensities (CIs) compared to using crops because of low upstream emissions.
- **FT** pathways have relatively lower CI values compared to other conversion pathways because they are designed to be self-sustainable (i.e., lower fossil inputs).
- **HEFA** pathways have higher CI values than FT fuels, due to their higher upstream emissions for feedstock production (for crops) and higher hydrogen inputs.
- For **ETJ** pathways, heat integration between ethanol and jet fuel production facilities can provide significant emission reduction benefits.
- The source of carbon in MSW (**fossil vs. biogenic**) impacts the CI values.
- For all crops, **induced land use change (ILUC) impact** should be added to the CIs
- Using waste feedstocks for SAF production may lead to **avoiding business-as-usual** waste management and associated emissions.
- Feedstock and fuel transportation impacts are generally small.
- **GREET and ICAO** use different datasets for some pathways and different allocation methods, some pathways have quite different LCA results.

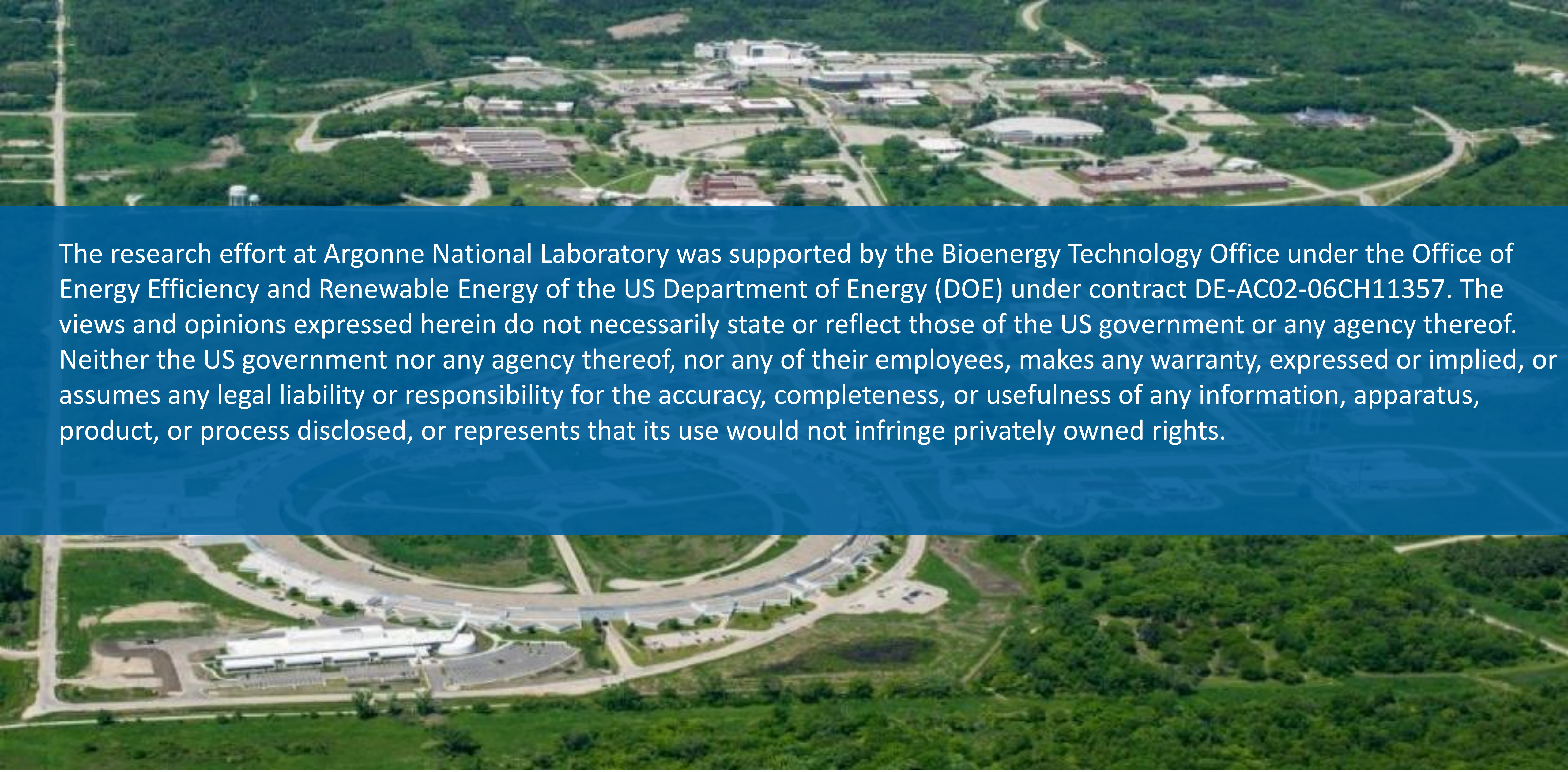
Lower life-cycle GHG emissions in SAF production pathways

- Use **waste feedstocks** rather than crops to reduce emissions associated with feedstock production and ILUC impact
- **Reduce fossil energy** inputs through the use of renewable hydrogen, renewable electricity, renewable natural gas, and biomass.
- Consider **heat integration**, if possible, which reduces fossil natural gas inputs.
- Avoid using fossil feedstocks (e.g., fossil portion in MSW), which may incur fossil carbon emissions from fuel combustion unlike biogenic SAFs.
- Avoided business-as-usual emissions from conventional waste management practices can provide emission reduction benefits if the current waste management practices have high GHG emissions (in particular CH_4).

Conversion and feedstock potentials for carbon neutrality and negativity of corn ethanol and ethanol-to-jet



Source: Jim Spaeth(2021) (https://www.energy.gov/eere/bioenergy/articles/sustainable-aviation-fuels-low-carbon-ethanol-production)



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