February 28, 2025

Introducing Trains and Tractors in R&D GREET®

2:00-3:00 p.m. CT

Instructors

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Table of contents

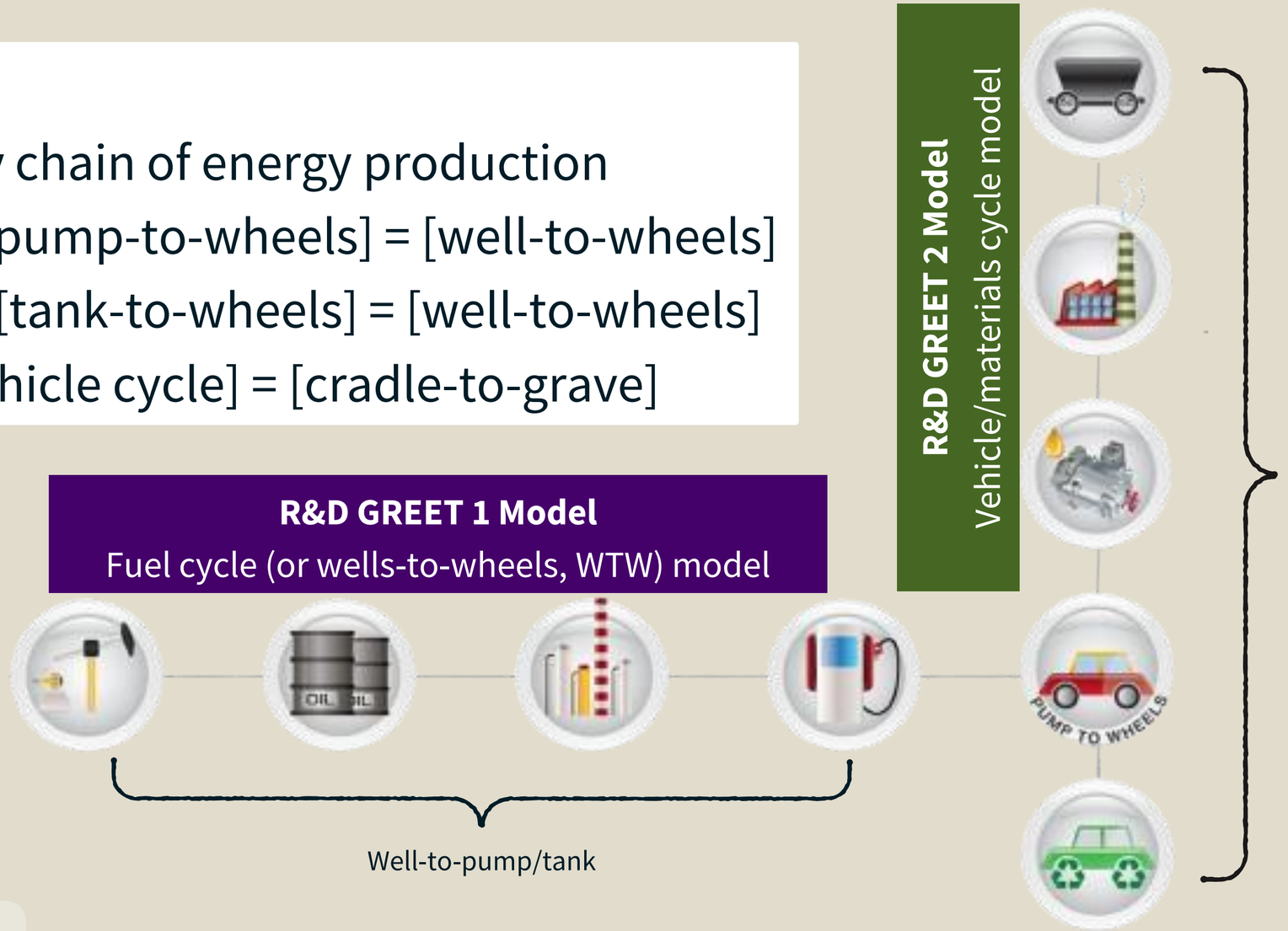
The R&D GREET model framework

R&D GREET 1: Fuel Cycle

- Includes the entire supply chain of energy production
- Trains: [well-to-pump] + [pump-to-wheels] = [well-to-wheels]
- Tractors: [well-to-tank] + [tank-to-wheels] = [well-to-wheels]
  - [well-to-wheels] + [vehicle cycle] = [cradle-to-grave]

Interacts with R&D GREET 2 for material cycle results*

*only relevant for tractors



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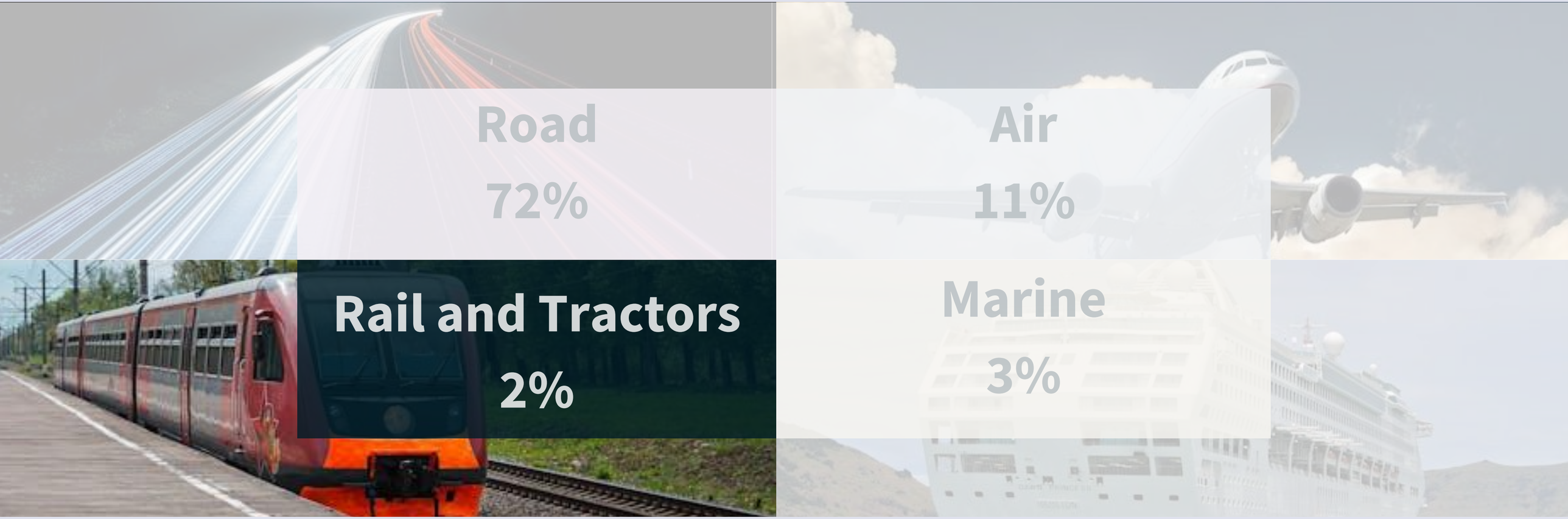
R&D GREET covers all transportation subsectors



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

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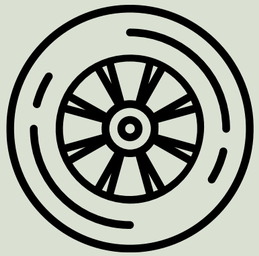
A simplified WTW pathway: *fuel cycle*

Process Progression



Emissions

Emissions

Emissions

Feedstock Stages
Production, Transportation, and Storage

Fuel Stages
Production, Transportation, Distribution, and Storage

Vehicle Operation
Vehicle Refueling, Fuel Combustion/conversion, and Fuel Evaporation

Energy Materials

Energy Materials

--- **Well-to-Wheels (WTW) System Boundary**

WTP/T Stages

P/TTW Stage

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A simplified vehicle cycle: *vehicle production (tractors)*

Emissions

Step 1
Ore Mining and Extraction

Energy Material

Emissions

Step 2
Size Reduction and Concentration

Energy Material

Emissions

Step 3
Transport of Concentrate

Energy Material

Emissions

Step 4
Chemical and Heat Treatments

Energy Material

Emissions

Step 5
Material Forming

Energy Material

Emissions

Step 6+
Any Other Processes

Energy Material

Emissions

Step 7
Vehicle Component Production

Energy Material

Emissions

Step 8
Vehicle Assembly

Energy Material

Tractor

Material Production

Vehicle Production

--- Vehicle Cycle System Boundary

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Train types in R&D GREET

Freight Rail (Class I)

Passenger Rail

Intercity (Amtrak)

Commuter

Light transit

Heavy transit

Available fuel pathways for rail engines in R&D GREET

Fossil	Fossil and Biomass	Renewable Fuels
• Diesel • Liquefied natural gas (LNG) • Liquefied petroleum gas (LPG) • Fischer-Tropsch Diesel (FTD)	• Dimethyl ether (DME) • FTD • Renewable gasoline (RG) • Biodiesel (BD)	• Hydrogen • Electricity • FTD • DME • Renewable diesel (RD)

Rail fuels in R&D GREET

Diesel

Feedstock: *crude oil and hydroprocessed pyrolysis oil*

LNG

Feedstock: *conventional and shale gas*

LPG

Feedstock: *crude oil and natural gas*

Rail fuels in R&D GREET

FTD

Feedstock: *natural gas, flared gas, natural gas/biomass, biomass, coal or coal/biomass via gasification*

RD, RG, and Biodiesel

Feedstock: *soybean, palm, rapeseed, jatropha, camelina, and algae*

DME

Feedstock: *natural gas, flared gas, biomass or coal via gasification*

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Rail fuels in R&D GREET

Liquid Hydrogen

Feedstock: *natural gas via steam methane reforming, electrolysis via solar photovoltaic, nuclear (thermos-chemical cracking of water), electrolysis with nuclear HTGR, coal or biomass gasification, and coke oven gas*

Distributed Liquid Hydrogen

Feedstock: *natural gas, electrolysis, ethanol, and methanol*

Electricity

Feedstock: *U.S. mix, North American Electric Reliability Corporation (NERC) Regional mix, natural gas power plants, oil power plants, coal power plants, nuclear power plants, hydroelectric power plants, natural gas combined cycle power plants, and geothermal power plants*

Data and Methods for Rail Vehicles in R&D GREET

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Rail fuel economy and emission factors in R&D GREET 1

Emission Factors

[g CO_2e/mmBtu fuel consumed]

Rail vehicles use emission factors in table 5.1 of "Rail_PTW" tab

Fuel Economies

Rail vehicle fuel economies for alternative fuels are estimated based on literature and simulation data from literature

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Data and methods for rail vehicles in R&D GREET

Energy Intensity Calculation

Energy intensity for freight railroad

$$= \frac{\text{Fuel use x lower heating value}}{\text{Ton-mile}}$$

Energy intensity for passenger railroad

$$= \frac{\text{Fuel use x lower heating value}}{\text{Passenger-mile}}$$

Data and methods for diesel-electric rail vehicles

For Intercity Rail

Fuel use & passenger-mile data source: *Amtrak Monthly Performance Report*

For Commuter, Light Transit, and Heavy Transit

Fuel use & passenger-mile data source: *2019 National Transit Database*

For Freight Rail

Fuel use & ton-mile data source: *2019 Surface Transportation Board R1 Report*

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Data and methods for rail vehicles in R&D GREET

GHG Emission Factors

CH_4 and N_2O emissions are estimated by multiplying the fuel specific heat input (in mmBtu) by the appropriate EFs from Table C-2 of EPA's Final Mandatory Reporting of GHG Rule (EPA 2009)

CO_2 emissions are calculated from fuel carbon intensity and fuel consumption

Criteria Air Pollutants (CAP) and Water Consumption

Criteria air pollutants (EPA NEI 2017, EIA, and e-GRID)

Water consumption (EIA and USGS)

Electricity Generation Mixes

Regional and national mixes (EIA's annual energy outlook)

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Capabilities for rail vehicles in R&D GREET

Units for Rail in R&D GREET

Per ton-mile, per passenger-mile, and per energy unit (mmBtu/MJ)

Vehicle Types for Rail in R&D GREET

Freight and passenger: intercity (Amtrak), commuter, light transit, and heavy transit

Fuel Types for Rail in R&D GREET

Gasoline, diesel, biodiesel, renewable diesel, renewable gasoline, dimethyl ether (DME), LNG, LPG, Fischer-Tropsch diesel (FTD), electricity, and hydrogen

Energy and Environmental Metrics in R&D GREET

Energy intensities of total, fossil (petroleum, gas, coal), renewable (biomass, hydro, wind, solar), nuclear, water use intensities, GHG emission intensities (total and CO_2, CH_4, and N_2O separately), air pollutants' emissions intensities of VOC, CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, BC, and OC

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Rail tabs in R&D GREET

Primary

Rail_WTP

Rail_WTW

Some Secondary

Fuel_Prod_TS

Fuel_Specs

EF

Petroleum

NG

Hydrogen

Algae

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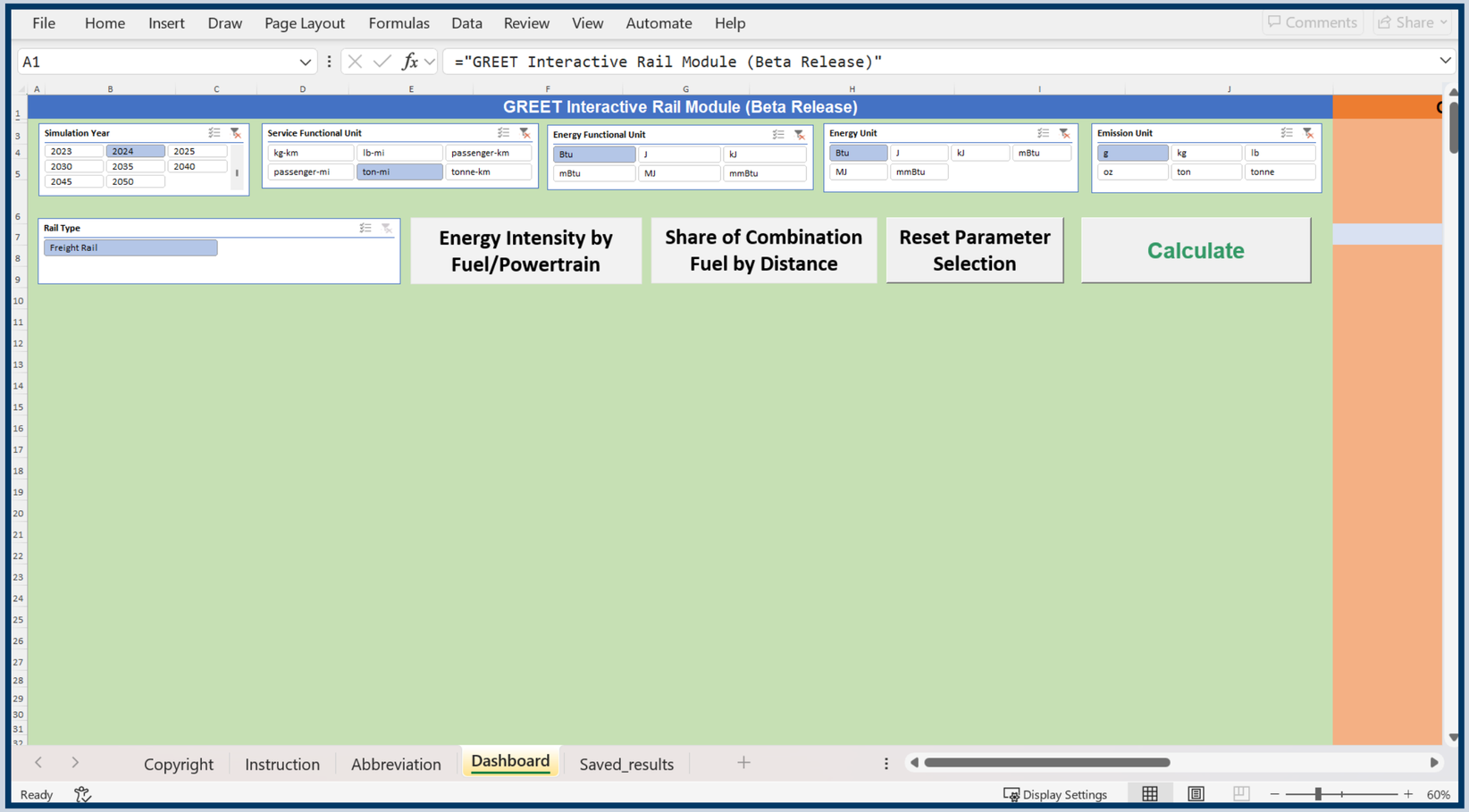
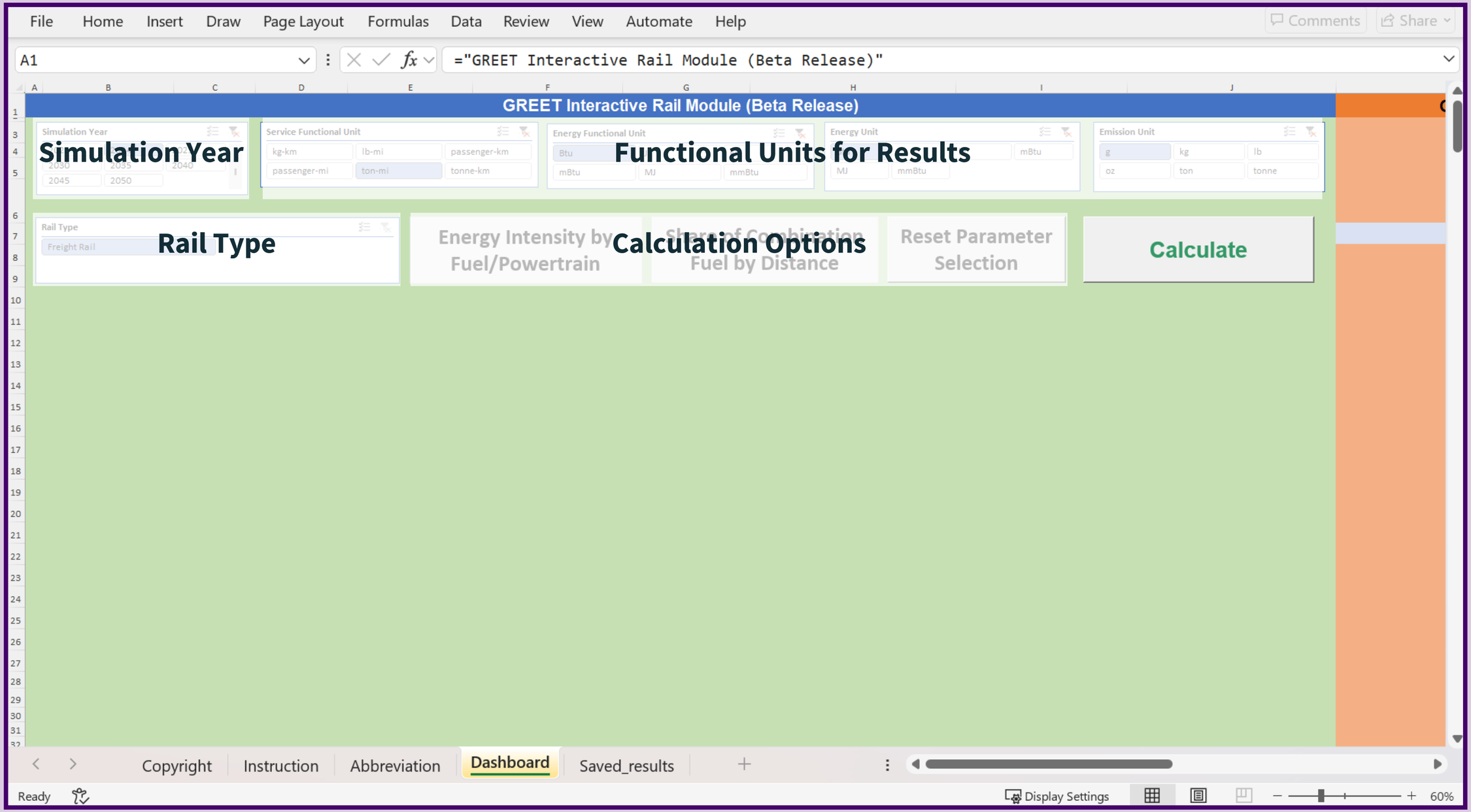
GREET rail module

Allows users to compare fuels for rail vehicles



[- R&D GREET Rail Module]



[- R&D GREET Rail Module]

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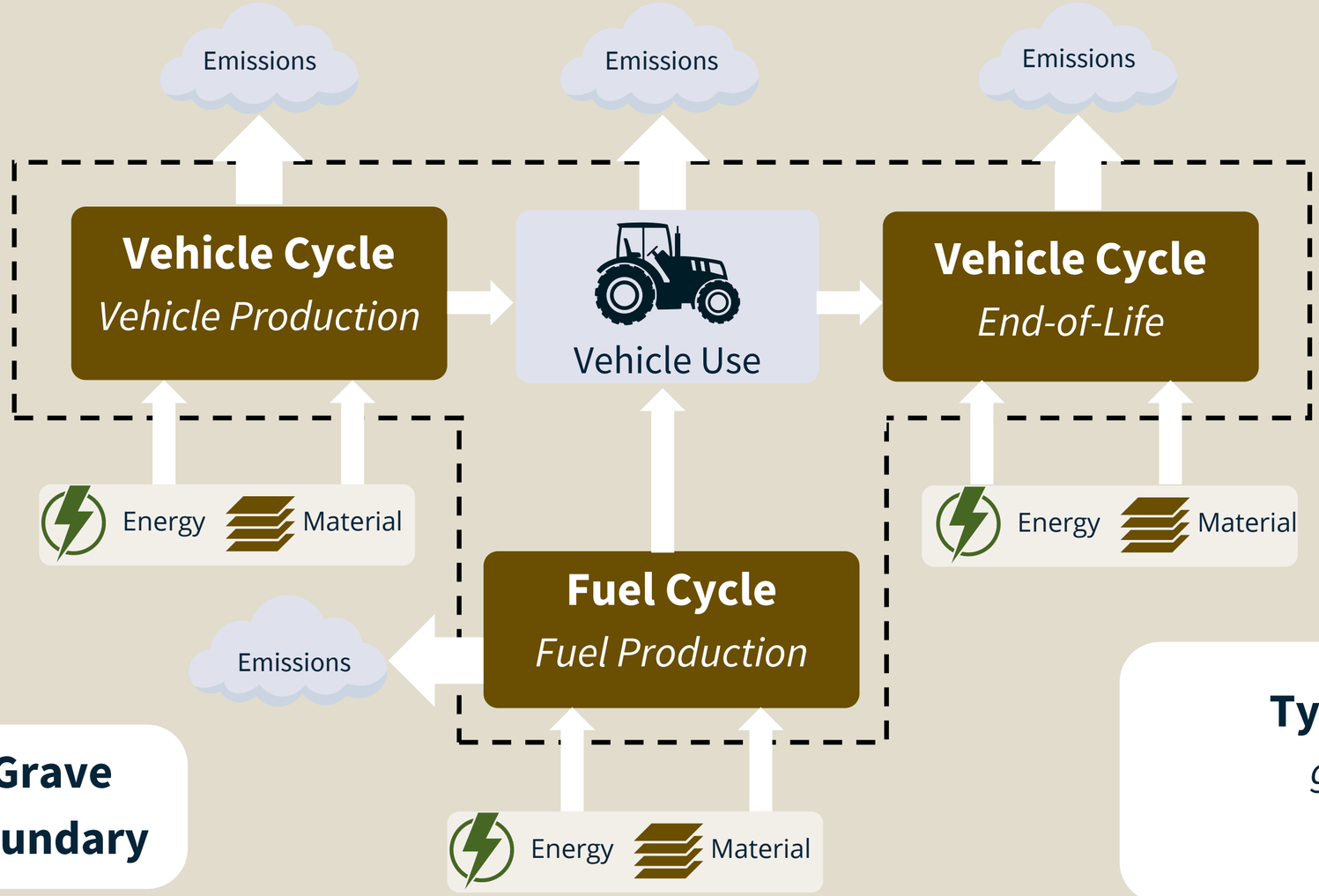
C2G life cycle in R&D GREET: *cradle-to-grave analysis*



--- **Cradle-to-Grave (C2G) System Boundary**

Typical Units

g CO_2e/mile

g CO_2e/hr

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Available fuel pathways for tractors in R&D GREET

Fossil	Fossil and Biomass	Renewable Fuels
• Diesel • Electricity • Fischer-Tropsch Diesel (FTD)	• Dimethyl ether (DME) • FTD • Biodiesel (BD)	• Hydrogen • Electricity • FTD • DME • Renewable diesel (RD)

Data and Methods for Tractors in R&D GREET

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Tractor fuel economy and emission factors in R&D GREET 1

Emission Factors

WTP emission factors come from each fuel production pathway, while PTW emission factors come from the GREET emission factors database for locomotives since they have similar EPA emissions regulations

Fuel Economy

Tractor energy consumption rates for conventional diesel internal combustion engine vehicles and alternative powertrains are calculated based on Autonomie tractor simulations at 50%, 75%, and 100% of maximum pulling power

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Data and methods for tractors in R&D GREET

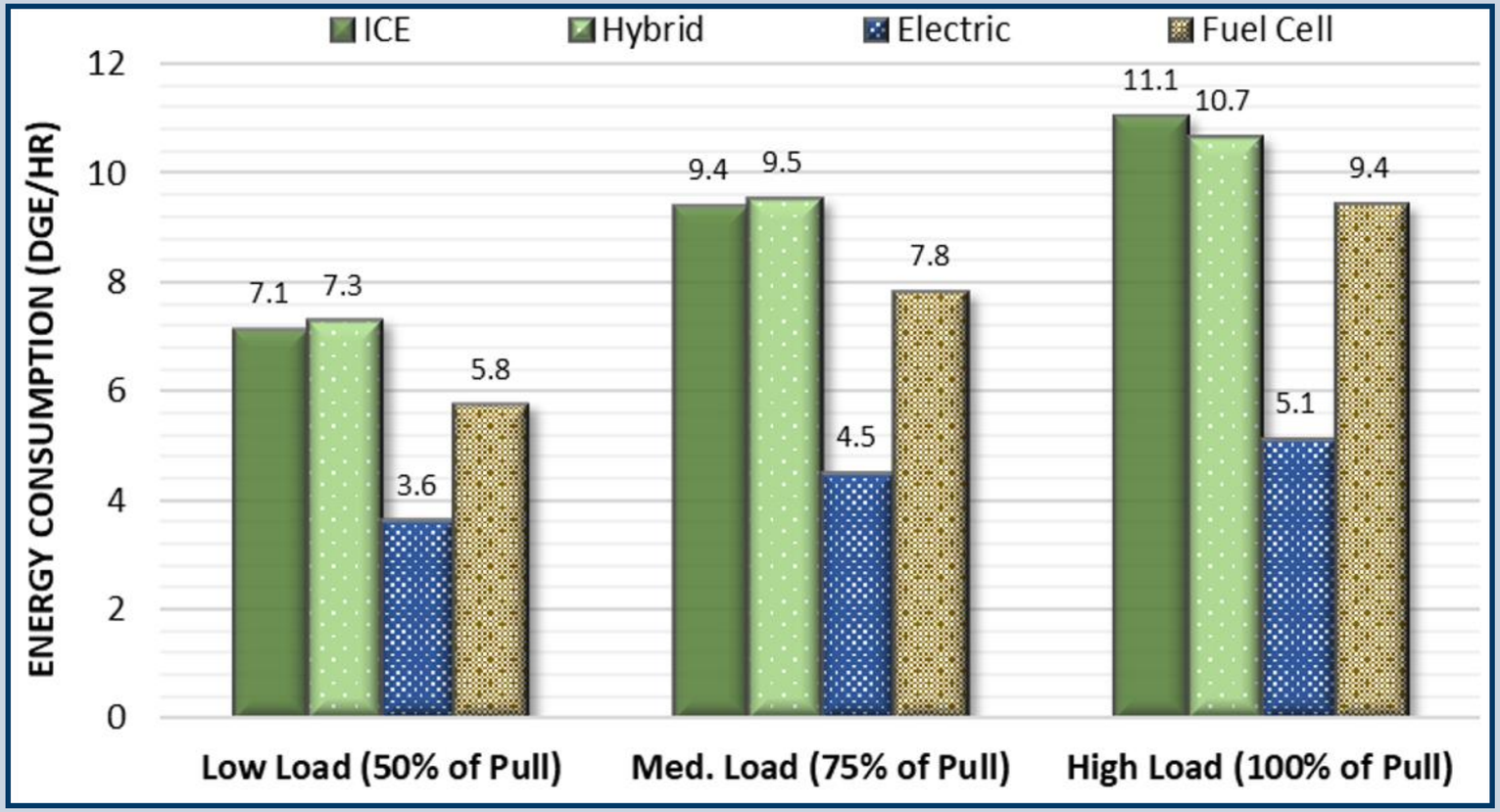
Energy Consumption Calculation

Tractor energy consumption is calculated from default or user-defined field operations by the percent of pull

Pull covers spraying, planting, harvesting, plowing, and more

Note: this figure was generated for illustrative purposes. As Argonne's Autonomie Model is updated, the values could change

Autonomie Large Off-road Tractor Modeling Results



- Argonne Autonomie Model

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Modeling assumptions for tractors in R&D GREET

Tractors are assumed to carry an **equal mix** of low, medium, and high load operations throughout the vehicle's lifetime

Non-powertrain components **remain the same** between tractors of different powertrains (hydraulic system, tractor chassis, tires, wheels, cab, 4WD system and more)

Battery electric tractors' battery size are determined for **10 hours of operation**

550 hours of operation are assumed **per year**

Modeling assumptions for tractors in R&D GREET

The tractor is assumed to have a **15,000 hour lifetime**

Front and rear tires are assumed to be **replaced** every 3,500 hours

Soil effects (tractor, crop yield, and more) are **not** taken into account

Additional support structure for batteries or hydrogen tanks is **not** added into the model

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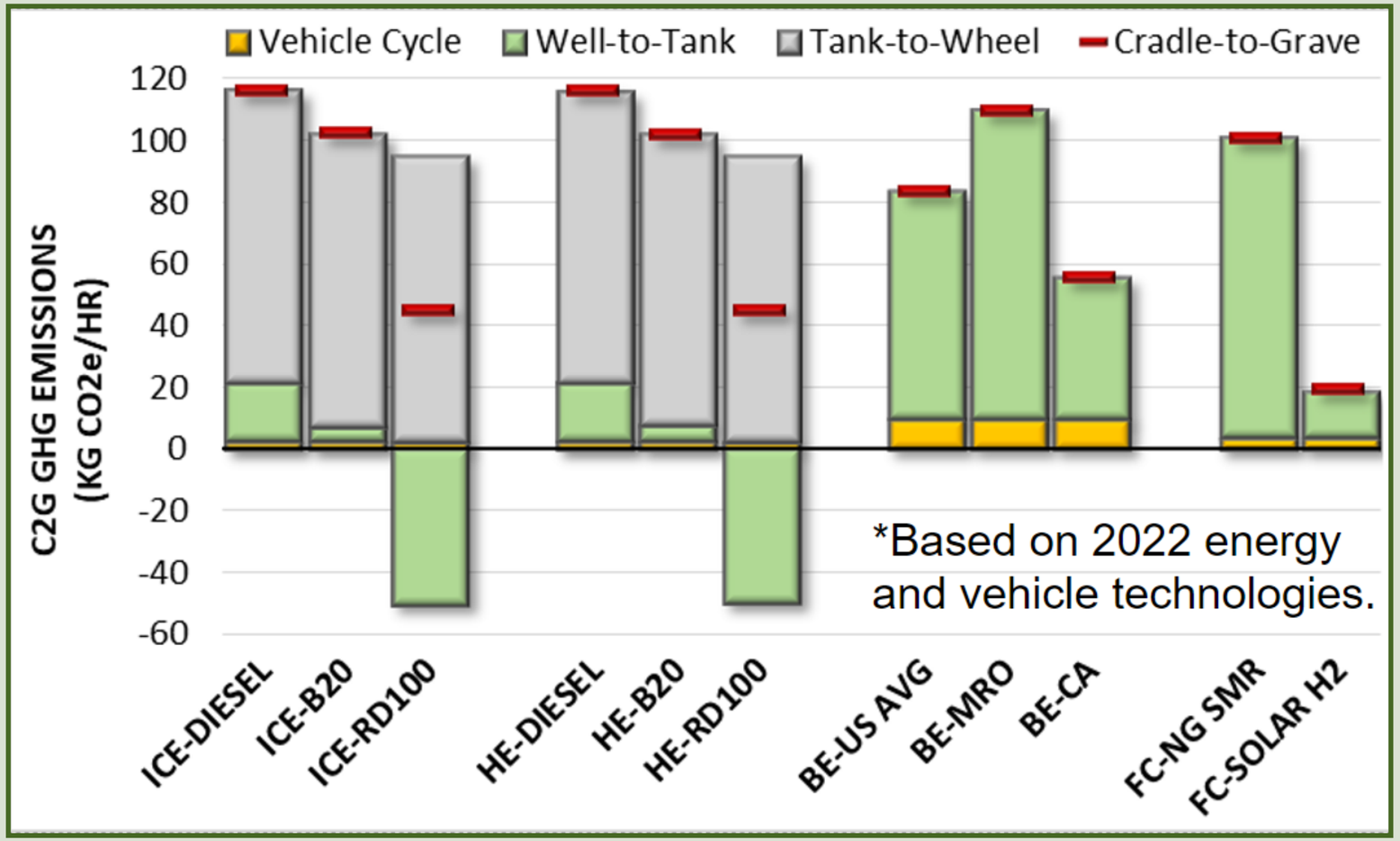
Life cycle C2G GHG emissions in R&D GREET 2

Large Tractor Life Cycle Cradle-to-Grave GHG Emissions



- R&D GREET 2023

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Capabilities for tractors in R&D GREET

Types of Tractor Technologies in R&D GREET

Internal combustion engine, hybrid electric vehicle, battery electric vehicle, and fuel cell vehicle

Fuel Types for Tractors in R&D GREET

Diesel, biodiesel, renewable diesel, DME, FTD, hydrogen, and electricity

Energy and Environmental Metrics in R&D GREET

Energy intensities of total, fossil (petroleum, gas, coal), renewable (biomass, hydro, wind, solar), nuclear, water use intensities, GHG emission intensities (total and CO_2, CH_4, and N_2O separately), air pollutants' emissions intensities of VOC, CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, BC, and OC

WTW and C2G Results

WTW results can be found in the "Tractor_WTW" tab in R&D GREET 1

C2G results can be found in the "Tractor" tab of R&D GREET 2

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Tractor tabs in R&D GREET 1

Primary

Tractor_WTW

Some Secondary

Fuel_Prod_TS

Fuel_Specs

EF

Petroleum

NG

Hydrogen

Algae

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Tractor tabs in R&D GREET 2

Primary
Tractor

Some Secondary
All tabs not associated with other vehicle types
Examples: *“Car,” “SUV,” “PUT,” and more*

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