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Argonne National Laboratory

U.S. Department of Energy

Accelerating science and technology for U.S. prosperity and security.

Multidisciplinary science and engineering research center, where talented researchers work together to answer the biggest questions facing humanity.

Operated by the University of Chicago

Over 2,000 research staff & post-docs



Systems Assessment Center

Analyzing the benefits and challenges of technologies to make the U.S. more sustainable, secure, and resilient.

- Assess technologies and programs against sustainability goals
 - Focus on greenhouse gas, criteria pollutants, and resource use.
 - Identifying opportunities for improvement.
- Diverse group of ~65 engineers, economists, analysts, modelers, and planners.



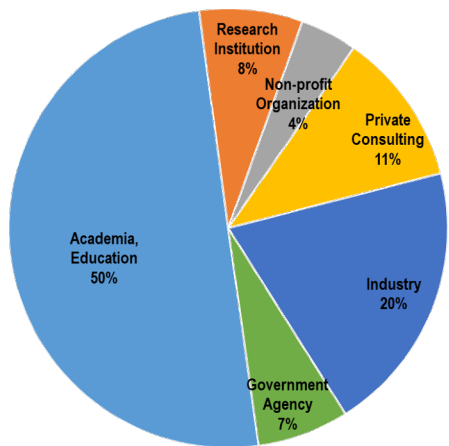
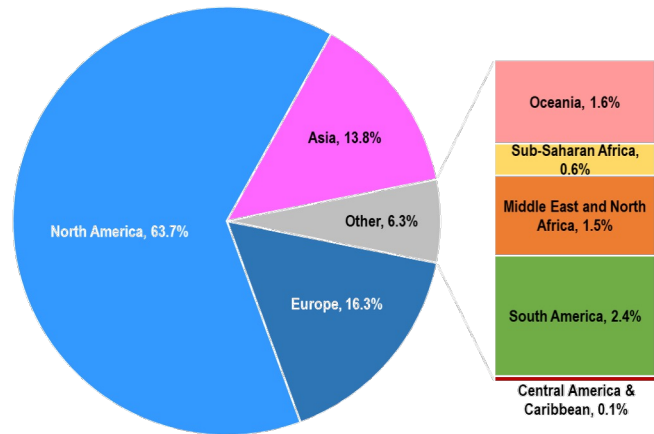
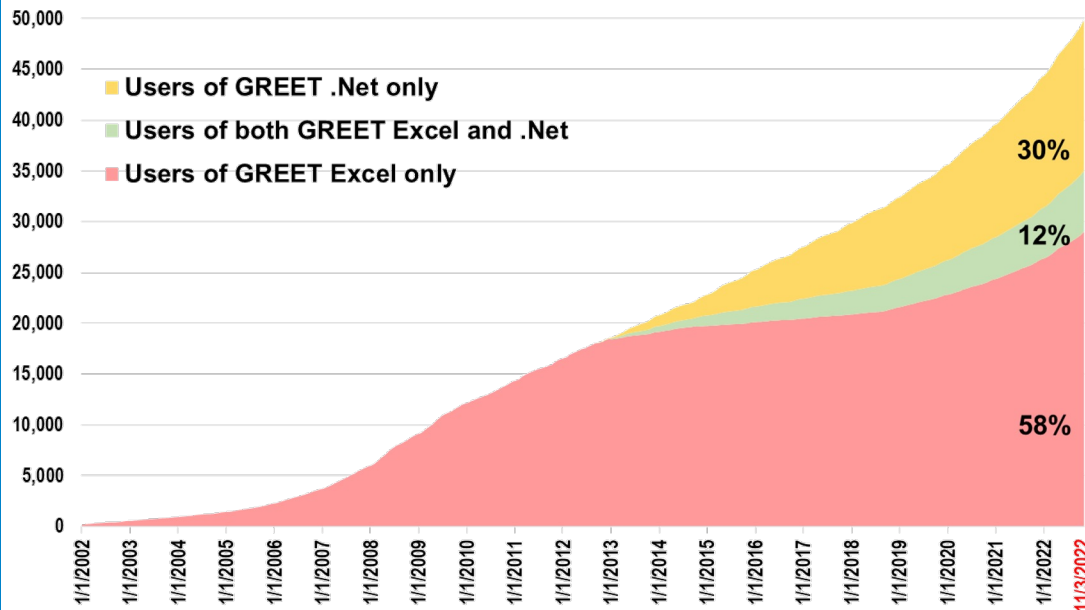
GREET Model

Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies

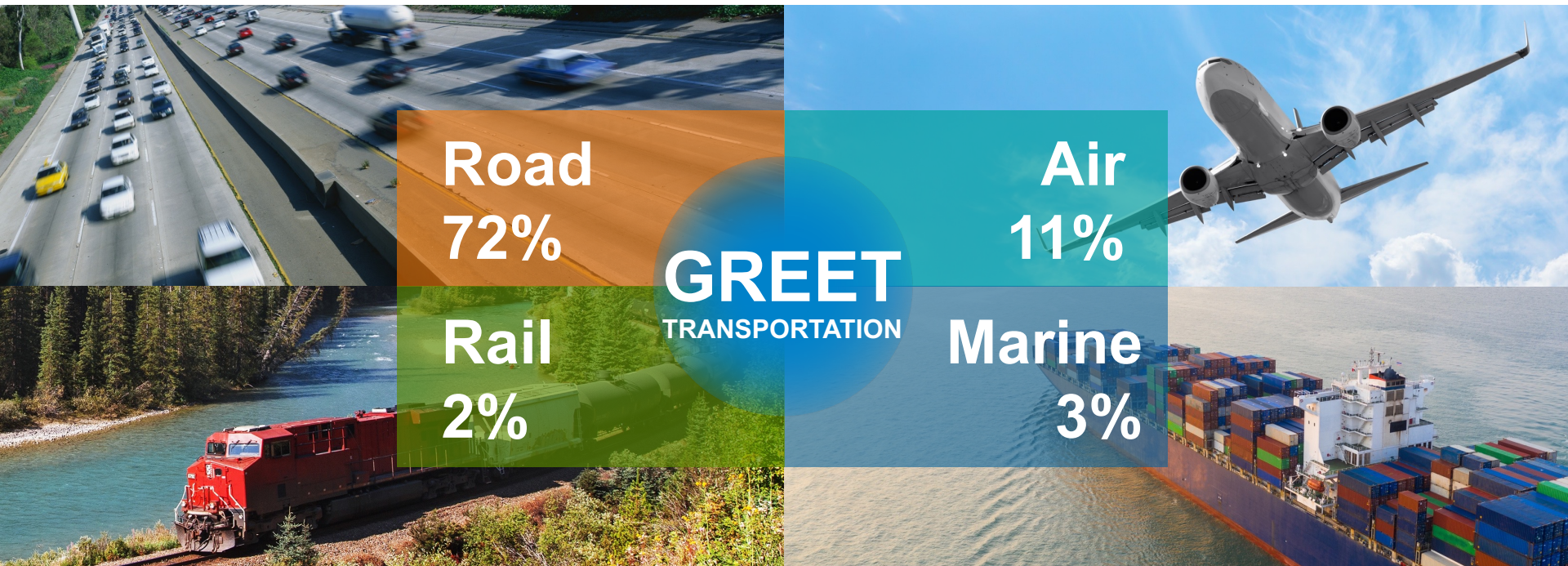
- **Consistent tracking of the life cycle performance of energy and products**
 - Used to inform and guide DOE research
- Argonne has been developing GREET since 1995 with **annual updates and expansions.**
- **Long-term support from U.S. Dept. of Energy**
 - Vehicle Technologies Office (VTO)
 - Hydrogen Fuel-Cell Technology Office (FCTO)
 - Bioenergy Technology Office (BETO)
- **Expanded from transportation-focus to include a wide range of technologies**
 - Fuels, Vehicles, Chemicals, Plastics, Agriculture, Metals, Concrete, Buildings, Batteries, Electricity Infrastructure



There are ~50,000 registered GREET users globally



GREET covers all transportation subsectors



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

GREET covers many groups of energy systems

Photo credit: Shutterstock.com



Waste-to-Energy and Waste-to-Product Studies

Landfill Gas

Argonne NATIONAL LABORATORY

ANL/ESD10-13

Well-to-Wheels Analysis of Landfill Gas-Based Renewable Natural Gas Pathways and Their Addition to the GREET Model

Energy Systems Division

Animal Waste

Argonne NATIONAL LABORATORY

ANL/ESD14

Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model

Energy Systems Division

Wastewater Sludge

Argonne NATIONAL LABORATORY

ANL/ESD16-19

Lifecycle Analysis of Renewable Natural Gas and Hydrocarbon Fuels from Wastewater Treatment Plants' Sludge

Energy Systems Division

MSW

Argonne NATIONAL LABORATORY

ANL/ESD16-20

Well-to-Wheels Analysis of Compressed Natural Gas and Ethanol from Municipal Solid Waste

Energy Systems Division

Journal of Cleaner Production

Volume 102, 1–12 (2016)

Life cycle analysis of waste-to-energy pathways

Uisang Lee, Pabula Thathana Bernades and Michael Wang

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Waste is generated every day whereas people pattern any activities in the United States since 201 million metric tons (MMT) of municipal solid waste (MSW) was generated in 2012 (EPA, 2013a). To date, waste management has relied largely on conventional methods focusing on the disposal of waste via landfill or combustion. Although the US Environmental Protection Agency (EPA) has had to enhance recycling, reusing, and recycling, more than half of generated waste (52.1%) in the United States was incinerated in 2012 (EPA, 2013a). Only about 6 percent (6.1%) of MSW was generated in the United States was recycled, while the rest was combusted (42.7%) or composted (10.1%) (EPA, 2013a). For incineration treatment, it was estimated that publicly owned treatment works (POTW) plants have per day of wastewater and generated sludge (WAS) of sludge, among which 60% (MMT) was bio-treatment for purposes such as biogas production or land application, according to the 2012 EPA Clean Water National Sewerage Capacity Assessment (CWSA) (EPA, 2013b). Annual waste (i.e., manure) generation is estimated at 107.8 MMT (EPA, 2013, 2012), and the direct conversion rate of manure to energy is 10% (EPA, 2013). Current waste management practices for MSW, wastewater sludge, and animal waste raise many environmental concerns. Landfilled MSW

Waste-to-Energy

Journal of Cleaner Production

Volume 102, 13 January 2016, 183–194

Life cycle analysis of gasification and Fischer-Tropsch conversion of municipal solid waste for transportation fuel production

Uisang Lee, A. H. Han, Gwi-Langwon, O. Pabula Thathana Bernades, Trausa Wang, Michael Wang

Highlights

- Evaluated carbon intensities of liquid fuels produced from municipal solid waste

U.S. DEPARTMENT OF ENERGY Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

Journal of Cleaner Production

Volume 111, 15 August 2016, 12763–12765

Life cycle analysis of renewable natural gas and lactic acid production from waste feedstocks

Uisang Lee^{a, *}, Arif Ahmad^b, Troy Robert Hawkins^c, Ling Tao^c, Pabula Thathana Bernades^d, Michael Wang^d

Highlights

- Life cycle analysis of renewable natural gas (RNG) and lactic acid (LA) production from four types of wet waste feedstocks: wastewater sludge, food waste, wine manure, and fat, oil, and grease (FOG); LA anaerobic digestion (AD) and LA fermentation, respectively. RNG can be used as an alternative to fossil natural gas, while LA from waste feedstocks can displace conventional LA production pathways

Journal of Cleaner Production

Volume 111, 15 August 2016, 12763–12765

Life cycle analysis of renewable natural gas and lactic acid production from waste feedstocks

Uisang Lee^{a, *}, Arif Ahmad^b, Troy Robert Hawkins^c, Ling Tao^c, Pabula Thathana Bernades^d, Michael Wang^d

Highlights

- Biodiverse PE can offer lower GHG emissions and FEC than the fossil-based counterparts.

Waste-to-products

Journal of Cleaner Production

Volume 111, 15 August 2016, 12763–12765

Life Cycle Greenhouse Gas Emissions and Energy Use of Polylactic Acid, Bio-Derived Polyethylene, and Fossil-Derived Polyethylene

Pabula Thathana Bernades^{a, *}, Arif Ahmad^b, Omid Zare^c, Mehdiye Zaidi^d

Highlights

- Biodiverse PE can offer lower GHG emissions and FEC than the fossil-based counterparts.

Waste gas-to-liquid fuels (CO₂ utilization)

Modeling and Analysis

Using waste CO₂ from corn ethanol biorefineries for additional ethanol production: life-cycle analysis

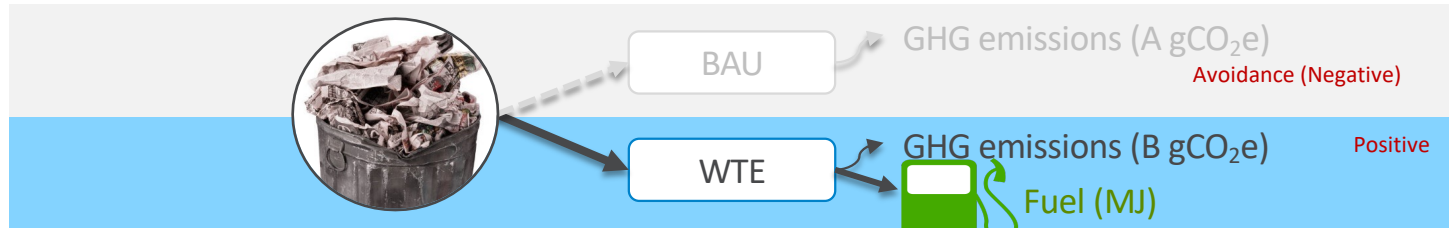
Uisang Lee, Troy R. Hawkins, Eddy Pez, Michael Wang, Argonne National Laboratory, Chicago, IL, USA; Han, Gwi-Langwon, O. Pabula Thathana Bernades, Trausa Wang, Michael Wang, Argonne National Laboratory, Chicago, IL, USA; Han, Gwi-Langwon, O. Pabula Thathana Bernades, Trausa Wang, Michael Wang, Argonne National Laboratory, Chicago, IL, USA

Highlights

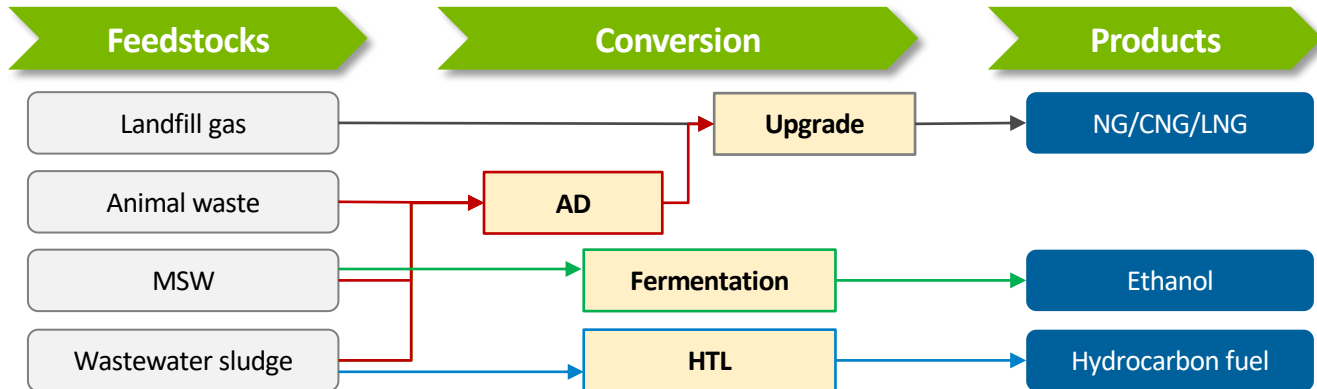
- Life cycle analysis of waste CO₂ utilization: environmental, economic, and policy analysis

LCA of WTE Pathways that May Provide Significant WTW GHG Reductions

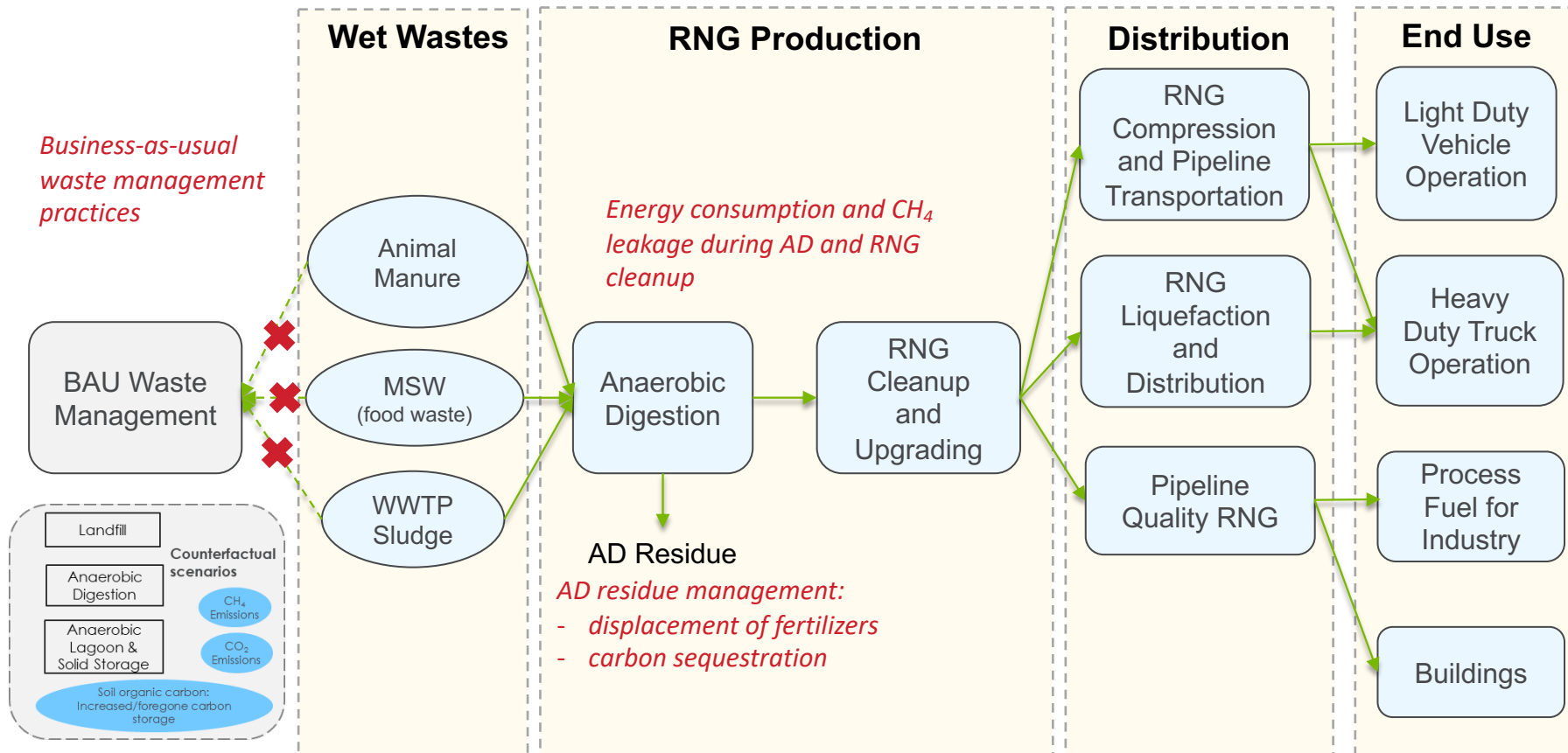
- LCA of waste-to-energy (WTE) pathways evaluate emissions associated with business-as-usual (BAU) waste management and account for avoided emissions.



Pathways in GREET

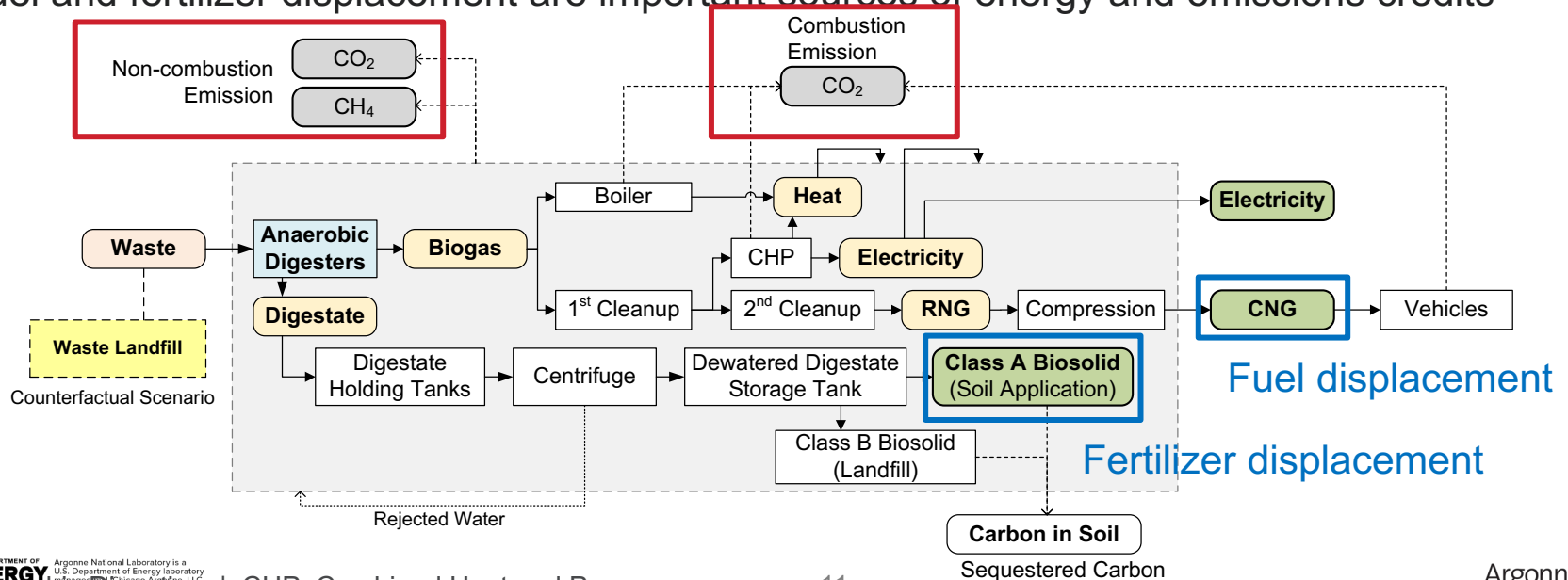


REET Renewable Natural Gas (RNG) Module



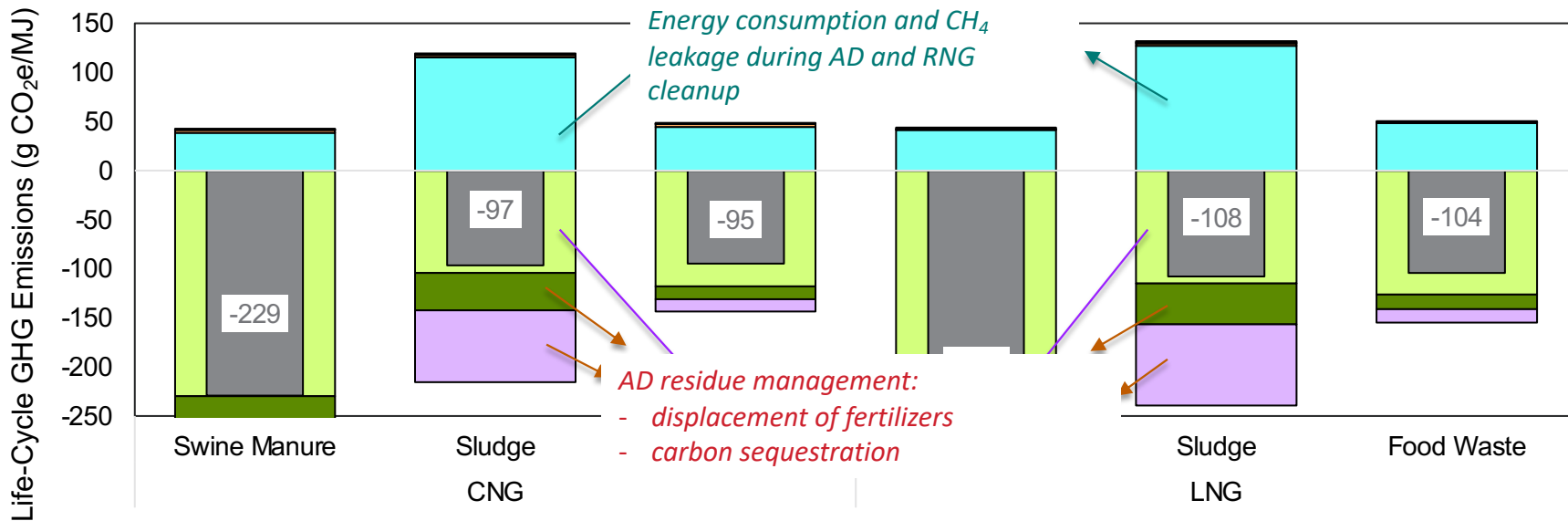
Alternative fuel production scenario: Renewable natural gas from food waste via AD

- ~~Heat and power generated from biogas combustion are used to meet the onsite demands~~
 - Grid electricity/pipeline NG are used to satisfy energy demand for biogas upgrading
- The biogas is upgraded and compressed to RNG
- Fuel and fertilizer displacement are important sources of energy and emissions credits



RNG is a very attractive option for decarbonizing heavy-duty transportation, which is hard to electrify and decarbonize.

Avoided GHG emissions and displacement credits can be significant.

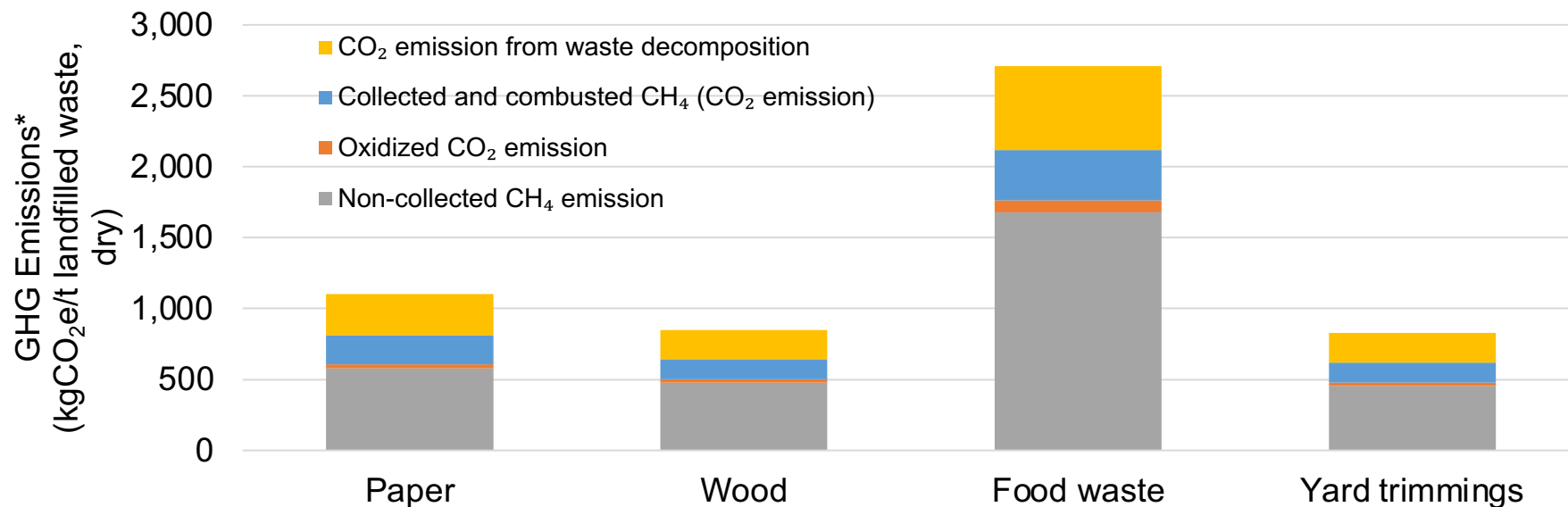


- Avoided BAU emissions/Foregone BAU credits
- Carbon sequestration by AD residue
- RNG compression/liquefaction
- Fuel combustion

- RNG production and upgrading
- Synthetic fertilizer displacement
- Fuel distribution
- Net total

Landfill specific parameters should be used to estimate avoided LFG emissions

- Due to significant variations in landfill conditions and operations, setting an appropriate BAU which diverts waste from is critically important.



GREET Aviation Module

- Can evaluate SAF pathways with various feedstock/conversion combinations
- Present process-level emission results to identify emission hotspots
- Combustion emissions by aircraft types are available
- Can be expanded for new pathways leveraging existing structure and datasets

GREET Excel Aviation Module

Jet Fuel Production Pathways: from Petroleum, NG, Biomass and Coal

1) Scenario Control and Key Input Parameters

1.1) Jet A Production
Type of Jet A: 2 (1: Conventional Petroleum Jet Fuel, 2: Ultra Low-Sulfur Jet Fuel)
Jet A Feedstock: 1 (1: Crude oil, 2: Hydro-treated Pyrolysis Oil)

1.2) Synthetic Paraffinic Kerosene (SPK) Production
Type of SPK: 2 (1: Fischer-Tropsch (FT) Jet, 2: Hydroprocessed Renewable Jet (HRJ), 3: Ethanol-To-Jet (ETJ), 4: Sugar-To-Jet (STJ))

1.2a) FT Jet Fuel Production from NG, Biomass and Coal
Feedstock Source for FT Jet: 1 (1: North American NG, 2: Non-North American NG, 3: Non-North American Flared Gas)

Simulation Options for Fuel Pathways: 5 (5: Biomass, 6: Coal, 7: Coal/Biomass, 8: NG/Biomass, 11: CO2 (e-fuel))

Feedstock	Natural Gas	Flared Gas	Landfill Gas	Biomass	Coal	Coal/Biomass	NG/Biomass	CO2
FT Jet Feedstock Share	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Plant Design Type	0	0	0	0	0	0	0	2
CO2 Sequestration Options for FTJ Plants	0	N/A	0	1	1	1	1	1
Percentage of CO2 to Be Captured	0.0%	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Share of coal and biomass out of total feedstock for coal/biomass co-feeding to Fischer-Tropsch Jet production

Feedstock	Mass Share	Energy Share
Coal	50%	56.7%
Biomass	50%	43.3%

Share of Willow, Poplar, Switchgrass, Miscanthus, Corn Stover, Forest Residue and Miscanthus out of Total Biomass for Fischer-Tropsch Jet Production

Feedstock	Mass Share	Energy Share
Willow	0.0%	0.0%
Poplar	0.0%	0.0%
Switchgrass	0.0%	0.0%
Miscanthus	0.0%	0.0%
Corn Stover	0.0%	0.0%
Forest Residue	100.0%	100.0%

Selection of Method for Estimating Credits of Electricity Co-Product for Fuel Pathways

Feedstock	NG	Flared Gas	BiNG	Biomass	Coal	Coal/Biomass	NG/Biomass
FT Jet Fuel	1	1	1	1	1	1	2

Allocation ratio of total energy and emission burdens to main fuel product

Feedstock	NG	Flared Gas	BiNG	Biomass	Coal	Coal/Biomass	NG/Biomass
Energy-based allocation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	62.3%
Market value-based allocation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	69.0%

Jet Fuel Signal: 2.24

GREET.net Aviation Module

Well-to-Wake Energy and Emissions

Aircraft Type: Single Aisle (SA) Fuel Type: Conventional Jet Fuel (Pathway: Convert)

Aircraft Parameters (Input)

Name	Average Payload	Average Trip Great Circle Distance	Consumption (kg Operated)	Consumption (LTO)	Cruise Urban Share	LTO Urban Share
Single Aisle (S)	18230 100 kg	1365 828 km	4986 089 kg	564 679 kg	0	1

Notes: For details, see report by A. Elgoway, et al. "Life Cycle Analysis of Alternative Aviation Fuels in GREET" http://greet.es.anl.gov/files/aviation_lca

Aircraft Emission (Input)

	VOC	CO	NOX	PM10	PM25	SOX	CH4	N2O	CO2	BC	POC	CO2_Bi	TotalCO
LTO Emissions g	6.283	4.642	8.357	2.106	2.106	7.906	2.284	1.775	5.739	5.475	0.000	1.785	1
Cruse Emissions g/(kg*km)	8.631	6.050	2.766	3.636	3.636	2.486	0.000	1.560	1.138	1.102	0.000	5.612	5

Results

PTWa (or PFEI): 0.651 kJ/(kg*km) WTWa: 9.719 kJ/(kg*km) Petroleum WTWa: 8.937 kJ/(kg*km)

Fossil WTWa: 9.675 kJ/(kg*km) Coal WTWa: 0.059 kJ/(kg*km) NG WTWa: 0.679 kJ/(kg*km)

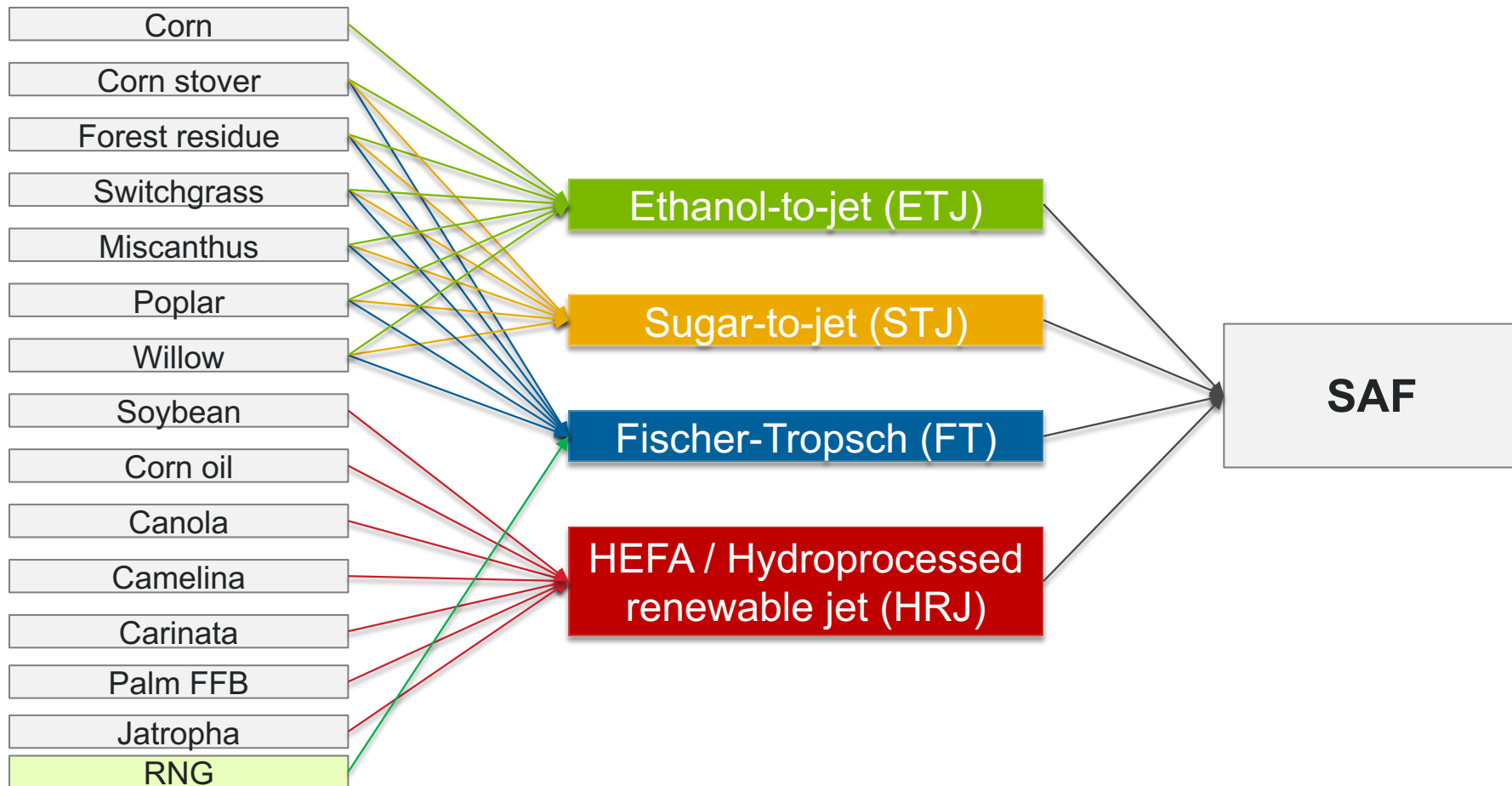
	VOC	CO	NOX	PM10	PM25	SOX	CH4	N2O	CO2	BC	POC	CO2_B	TotalCO
PTWa Emissions g/(kg*km)	1.115	7.911	3.101	3.721	3.721	2.800	9.175	1.800	6.313	1.116	1.124	0.000	6.325
PTWa Urban Emissions g/(kg*km)	2.524	1.860	3.356	8.450	8.457	3.170	9.175	1.800	7.131	3.020	2.199	0.000	7.166
WTP Emissions g/(kg*km)	5.594	8.150	1.258	8.070	6.852	3.150	8.206	1.240	7.288	1.090	2.035	-1.450	7.304
WTP Urban Emissions g/(kg*km)	2.180	1.050	1.569	2.410	2.080	5.960	1.925	2.680	2.189	2.550	3.893	-1.880	2.196
WTWa Emissions g/(kg*km)	1.675	8.730	3.227	4.520	4.406	3.110	8.215	3.040	7.042	1.270	1.327	-1.450	7.066
WTWa Urban Emissions g/(kg*km)	4.704	1.970	3.513	3.250	2.925	3.770	2.016	2.060	9.320	5.580	6.092	-1.880	9.366

JetFuel_WTP

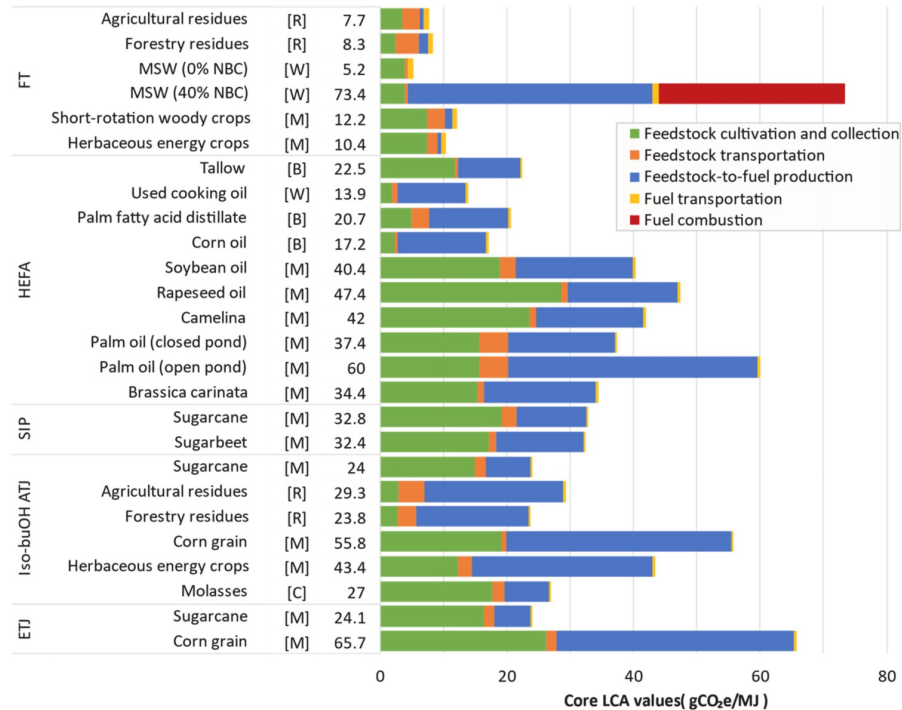
JetFuel_PTWa

JetFuel_WTWa

Available Sustainable Aviation Fuel Pathways in GREET



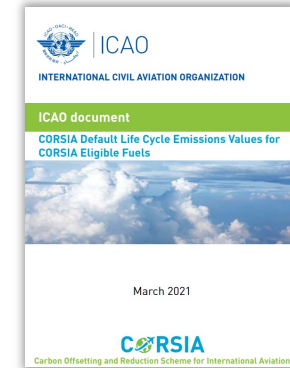
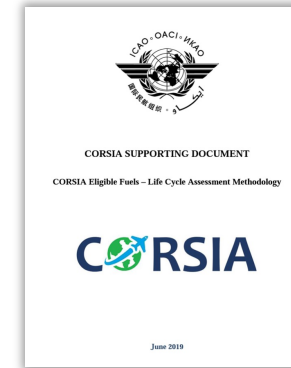
GREET Provides the Carbon Intensities for Carbon Offsetting and Reduction Scheme for International Aviation (CORSA)



(Source: 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

Petroleum jet fuel baseline: 89 gCO₂e/MJ



GREET LCA Informs Policy and Regulation

California Environmental Protection Agency
 **Air Resources Board**



Environment and
Climate Change Canada

- **California-GREET** is an adaptation of Argonne's GREET model
- **Oregon Clean Fuels Program** also uses an adaptation of Argonne's GREET model
- Specified in **Inflation Reduction Act** related to the **Clean Fuel Production Credit** and the **Clean Hydrogen Credit**
- **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
- **U.S. Maritime Administration** - renewable marine fuel options for **IMO 2020 sulfur limits**
- **U.S. Dept. of Agriculture bioenergy LCA** and carbon intensity of farming practices
- **Canadian Clean Fuel Standard** for Environment and Climate Change Canada fuel pathways

Acknowledgements

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