Life Cycle Analysis of Sustainable Aviation Fuels with R&D GREET Model

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Argonne's R&D GREET is to inform the life cycle analysis of technical community. Not all pathways and data in R&D GREET are appropriate for use in circumstances where a high level of quantitative certainty or precision is required. GREET is referenced in numerous independent state and federal compliance and incentive programs (including solicitations, rulemakings, and tax incentives), but it is important to note that R&D GREET is not the version used by any of these specific programs. Argonne does not warrant that use of R&D GREET is consistent with the requirements of any particular regulatory or incentive program.

U.S. DEPARTMENT OF ENERGY

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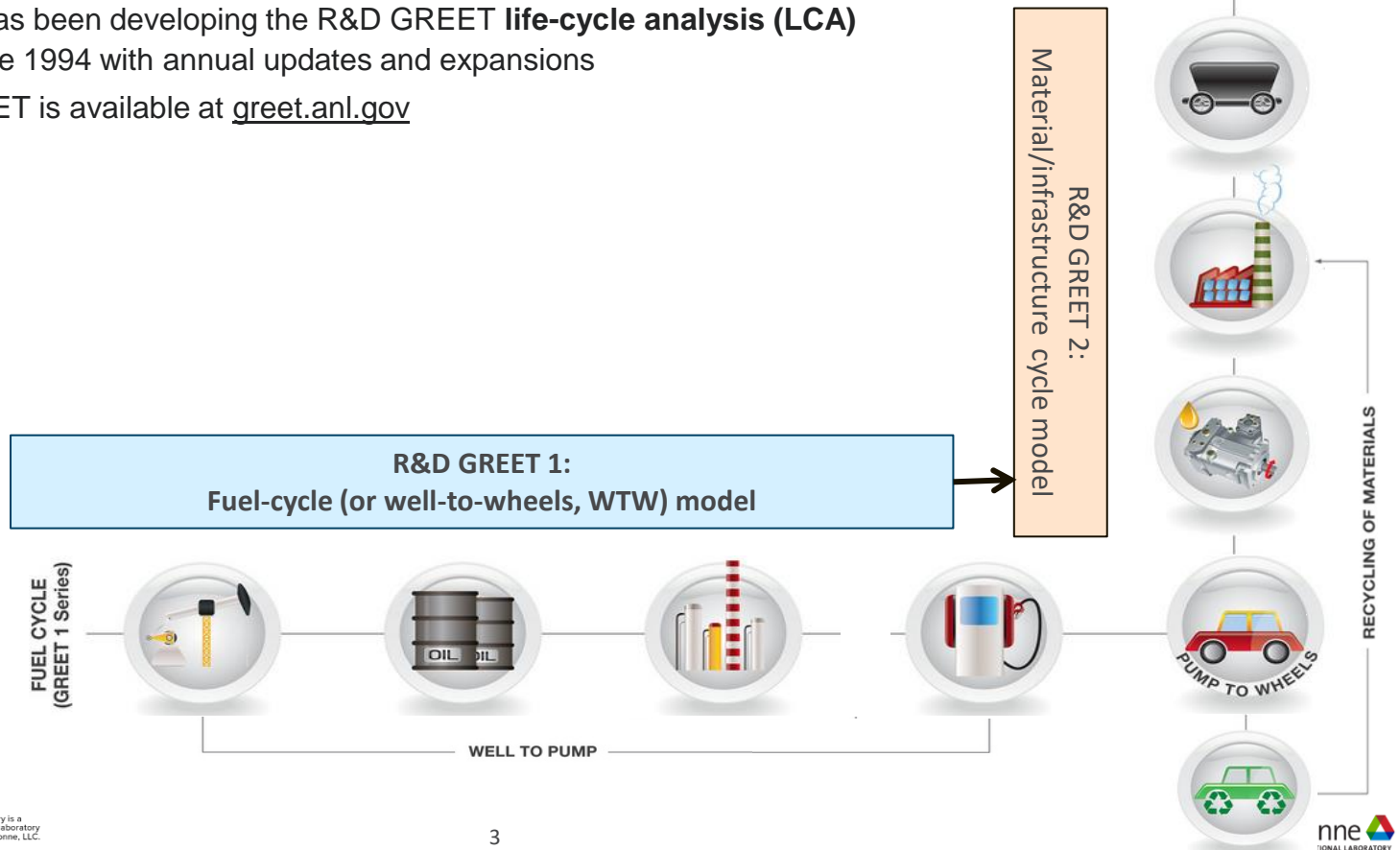1946–2021

The R&D GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model framework

(Vehicle manufacturing cycle as the example)

- Argonne has been developing the R&D GREET **life-cycle analysis (LCA)** model since 1994 with annual updates and expansions
- R&D GREET is available at greet.anl.gov

VEHICLE CYCLE (GREET 2 Series)

R&D GREET 2: Material/infrastructure cycle model

R&D GREET 1: Fuel-cycle (or well-to-wheels, WTW) model

FUEL CYCLE (GREET 1 Series)

RECYCLING OF MATERIALS

PUMP TO WHEELS

WELL TO PUMP

>65,000 Registered R&D GREET Users Globally

Area chart legend:
- Users of GREET .Net only
- Users of both GREET Excel and .Net
- Users of GREET Excel only

Chart values: 31.5% (GREET .Net only), 13.7% (both), 54.8% (GREET Excel only)

Y-axis: 0 to 70,000 (in 5,000 increments)
X-axis: 1/1/2002 through 1/28/2025

Regional pie chart:
- North America, 61.7%
- Europe, 16.6%
- Asia, 15.5%
- Other, 6.3%

Other breakdown:
- Oceania, 1.6%
- Sub-Saharan Africa, 0.6%
- Middle East and North Africa, 1.7%
- South America, 2.3%
- Central America & Caribbean, 0.1%

Sector pie chart:
- Academia, Education 48%
- Industry 22%
- Private Consulting 12%
- Research Institution 8%
- Government Agency 6%
- Non-profit Organization 4%

Logos: Oak Ridge National Laboratory, Cummins, USDA, United States Environmental Protection Agency, International Energy Agency (iea), Boeing, ICAO, National Energy Technology Laboratory (NETL), United States Department of Transportation, Ford, MIT (Massachusetts Institute of Technology), RFA, Chevron, GM, UC Davis University of California, California Environmental Protection Agency Air Resources Board, BMW, UC Davis University of California, FAA, University of Michigan, Shell, Volvo, NASA, growth energy, University of California Berkeley (Cal), Chrysler, NREL, aramco, bp, ConocoPhillips, Tesla, PetroChina, Argonne National Laboratory 75 1946–2021

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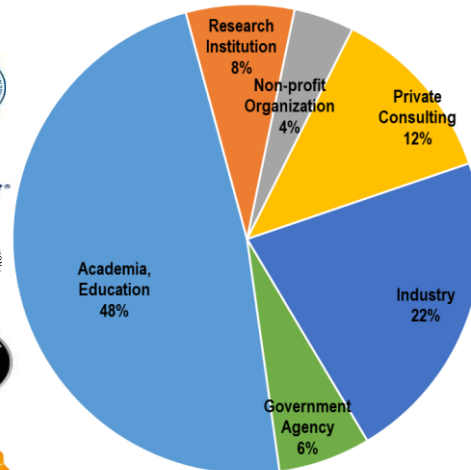
Argonne GREET website has R&D GREET, technical reports, journal articles, and technical memos.

ANL/ESIA-24/20

Summary of Expansions and Updates in R&D GREET® 2024

Prepared by
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Systems Assessment Center
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Argonne National Laboratory

January 2025

Argonne's R&D REET Model
https://greet.anl.gov

Energy Systems and Infrastructure Analysis

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RESEARCH   **CAPABILITIES**   **PUBLICATIONS**   **NEWS**

R&D GREET®

Publications

Databases

R&D GREET Model Platforms

R&D GREET .Net

R&D GREET Excel

Fuel-Cycle Model

Vehicle-Cycle Model

GREET Tools

R&D GREET Building Module

R&D GREET Marine Module

R&D GREET Rail Module

R&D GREET Battery Module

ICAO-GREET Model

GREET+ Model

FD-CIC Tool

WTW Calculator

AFLEET Tool

This is Argonne National Laboratory's R&D version of GREET.
For GREET versions used for determining tax credits, please click here.
A brief introduction to R&D GREET can be found here.

R&D GREET® Model
The **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**echnologies Model

GREET News
R&D GREET 2024 Release   January 10, 2025
The Argonne National Laboratory's Systems Assessment Center is pleased to announce the 2024 release of the suite of R&D GREET Models. Please read Summary of Expansions and Updates in R&D GREET® 2024 (451KB pdf) for more details on updates in this version.

DISCLAIMER
R&D GREET 2024 is being released, consistent with Argonne National Laboratory's routine annual R&D GREET update process. Consistent with annual updates since 1995, R&D GREET (also historically called "ANL GREET") includes representation of new fuel pathways and updates to underlying assumptions. Pathways represented in the tool include two major categories: A) those that have been rigorously evaluated and have high certainty; and B) those that are preliminary, which could include pathways that have not recently been evaluated; those where there is still a gap in the science or data, and/or those that are currently under internal or external peer review. Argonne's annual releases of R&D GREET are comprehensive in order to inform the life cycle analysis technical community and elicit stakeholder feedback. These annual releases are meant to share the early-stage perspectives in life-cycle analysis, particularly in preliminary form, so as to gather feedback from the academic and technical expert community and determine where additional research, analysis and data are needed. Not all pathways and data in R&D GREET are appropriate for use in circumstances where a high level of quantitative certainty or precision is required. Inclusion of a pathway or module in R&D GREET does not necessarily represent U.S. Government concurrence for any specific use, but instead is intended to gather technical feedback and advance the science of life-cycle analysis.
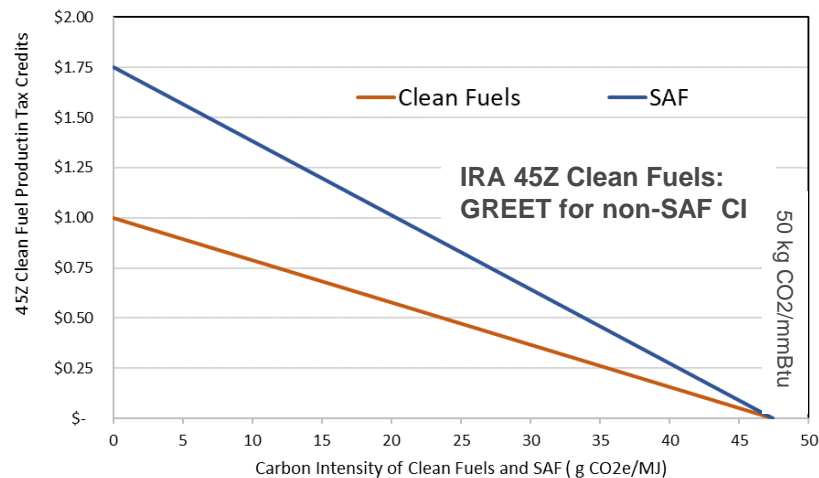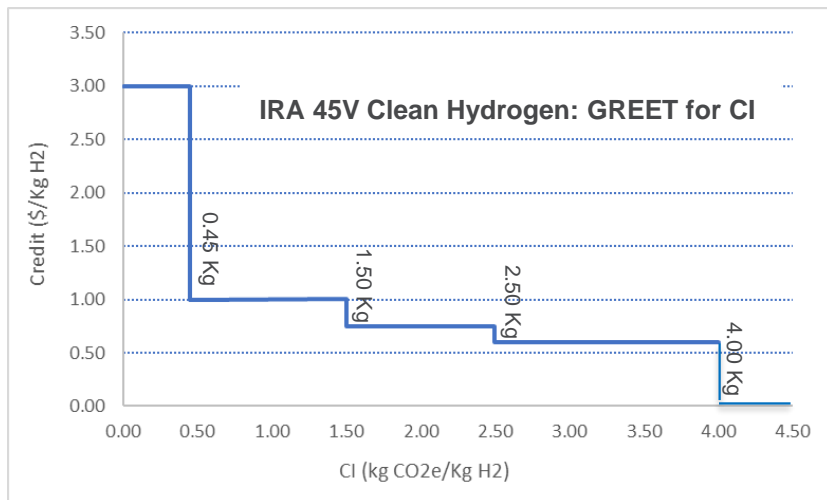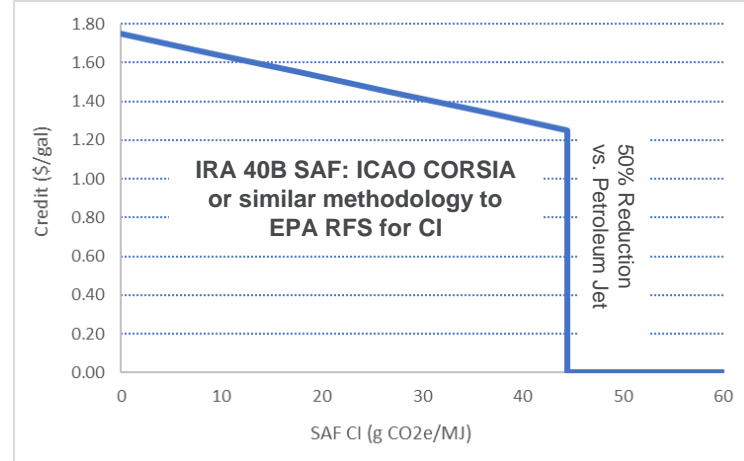
GREET informs policies and regulations

- **California Low-Carbon Fuel Standard** uses CA-GREET, an adaptation of Argonne GREET model

- **Oregon Clean Fuels Program** uses an adaptation of Argonne's GREET model

- **State of Washington Clean Fuel Regulation** relies on CA-GREET

- **State of New Mexico Clean Transportation Fuel Program** relies on Argonne's GREET

- **U.S. EPA** uses GREET with other sources for **Renewable Fuels Standard** pathway evaluations

- **National Highway Traffic Safety Administration** for fuel economy regulation

- **Federal Aviation Administration** and **International Civil Aviation Organization** using GREET to evaluate aviation fuel pathways

- **Canadian Clean Fuel Regulation** for Environment and Climate Change Canada fuel pathways

- LCA results for use in different provisions of the 2021 **Bipartisan Infrastructure Law** and the 2022 **Inflation Reduction Act**

SAF, clean fuel, and clean hydrogen incentives under the Inflation Reduction Act (IRA)

IRA 40B SAF: ICAO CORSIA or similar methodology to EPA RFS for CI

IRA 45V Clean Hydrogen: GREET for CI

IRA 45Z Clean Fuels: GREET for non-SAF CI

DOE Policy GREET Website

GREET

The U.S. Department of Energy's (DOE's) Argonne National Laboratory began developing the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET®) life cycle assessment suite of models in 1994, with the first version released in 1995. Life cycle assessment is a framework for assessing the environmental impacts associated with all stages of the supply chain of a technology or product.

The GREET model was developed to evaluate energy and environmental performance of technologies to assess research, development, and deployment (RD&D) progress, inform RD&D directions, and inform performance goals set by governments, corporations, and other stakeholders. Its development and applications have been an integral part of DOE's RD&D efforts to pursue energy and material technologies for energy efficiency, affordability, and environmental sustainability.

GREET is a tool that assesses a range of life cycle energy, emissions, and environmental impact challenges and that can be used to guide decision making, R&D, and regulations related to transportation and the energy sector.

Access specific GREET versions below:

R&D GREET   40BSAF-GREET   45VH2-GREET   45ZCF-GREET   CA-GREET4.0   ICAO-GREET

The Argonne National Laboratory R&D GREET Model is used to evaluate energy use and emissions output of transportation and energy sector technologies to assess research and development progress and inform RD&D direction.

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40BSAF-GREET key features

Include 7 SAF pathways

- U.S. corn ethanol to jet
- U.S. soybean HEFA to jet
- U.S./Canadian canola HEFA to jet
- Brazilian sugarcane ethanol to jet
- Used cooking oil HEFA to jet
- Tallow HEFA to jet
- Distillers corn oil HEFA to jet

Allow variations in key life-cycle stages to lower SAF CIs

- Farming: U.S. corn and soybean only through Climate-Smart Agriculture by USDA
  - 10 g/MJ CI credits for corn
  - 5 g/MJ for soybean
- Ethanol plants:
  - RNG
  - Clean hydrogen
  - Clean electricity
  - CCS
- Ethanol-to-jet plants:
  - RNG
  - Clean hydrogen
  - Clean electricity
- HEFA plants:
  - RNG
  - Clean hydrogen
  - Clean electricity

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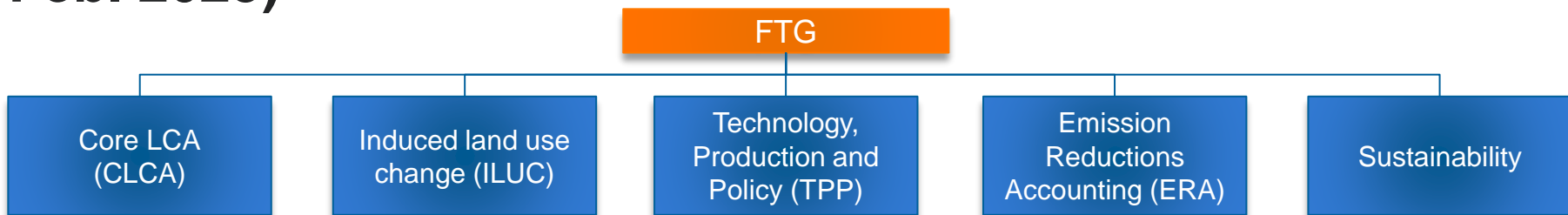# R&D GREET 2023 Rev1 serves as the calculation engine for 40BSAF-GREET

Table 1. Sample LCA results for the seven SAF pathways, including D-LCA results based on the default inputs in R&D GREET 2023 Rev1[a]

	Corn ATJ-E	Soybean HEFA	Canola HEFA	Sugarcane ATJ-E	UCO HEFA	Tallow HEFA	Distillers Corn Oil HEFA
Total LCA Results	**72.1**	**39.8**	**56.0**	**60.2**	**17.0**	**17.6**	**12.2**
Direct LCA	**61.0**	**23.5**	**32.3**	**54.3[b]**	**17.0**	**17.6**	**12.2**
I-effects	**11.1**	**16.2**	**23.7**	**5.9**			
ILUC	9.0	12.2	18.1	10.6			
Crop production	3.8	3.5	5.9	-3.0			
Livestock	-1.4	1.4	0.1	-1.6			
Rice methane	-0.3	-0.8	-0.3	-0.1			

[a]   Results in g of CO_2- equivalent [CO_2e] CO_2, CH_4, and N_2O per MJ of SAF; lower-heating value based.

[b]   The value here does not include potential GHG credit from exported electricity of sugarcane ethanol plants. The amount of exported electricity can vary significantly among sugarcane ethanol plants.

Fuels Task Group (FTG) of ICAO (Working Group 5 since Feb. 2025)

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                                    FTG
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| Core LCA (CLCA) | Induced land use change (ILUC) | Technology, Production and Policy (TPP) | Emission Reductions Accounting (ERA) | Sustainability |

Subgroups	Key Contributors	Major Objectives
CLCA	**Argonne**, MIT, JRC, U Hasselt	Develop default core LCA values for SAFs and Guidance Document for LCA data submission
ILUC	Purdue, IIASA	Quantify the induced land use change and associated emissions due to global aviation biofuels production
TPP	WSU, U Hasselt	Develop guidance for States considering introducing policy support to advance deployment of SAFs
ERA	FAA, Transport Canada	Identify emission reductions not captured in LCA. Review potential double-counting and double-claiming issues
Sustainability	The DOT Volpe Center, IATA, EDF	Develop recommendations on sustainability criteria (environmental, social and economic) for SAFs

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Argonne generated LCA values of SAF pathways using a R&D GREET version

(Prussi et al. 2021)
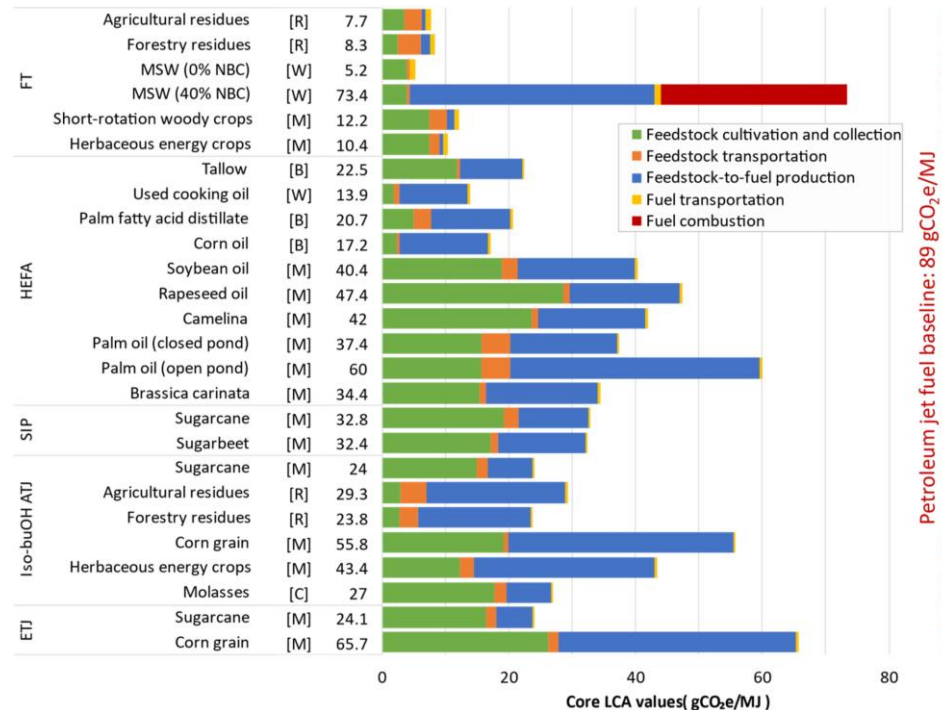
- Argonne has been a member of ICAO's Fuels Task Group (FTG) since inception

- 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

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Visit https://greet.es.anl.gov/

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