January 22, 2025

Intro to the R&D GREET® Excel Model

3:00-4:00 p.m. CT

Instructor

Hao Cai, Argonne National Laboratory

Argonne National Laboratory Subject Matter Experts

Michael Wang, Hao Cai, Amgad Elgowainy

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

R&D GREET disclaimer

The R&D GREET effort at Argonne National Laboratory is supported by the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy and Carbon Management, the Office of Clean Energy Demonstration, the Office of Technology Transitions, the Office of Nuclear Energy, and ARPA-E of the US Department of Energy (DOE) under contract DE-AC02-06CH11357.

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.

GREAT PLAINS INSTITUTE Argonne NATIONAL LABORATORY U.S. Department of ENERGY

GREET end-user licensing terms and conditions

Commercial use:

For commercial use, please contact www.anl.gov/partners.

Non-commercial use:

This license is based on the Creative Commons Attribution-Non Commercial 4.0 International Public License, with the following modified definition. Non-Commercial means internal use (including use for internal business or operational purposes by for-profit entities), use by non-profit entities, or use for United States federal, state, or local government purposes. Government purposes include work performed pursuant to a United States federal, state, or local government funding agreement, and work performed by or on behalf of the United States federal, state, or local government. For purposes of this Public License, the exchange of the Licensed Material for other material subject to Copyright and Similar Rights by digital file-sharing or similar means is Non-Commercial provided there is no payment of monetary compensation in connection with the exchange.

Redistribution and use of the GREET software are permitted for non-commercial uses and provided that the following conditions are met:

1. Redistributions of the GREET software must retain the above copyright notice, this list of conditions, and the following disclaimer. Modification or reverse compilation of the source code is not permitted.
2. Neither the names of UChicago Argonne, LLC or the Department of Energy nor the names of its contributors may be used to endorse or promote products derived from this software without prior written permission.
3. The software redistribution, if any, must include the following acknowledgment: "This product includes software produced by UChicago Argonne, LLC under Contract No. DE-AC02-06CH11357 with the Department of Energy."
4. Any published results should indicate that the GREET software was developed by Argonne National Laboratory. If you publish results generated using GREET you should identify the GREET software version number. If you publish results generated using input data other than the input data supplied with the GREET software you must indicate that these results relied upon changed input data.

Table of contents

Life Cycle Analysis Methodology

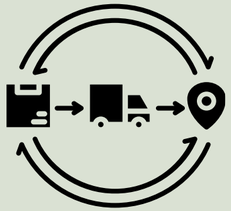
GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

There are two main flavors of life cycle assessment (LCA)

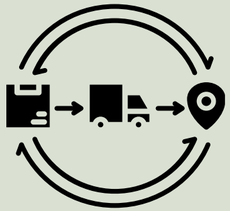
Process-based LCA



Follow the mass throughout the supply chain

Economic input-output LCA

Follow the money throughout the economy



GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

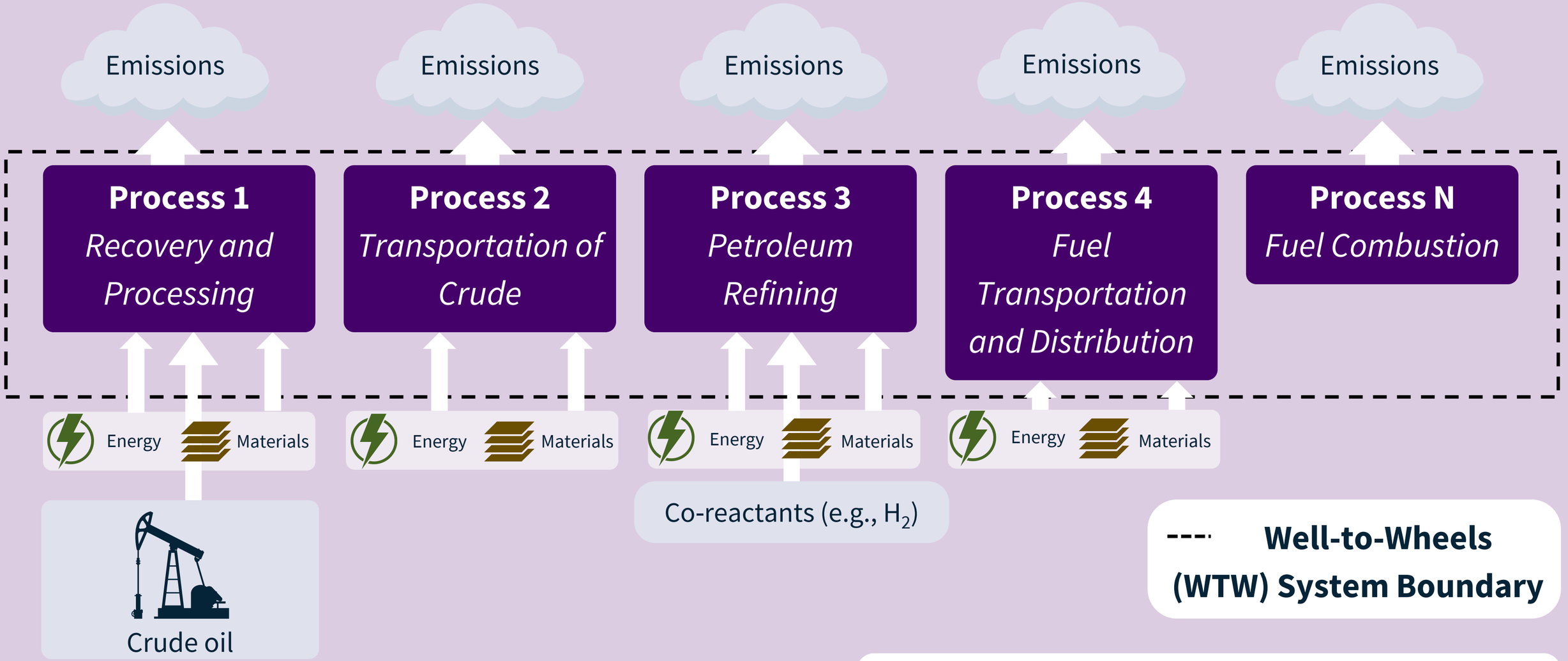
U.S. Department of ENERGY

Process-based LCAs

Sums up the individual contributions along a product's life cycle

Requires detailed data at every stage along the life cycle

Process-based LCA example with conventional gasoline



All direct and upstream activities are included

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

Some strengths and limitations of process-based LCA

Strengths

- Relatively Accurate
- Detailed understanding

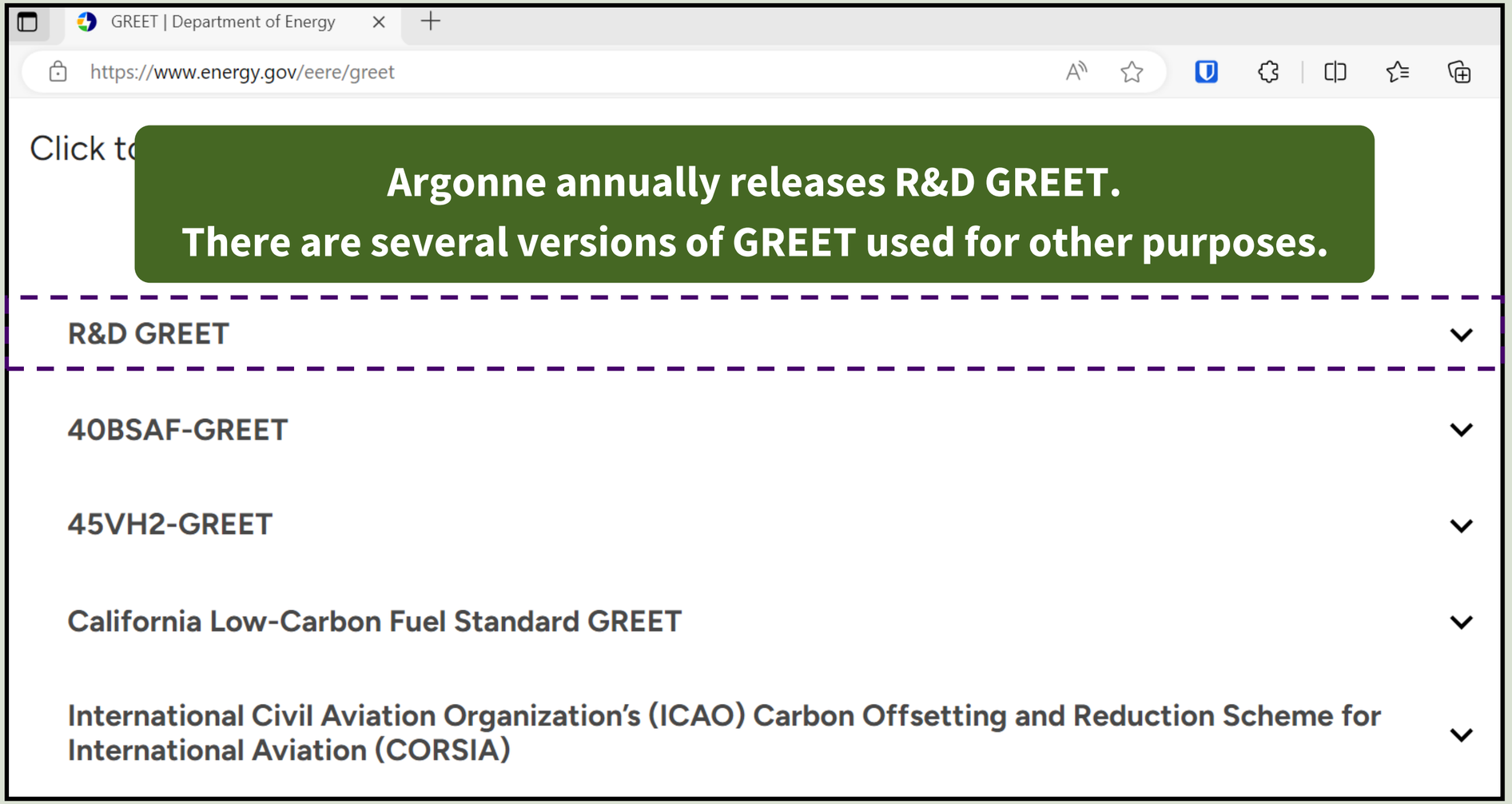
Limitations

- Data-intensive
- System boundary considerations

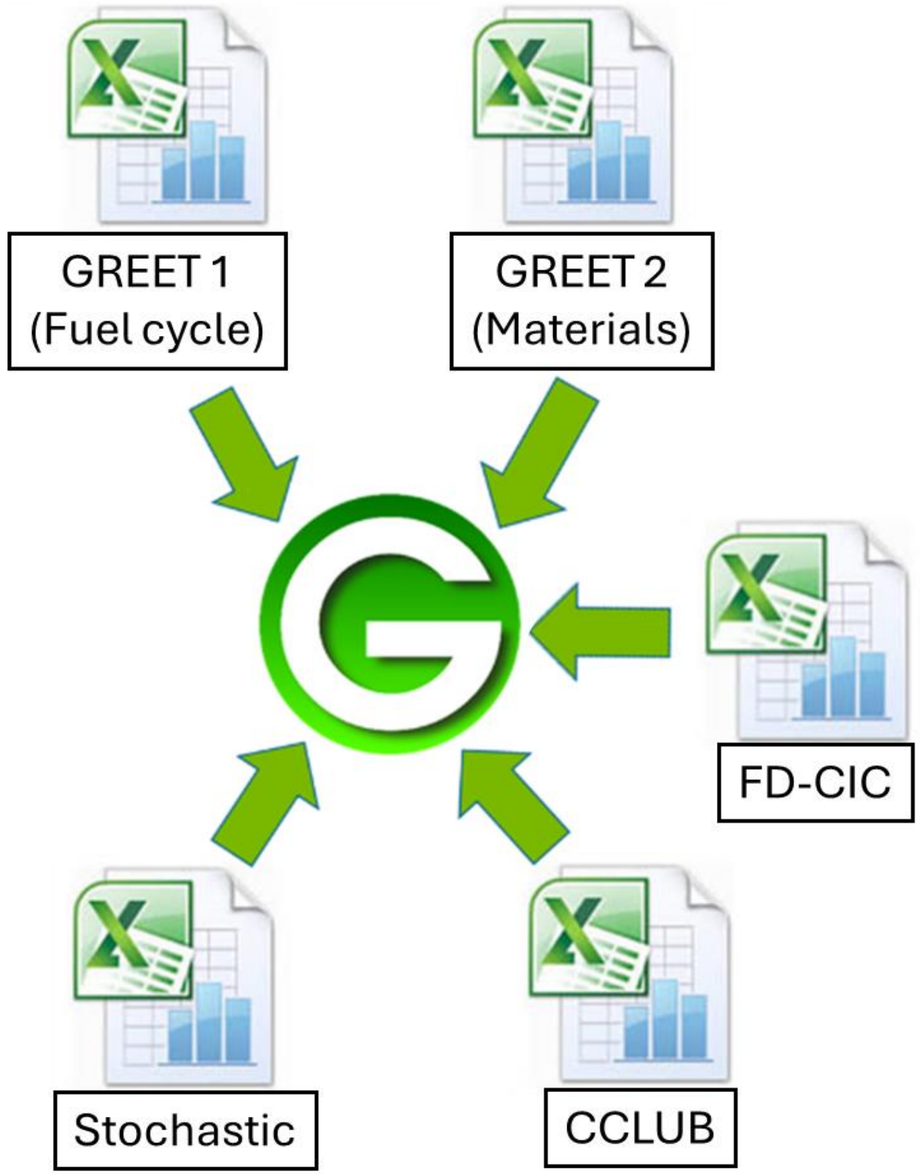
GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

What Does GREET Encompass?

Versions of GREET



What makes up R&D GREET?



R&D GREET 1: Fuels Cycle - energy/products/fuels

R&D GREET 2: Vehicle/Material Cycle - vehicles/materials

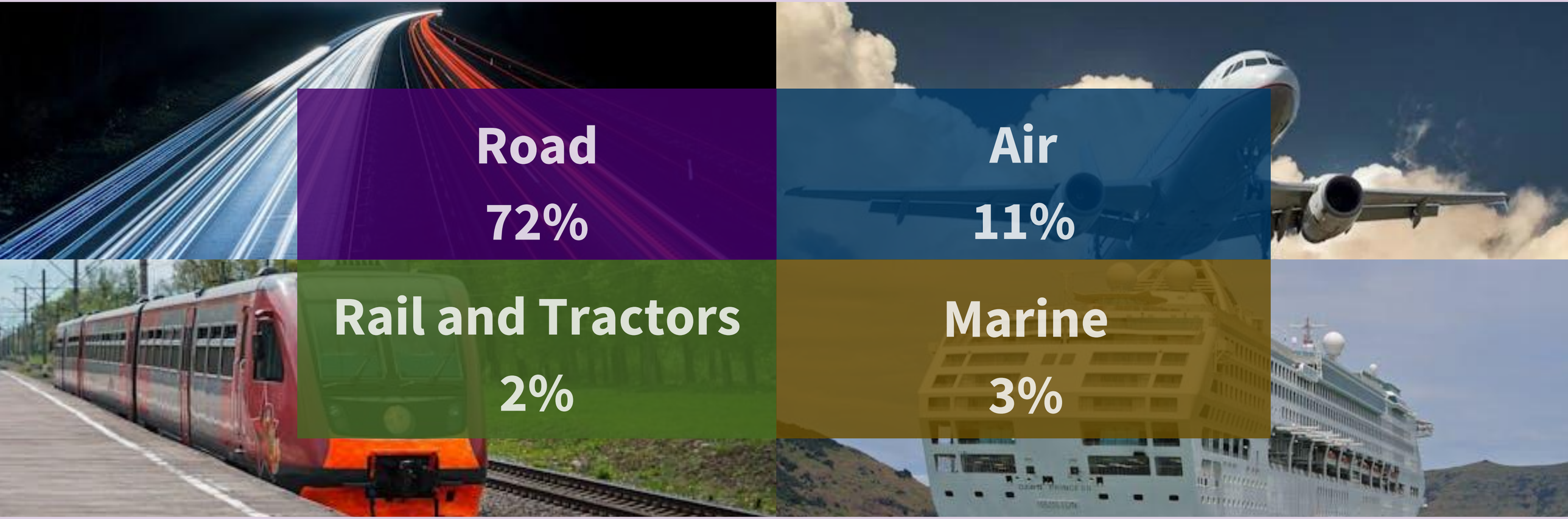
CCLUB - land-use and land-management changes

FD-CIC (Feedstock Carbon Intensity Calculator) - producing domestic and international agricultural feedstocks

Stochastic Toolkit - running stochastic analyses and determining error bars on LCA estimates

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

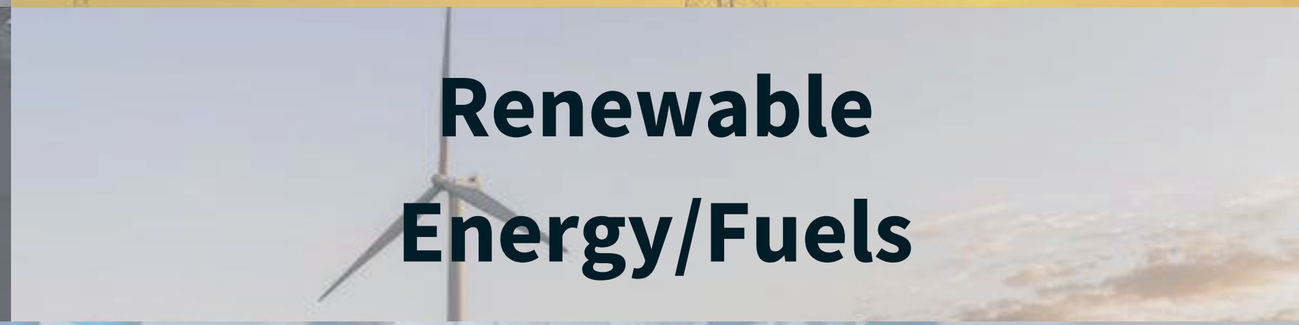
R&D GREET covers all transportation subsectors



Share of U.S. transportation GHG emissions; remaining 12% for U.S. is from pipelines and off-road

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

R&D GREET covers many groups of energy systems



GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

R&D GREET in the petroleum sector

Conventional Oil
Shale Oil
Oil Sands

Gasoline
Diesel
Jet fuel
Liquified petroleum gas (LPG)
Naphtha
Residual oil
and more

GREAT PLAINS INSTITUTE
Argonne NATIONAL LABORATORY
U.S. Department of ENERGY

R&D GREET in the natural gas sector

Conventional Natural Gas
Shale Gas

Natural gas end use in electric, industrial, and residential sectors

Transportation sector: compressed natural gas (CNG) and liquified natural gas (LNG)

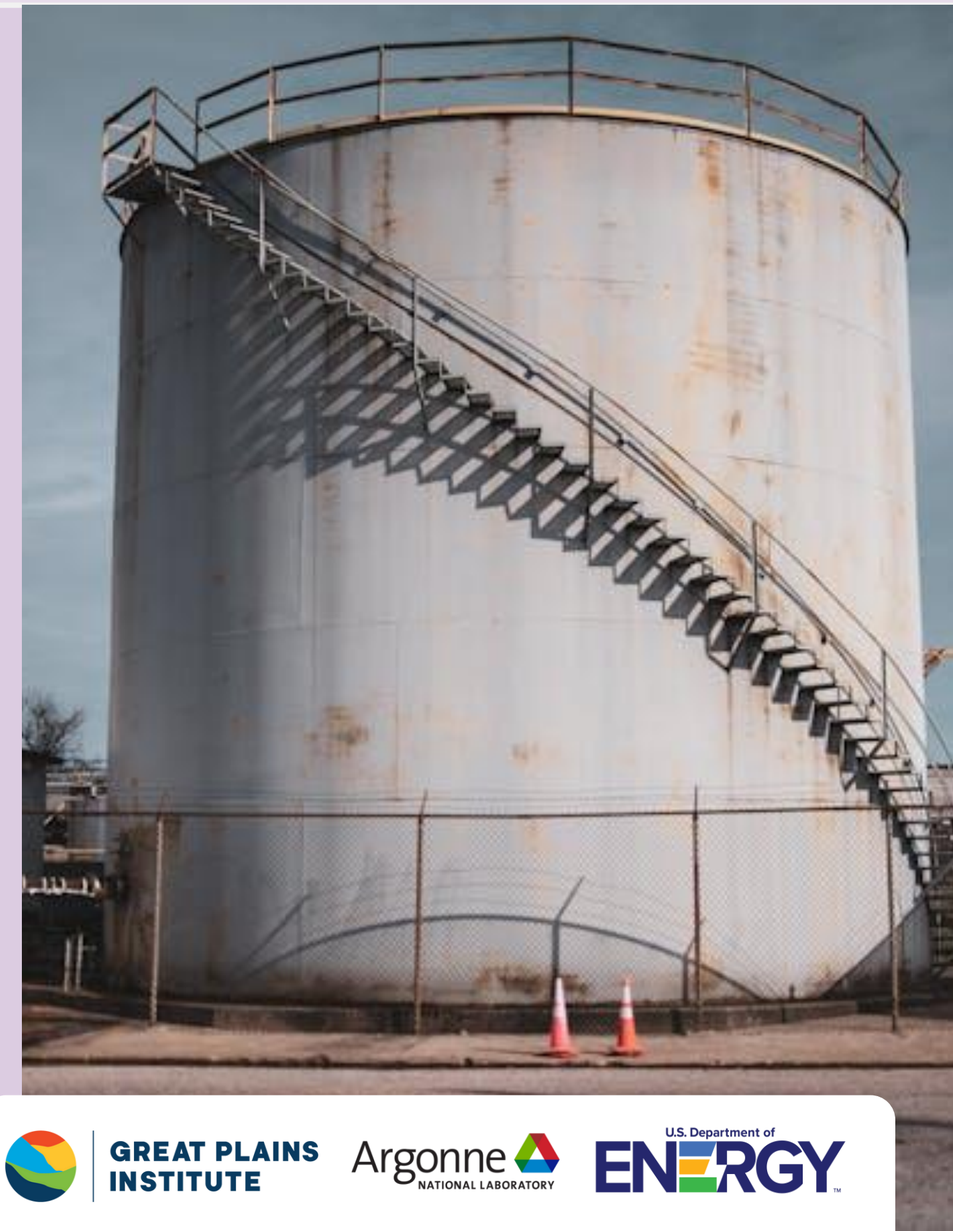
Alternative fuels: LPG, methanol, dimethyl ether (DME), Fischer Tropsch (FT) diesel, FT jet and more

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

R&D GREET in the hydrogen economy

Gaseous hydrogen
Liquid hydrogen
With carbon capture and sequestration (CCS), if applicable

Natural Gas
Biomass
Coal
Petroleum Coke
Coke Oven Gas
Electrolysis with Electricity
Nuclear Energy
and More



GREAT PLAINS INSTITUTE
Argonne NATIONAL LABORATORY
U.S. Department of ENERGY

R&D GREET and electric systems

Electricity generation at U.S. plant level
Aggregate to national, NERC, state, EPA eGRID, and DOE Needs Study regional levels
Vaious power generation technologies with CCS, if applicable

Natural Gas
Coal
Residual Oil
Biomass
Nuclear
Hydro
Wind
Solar

GREAT PLAINS INSTITUTE
Argonne NATIONAL LABORATORY
U.S. Department of ENERGY

R&D GREET and renewable energy/fuels

Corn
Soybean
Sorghum
Rapeseeds
Sugarcane
Dedicated Energy Crops
Crop Residues
Forest Residues
Municipal Solid Waste (MSW)
Animal Wastes
Algae
and More

Ethanol
Biodiesel
Renewable diesel
Renewable gasoline
Sustainable aviation fuel
Renewable natural gas
and more

GREAT PLAINS INSTITUTE
Argonne NATIONAL LABORATORY
U.S. Department of ENERGY

R&D GREET and electro-fuels

Renewable Hydrogen via Electrolysis

Wind

Solar

Nuclear

CO_2 Sources

Ethanol plants

NG SMR plants

Cement plants

Electro-Fuels

Gasoline

Diesel

Jet fuel

Methanol

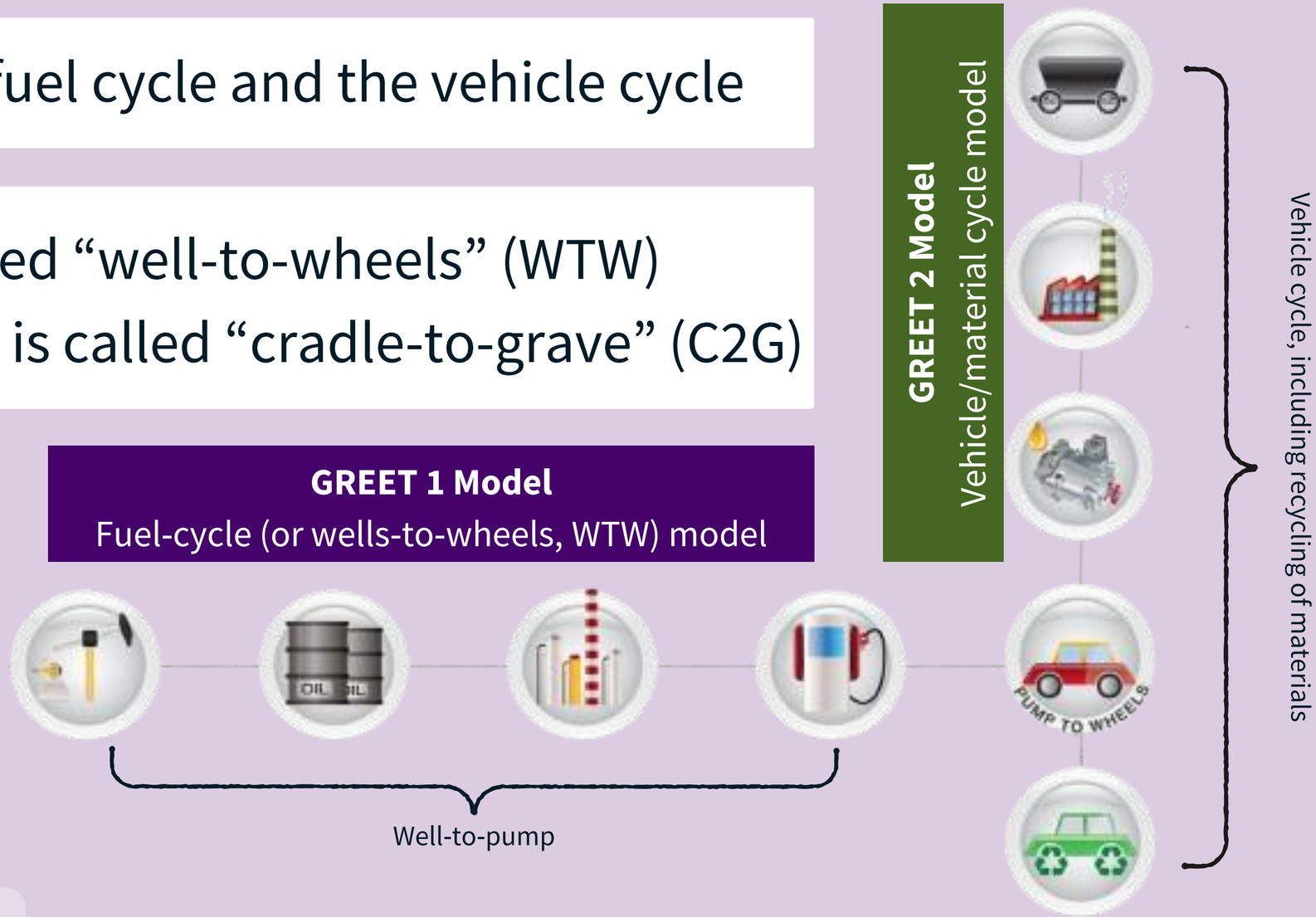
Ammonia

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

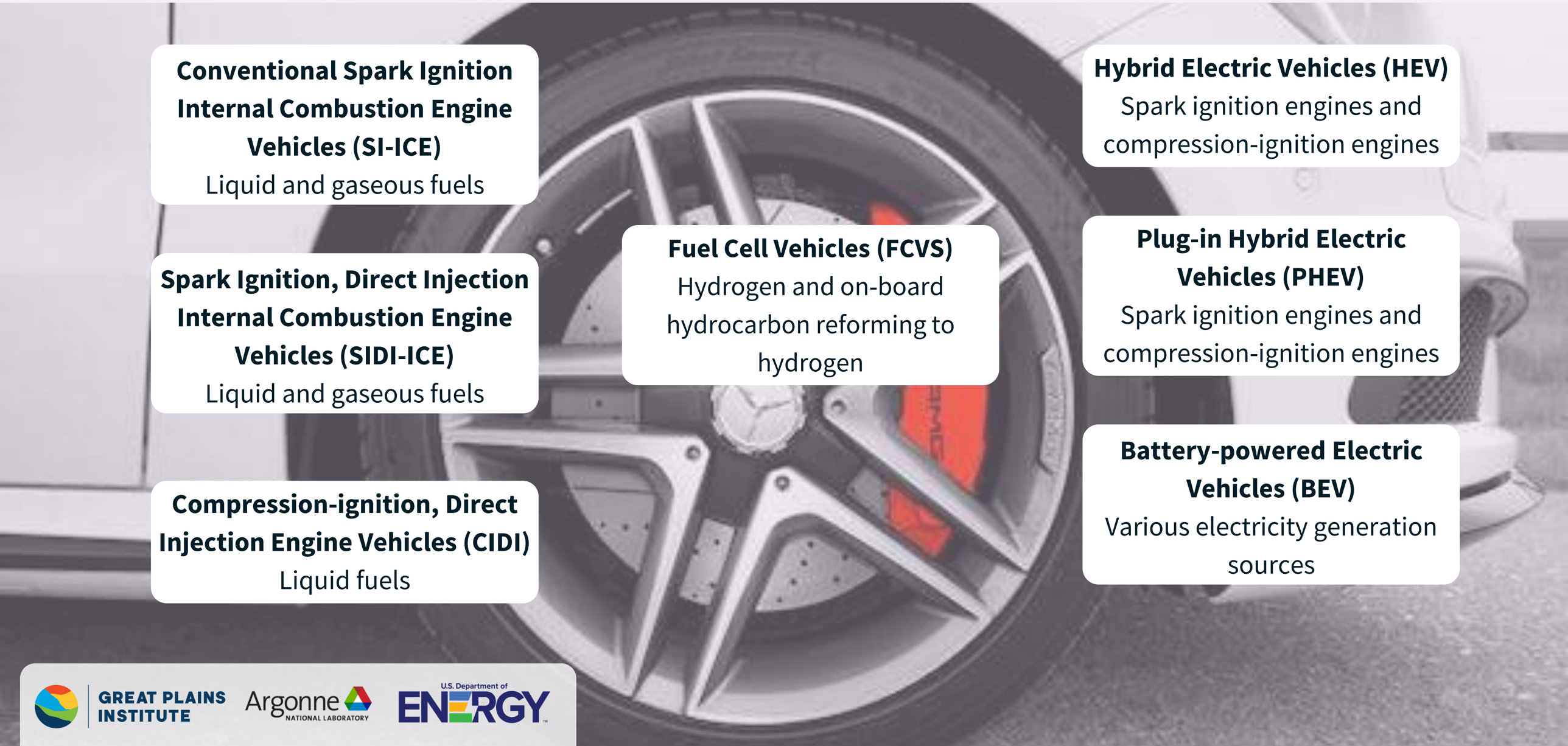
The R&D GREET model framework

GREET covers both the fuel cycle and the vehicle cycle

Fuel cycle LCA is called “well-to-wheels” (WTW)
Fuel and vehicle cycle LCA is called “cradle-to-grave” (C2G)



R&D GREET covers a variety of vehicle technologies



Conventional Spark Ignition Internal Combustion Engine Vehicles (SI-ICE)
Liquid and gaseous fuels

Spark Ignition, Direct Injection Internal Combustion Engine Vehicles (SIDI-ICE)
Liquid and gaseous fuels

Compression-ignition, Direct Injection Engine Vehicles (CIDI)
Liquid fuels

Fuel Cell Vehicles (FCVS)
Hydrogen and on-board hydrocarbon reforming to hydrogen

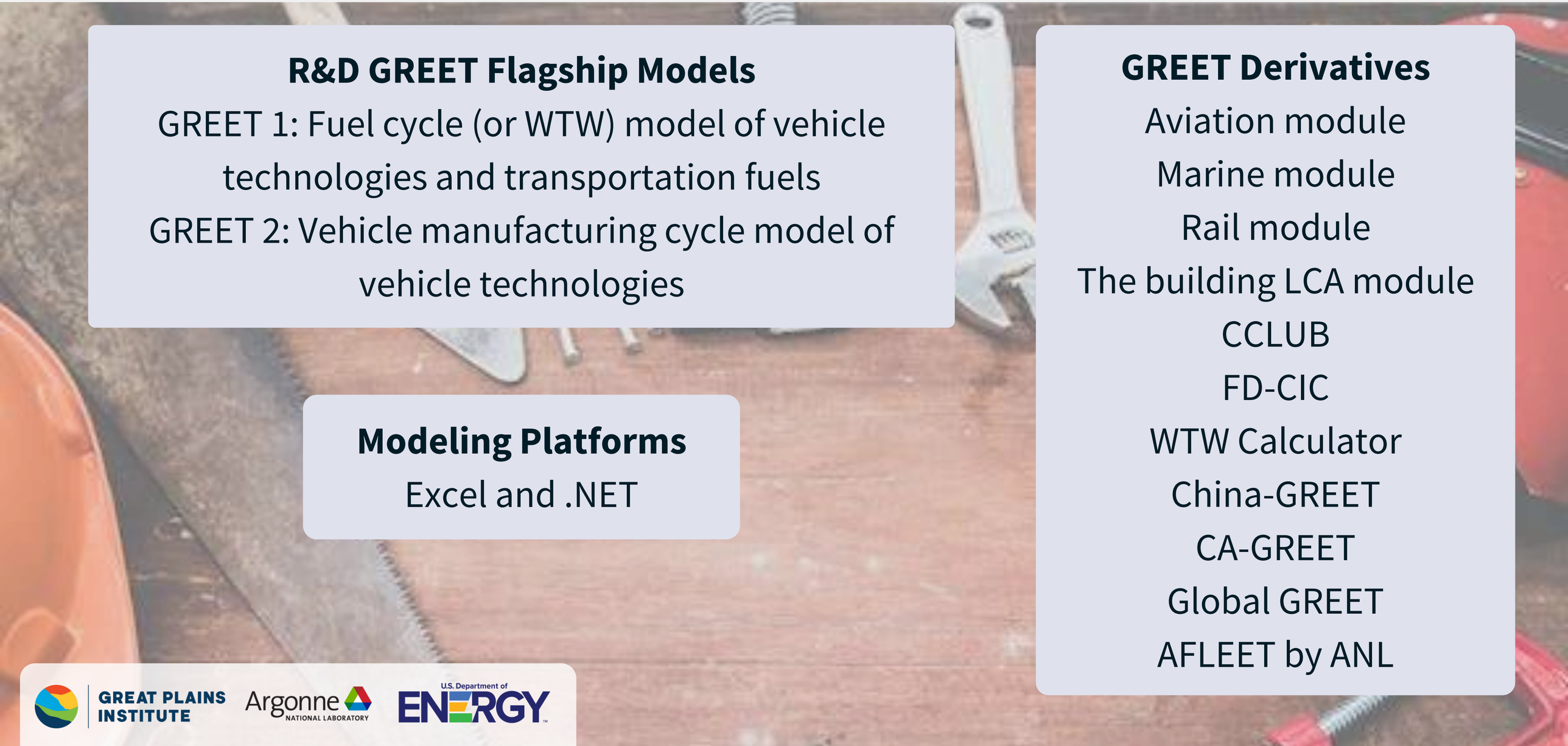
Hybrid Electric Vehicles (HEV)
Spark ignition engines and compression-ignition engines

Plug-in Hybrid Electric Vehicles (PHEV)
Spark ignition engines and compression-ignition engines

Battery-powered Electric Vehicles (BEV)
Various electricity generation sources

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

GREET includes a suite of models and tools



R&D GREET Flagship Models

GREET 1: Fuel cycle (or WTW) model of vehicle technologies and transportation fuels

GREET 2: Vehicle manufacturing cycle model of vehicle technologies

Modeling Platforms

Excel and .NET

GREET Derivatives

Aviation module

Marine module

Rail module

The building LCA module

CCLUB

FD-CIC

WTW Calculator

China-GREET

CA-GREET

Global GREET

AFLEET by ANL

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

GREET Relies on Data

Background vs Foreground Data

Background Data

Data used to set up the environment of the system, such as emission factors

Foreground Data

Data that can be altered and used to simulate bespoke scenarios

GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

Primary vs Secondary Data

Primary Data

Data from facility operations, such as surveys

Secondary Data

Simulations with process engineering modeling, literature data, and approximations

GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

R&D GREET relies on a variety of data sources

Baseline technologies and systems: background data

Field operation data: foreground data

Simulations with models: foreground data

Collaborations with other organizations and industries

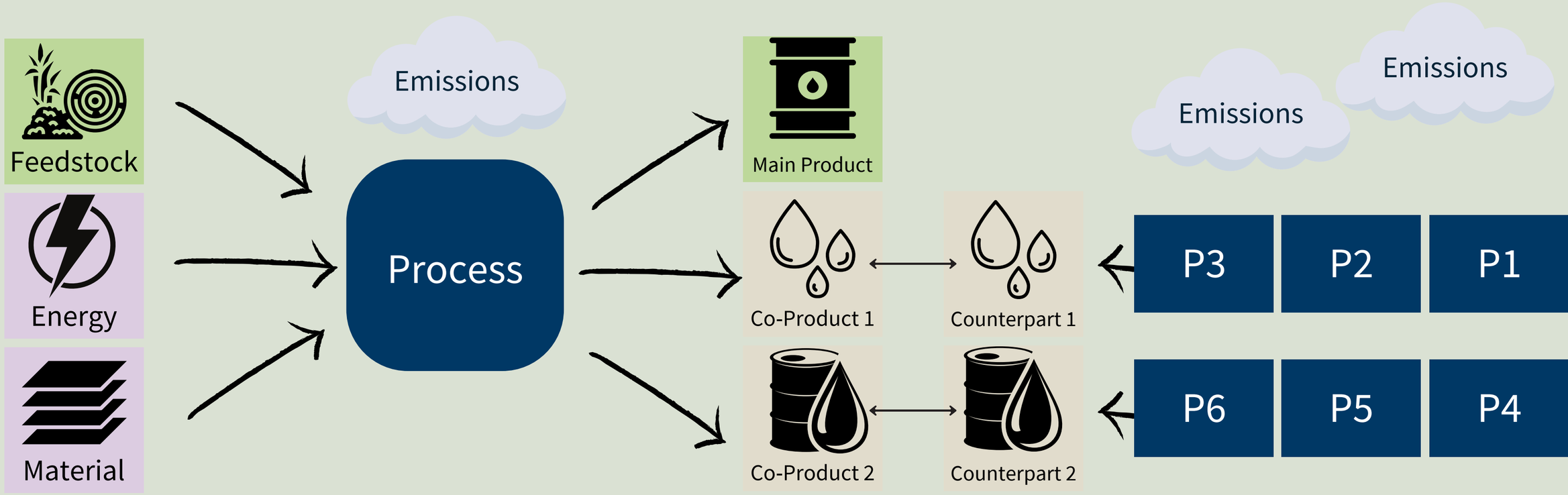
GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

Co-product handling: displacement (substitution)

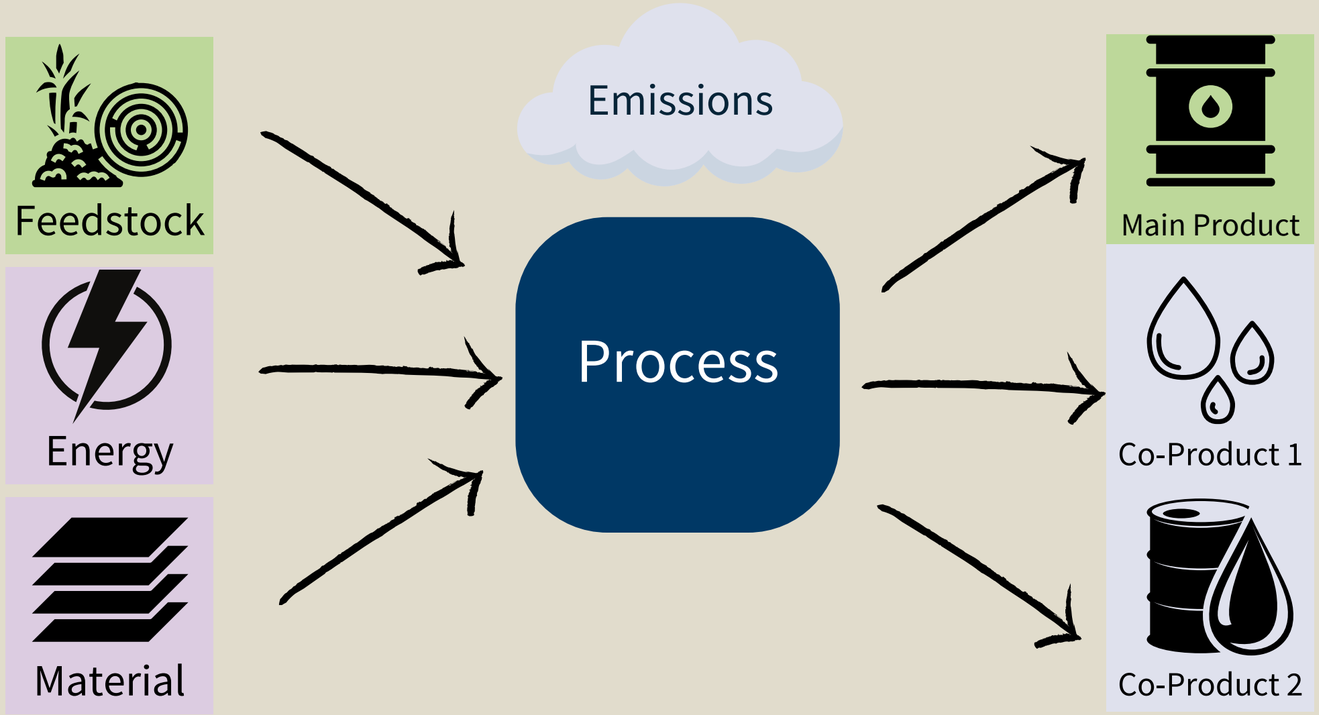
Main product carries the burden of all energy and emissions throughout the process
All life cycle energy and emissions of the displaced product are credited to the main product



GREAT PLAINS INSTITUTE
Argonne NATIONAL LABORATORY
U.S. Department of ENERGY

Co-product handling: allocation

Main product and co-product carry energy and emissions burden based on their ratios in the total products



Allocation Factor X%

Allocation can be done on a mass, energy, or market-value basis

R&D GREET Results

GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

Functional units

Energy

- British thermal units: **Btu**
- Million British thermal units: **mmBtu**
- Megajoules: **MJ**

Emissions

- Grams: **g**
- Kilograms: **kg**
- Pounds: **lbs**

Volume

- Gallons: **gal**

Energy and Emissions Intensity

Per Distance:

- grams per mile: **g/mile**
- British thermal unit per mile: **Btu/mile**

Per Energy:

- grams per million Btu: **g/mmBtu**
- grams per megajoule: **g/MJ**

GREET results include several metrics

Energy use

- **Total energy**: fossil energy and renewable energy
- **Fossil energy**: petroleum, natural gas, and coal
- **Renewable/other energy**: biomass, nuclear energy, hydro-power, wind power, and solar energy

Air pollutants

- VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x
- Estimated separately for total and urban
- Results can help address environmental justice impacts

Greenhouse gases

- CO_2, CH_4, and N_2O
- CO_2e of the five (combined with their global warming potentials)

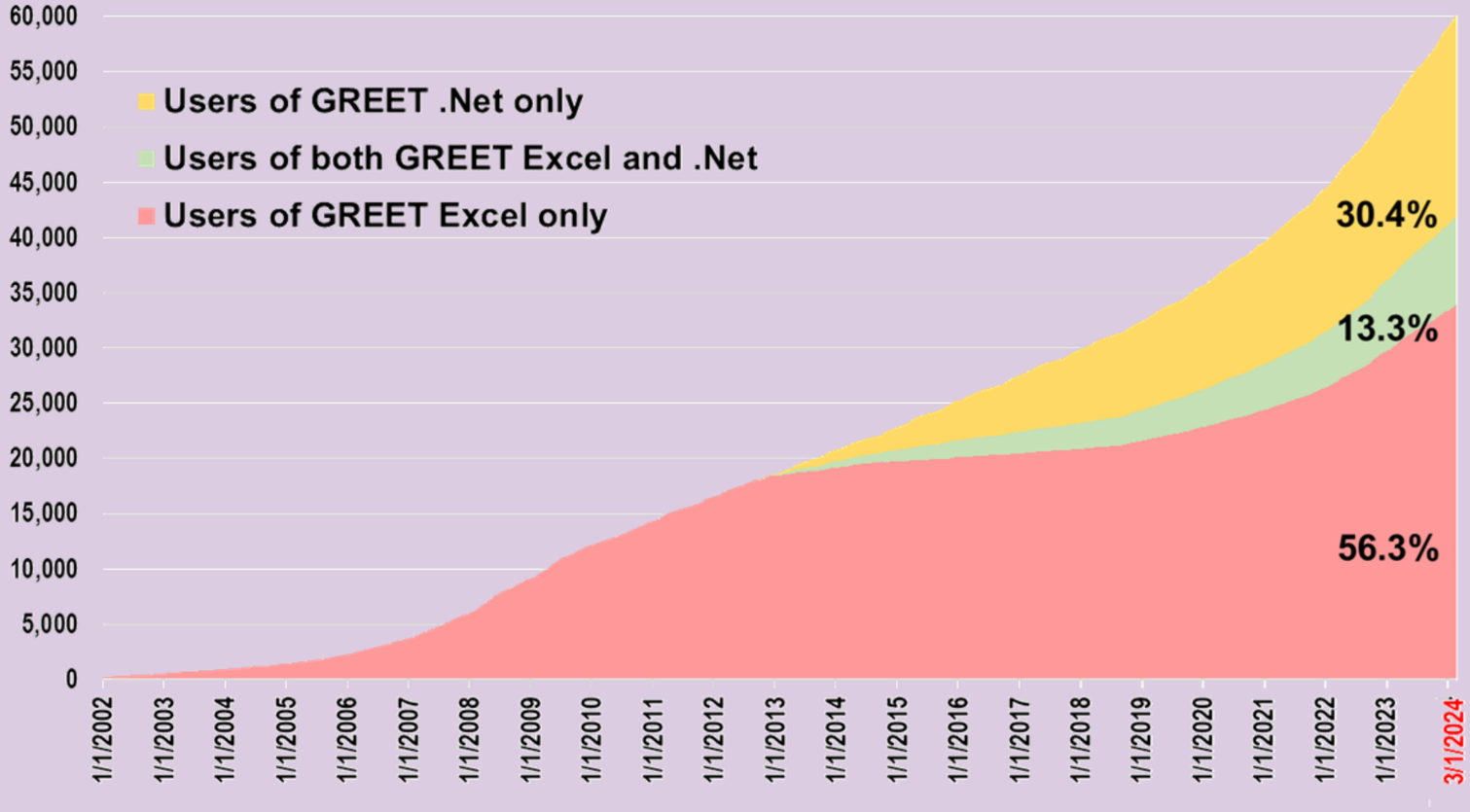
Water consumption

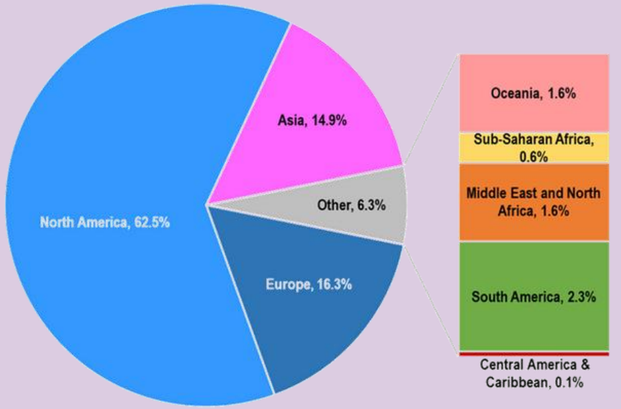
- Water consumption by different stages of technology supply chains

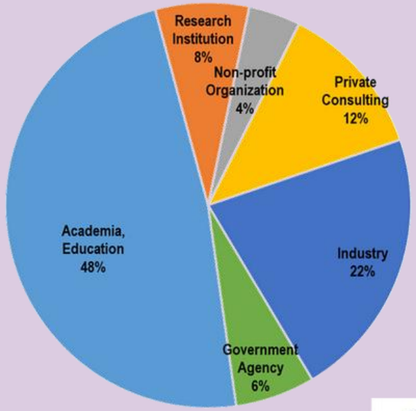
How is R&D GREET Used?

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

~ 60,000 registered GREET users globally







GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

GREET models are used to inform policies and regulations

CA-GREET, Oregon Clean Fuels Program, and State of Washington are adapted from Argonne's GREET model

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

National Highway Traffic Safety Administration uses GREET for fuel economy regulation

Federal Aviation Administration and **the International Civil Aviation Organization** uses GREET to evaluate aviation fuel pathways

USDRIVE uses GREET for their Well-to-Wheels Report

U.S. Maritime Administration provides renewable marine energy options for IMO GHG intensity and sulfur limits

U.S. Dept. of Agriculture uses GREET for a bioenergy LCA for calculating carbon intensity of farming practices

Canadian Clean Fuel Regulation uses GREET for environment and climate change Canada fuel pathways

2021 Bipartisan Infrastructure Bill and **the 2022 Inflation Reduction Act** use LCA results for different provisions

GREAT PLAINS INSTITUTE | Argonne NATIONAL LABORATORY | U.S. Department of ENERGY

Questions?

hcai@anl.gov

golson@gpisd.net

Visit https://greet.anl.gov/

Contributors

Gabrielle Olson, Branden Leonhardt,

Longwen Ou, Uisung Lee, and Hao Cai

GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY

THANK YOU

GREAT PLAINS INSTITUTE

Argonne NATIONAL LABORATORY

U.S. Department of ENERGY