LIFE CYCLE ANALYSIS OF VEHICLES AND MATERIALS WITH THE GREET LCA MODEL

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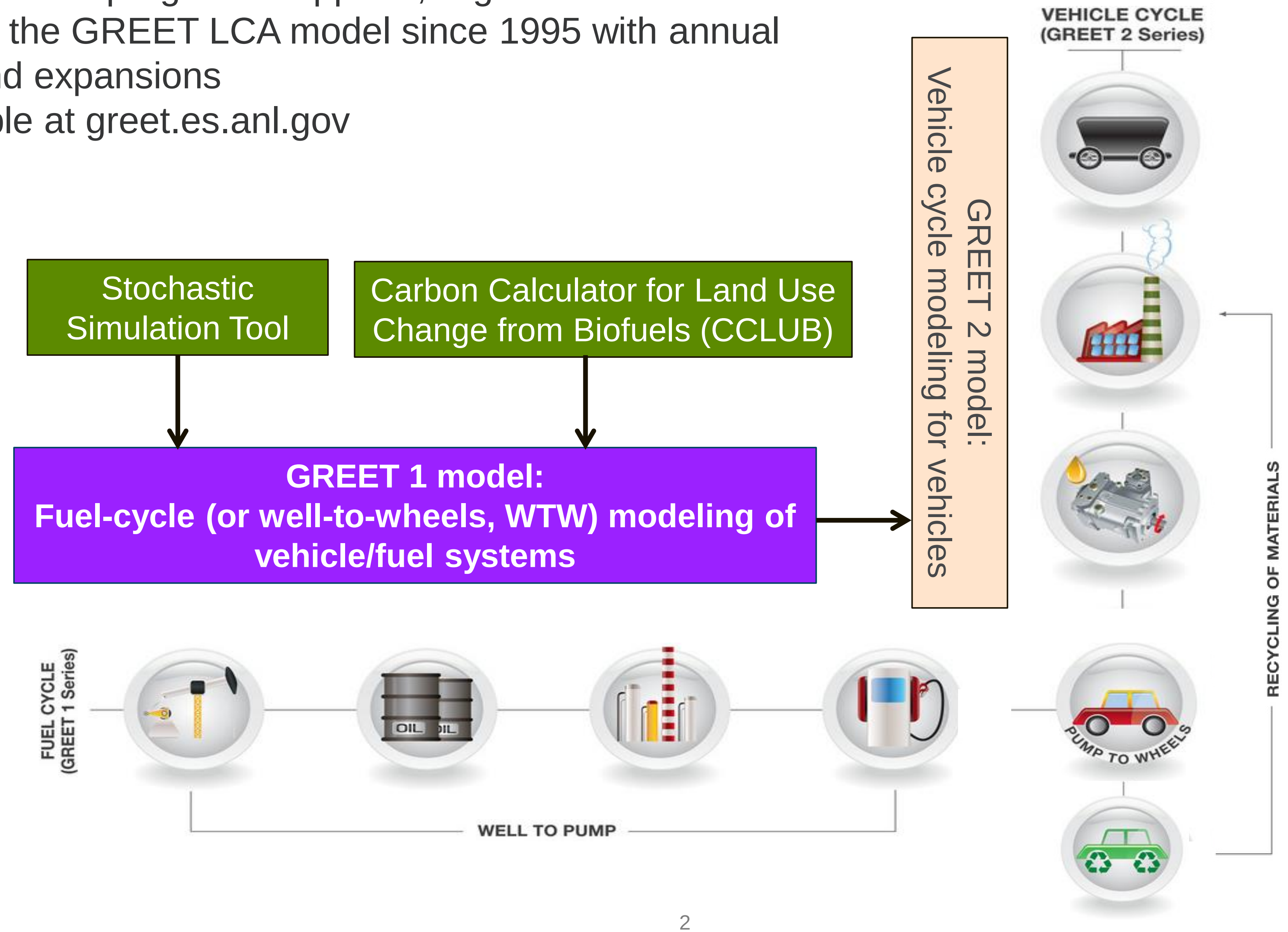
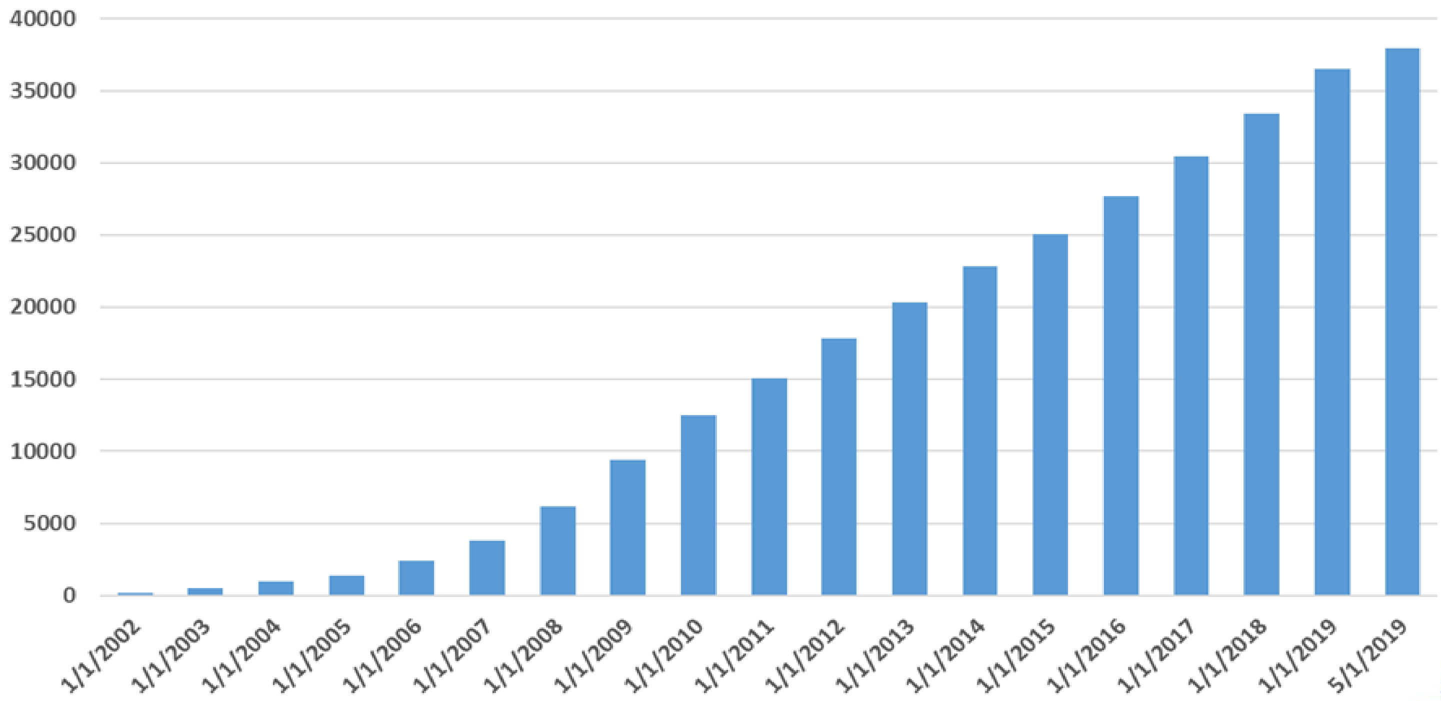
International Transport Forum Workshop
Paris, Oct. 1, 2019

The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model

- With DOE EERE programs supports, Argonne has been developing the GREET LCA model since 1995 with annual updates and expansions
- It is available at greet.es.anl.gov



There are 38,000 registered GREET users globally



- Geographically, 71% in North America, 14% in Europe, 9% in Asia
- 57% in academia and research, 33 % in industries, 8% in governments

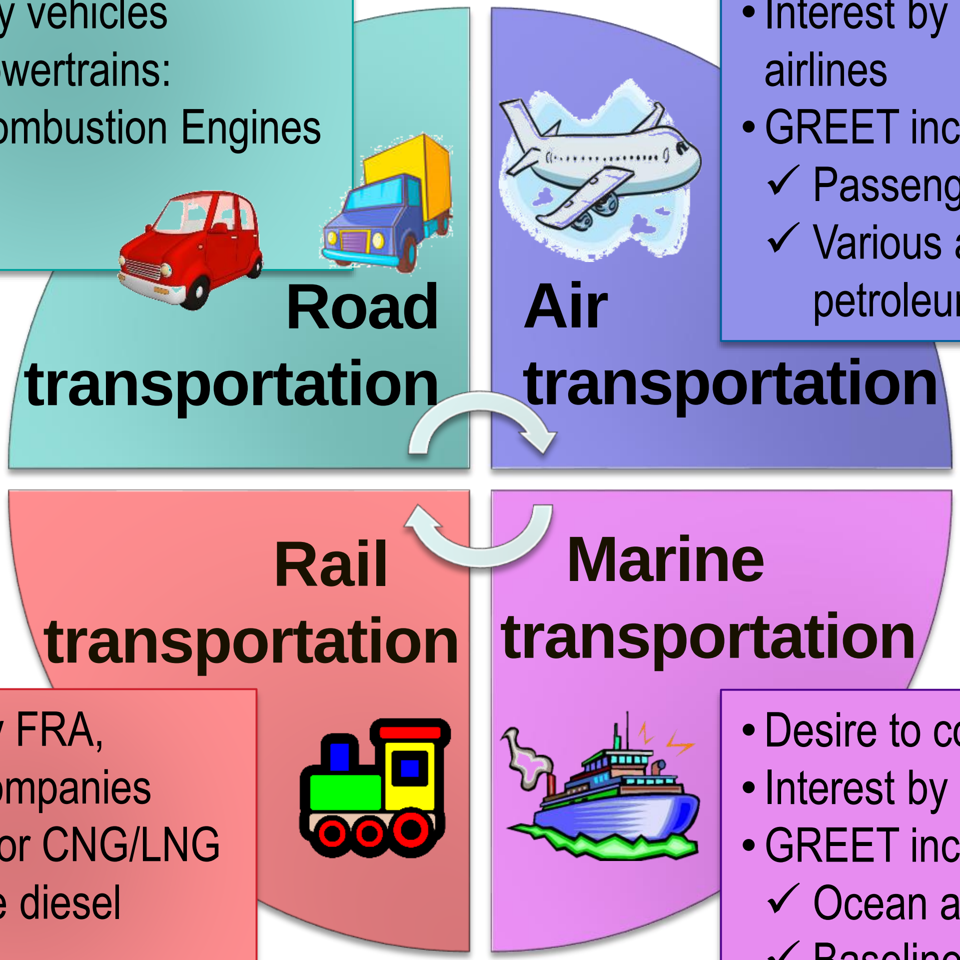
GREET outputs include energy use, criteria pollutants, greenhouse gases, and water consumption

- **Energy use – addressing energy diversity/security**
  - Total energy: fossil energy and renewable energy
    - Fossil energy: petroleum, natural gas, and coal (they are estimated separately)
    - Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy
- **Air pollutants – addressing air pollution**
  - VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x
  - They are estimated separately for
    - Total (emissions everywhere)
    - Urban (a subset of the total)
- **Greenhouse gases (GHGs) – addressing climate change**
  - CO_2, CH_4, N_2O, black carbon, and albedo
  - CO_{2e} of the five (with their global warming potentials)
- **Water consumption – addressing water supply and demand (energy-water nexus)**

GREET includes all transportation subsectors

- Light-duty vehicles
- Medium-duty vehicles
- Heavy-duty vehicles
- Various powertrains:
  Internal Combustion Engines
  Electrics
  Fuel cells

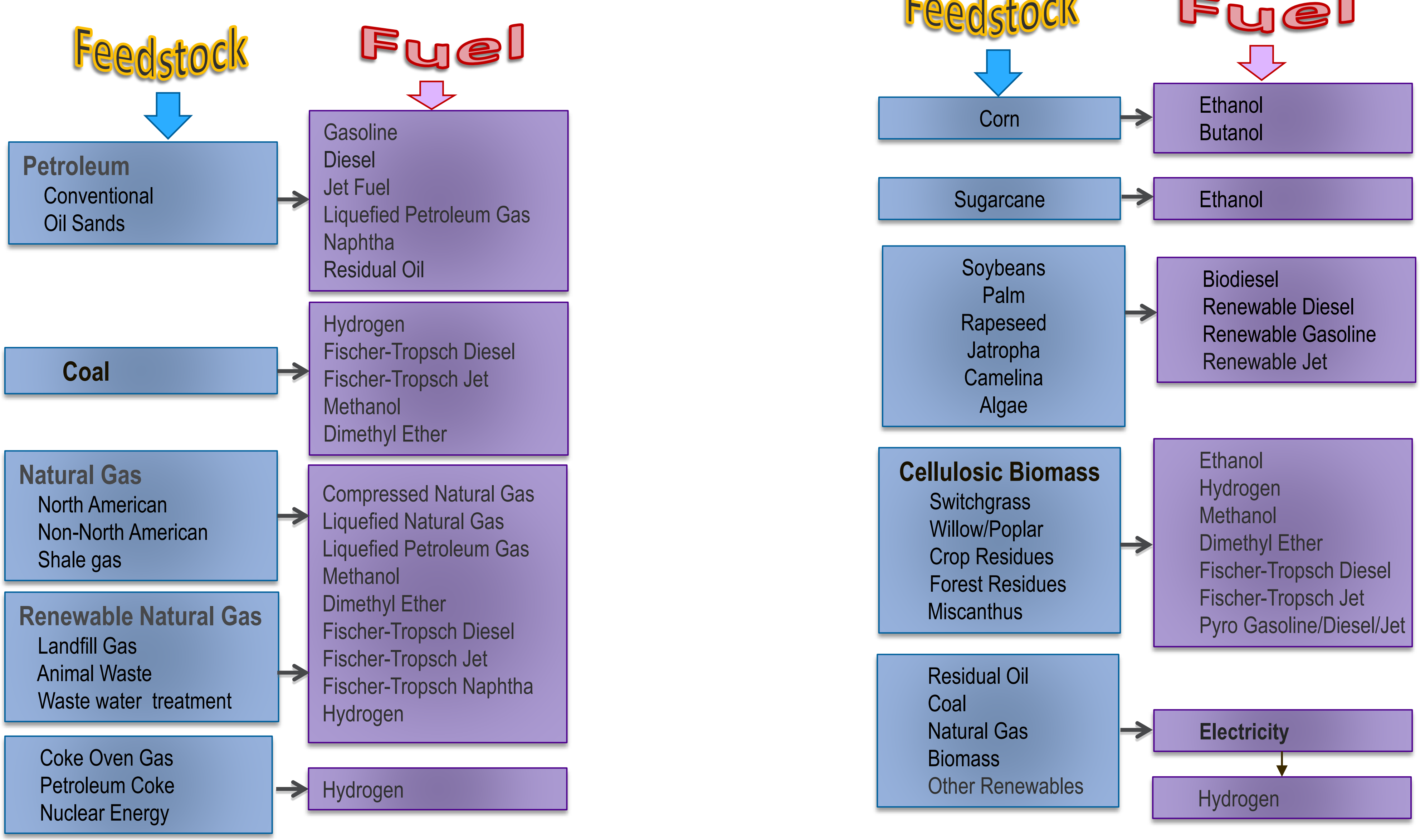
- Globally, a fast growing sector with GHG reduction pressure
- Interest by DOD, ICAO, FAA, and commercial airlines
- GREET includes
  - ✓ Passenger and freight transportation
  - ✓ Various alternative fuels blended with petroleum jet fuels



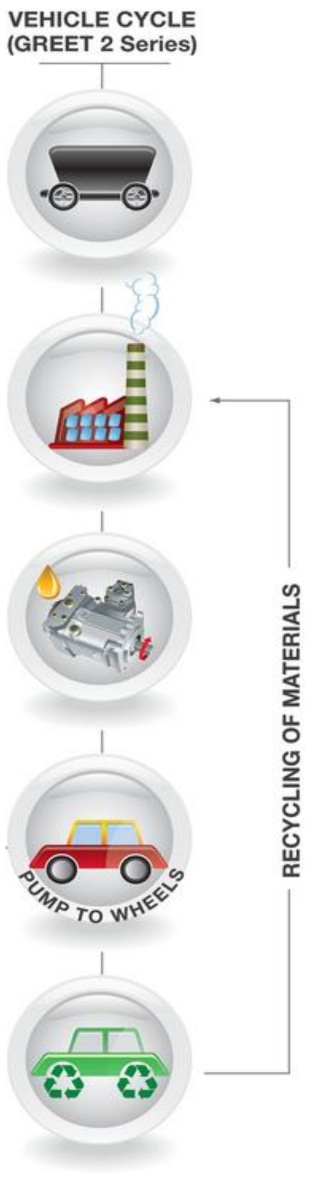
- Interest by FRA, railroad companies
- Potential for CNG/LNG to displace diesel

- Desire to control air pollution in ports globally
- Interest by EPA, local governments, IMO
- GREET includes
  - ✓ Ocean and inland water transportation
  - ✓ Baseline diesel and alternative marine fuels

GREET 1 includes more than 100 fuel production pathways from various energy feedstock sources

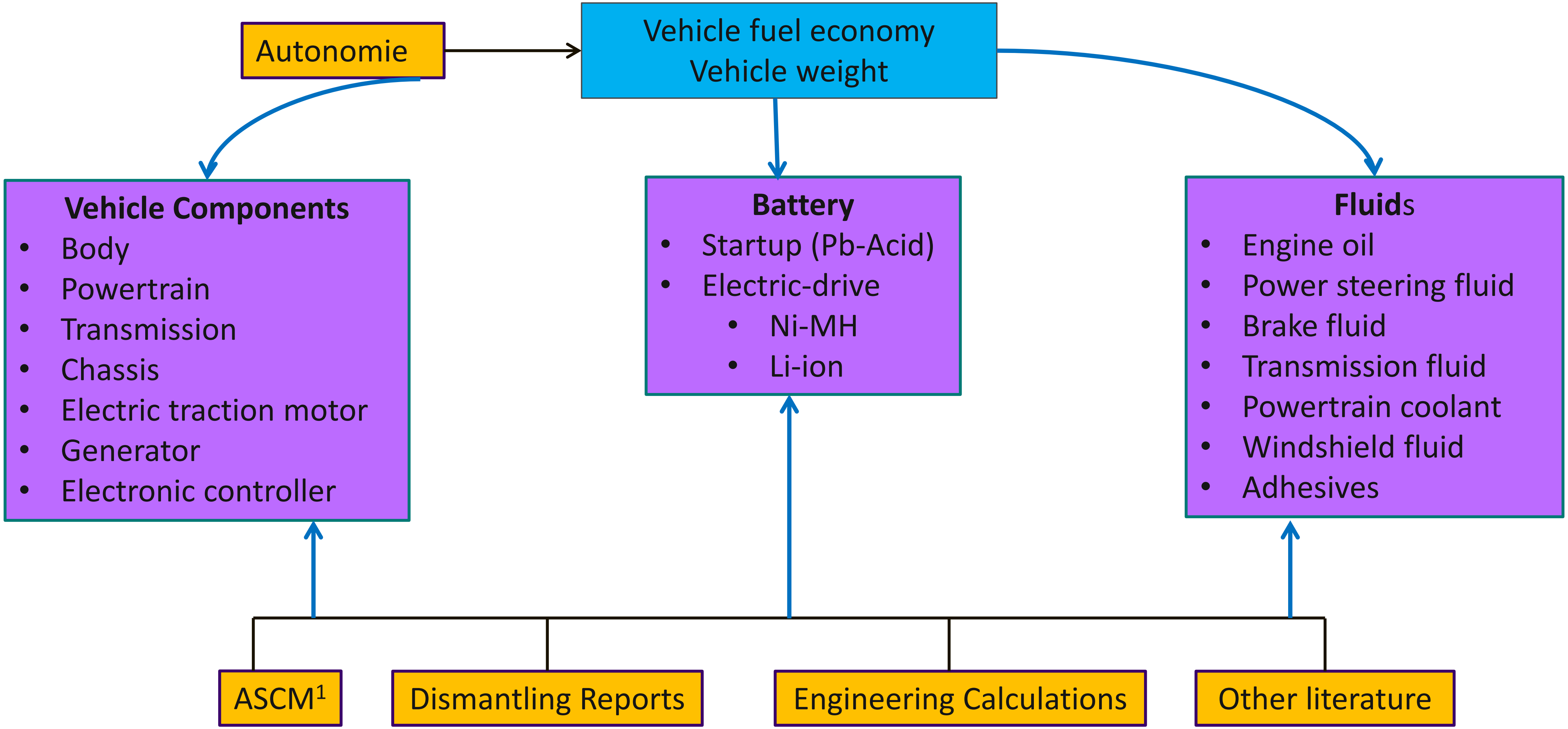


GREET 2 simulates vehicle cycle from material recovery to vehicle disposal



- Raw material recovery
- Material processing and fabrication
- Vehicle component production
- Vehicle assembly
- Vehicle disposal and recycling

GREET 2 includes vehicle components and their materials



1. Automotive System Cost Model, IBIS Associates and Oak Ridge National Laboratory

GREET 2 includes life-cycle inventories of 60+ materials

Material Type	Number in GREET	Examples
Ferrous Metals	3	Steel, stainless steel, iron
Non-Ferrous Metals	12	Aluminum, copper, nickel, magnesium
Plastics	23	Polypropylene, nylon, carbon fiber reinforced plastic
Vehicle Fluids	7	Engine oil, windshield fluid
Others	17	Glass, graphite, silicon, cement
Total	**62**	

Key issues in vehicle-cycle analysis

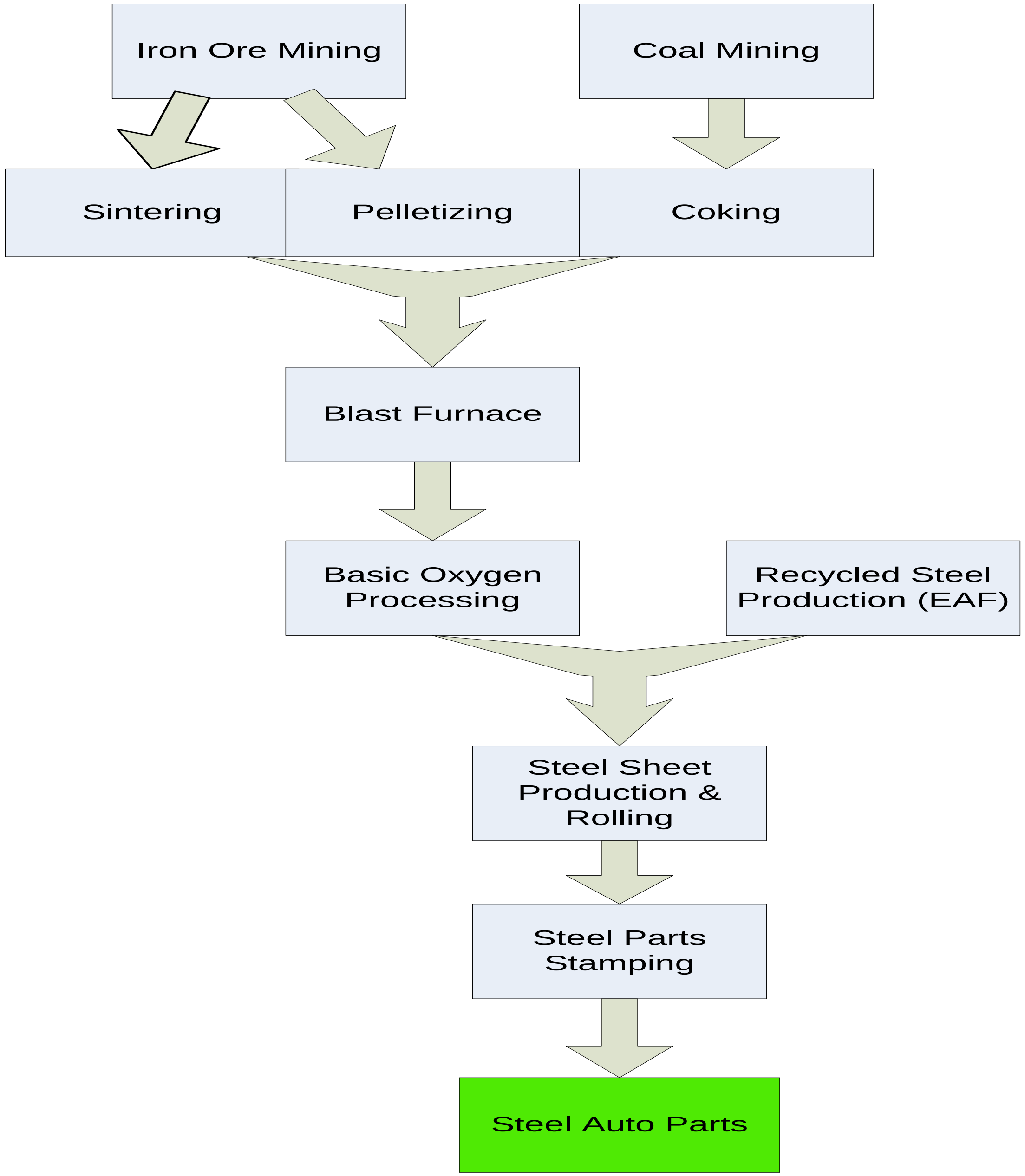
- Use of virgin vs. recycled materials
- Vehicle weight and lightweighting
- Vehicle lifetime, component rebuilding/replacement

GREET relies on a variety of data sources

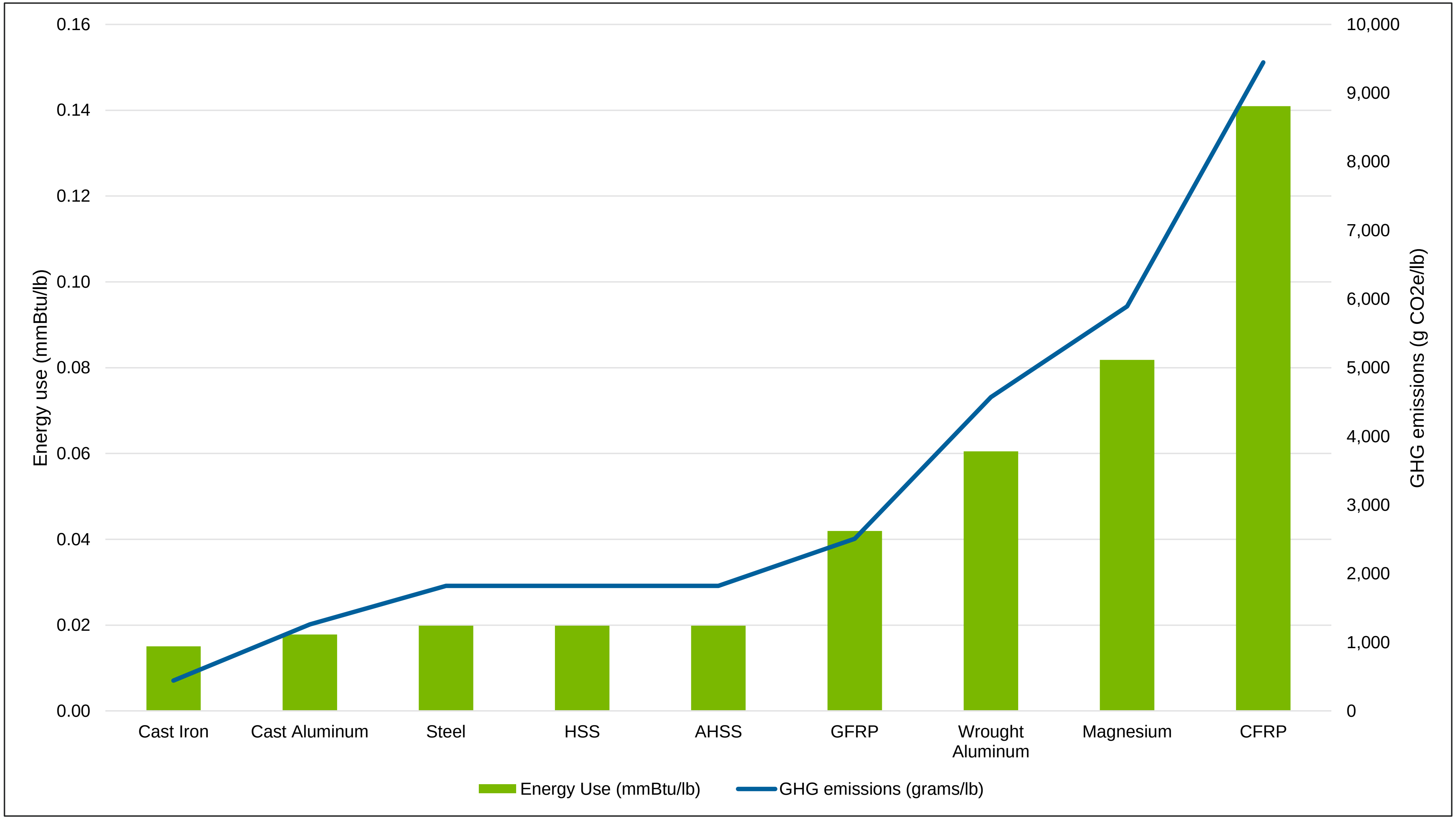
- Baseline technologies and systems
  - Energy Information Administration's data and its Annual Energy Outlook projections
  - EPA eGrid for electric systems
  - US Geology Services for water data
- Field operation data:
  - Oil sands and shale oil operations
  - Ethanol plants energy use
  - Farming data from USDA
- Simulations with models:
  - ASPEN Plus for fuel production
  - ANL Autonomie for fuel economy
  - EPA MOVES for vehicle emissions, EPA AMPD for stationary emissions
  - LP models for petroleum refinery operations
  - Electric utility dispatch models for marginal electricity analysis
- Collaboration with other national laboratories (e.g., techno-economic analysis results from NREL)
- Industry inputs:
  - Fuel producers and technology developers on fuels
  - Automakers and system components producers on vehicles

Key Parameters for Material Production: Example of Steel

- Steel is modeled step-by-step from ore mining to part stamping
- Other metals are examined in three stages
  - Mining
  - Primary (virgin) production
  - Secondary (recycled) production



Life cycle energy use and GHG emissions vary largely among automotive materials: GREET 2 results



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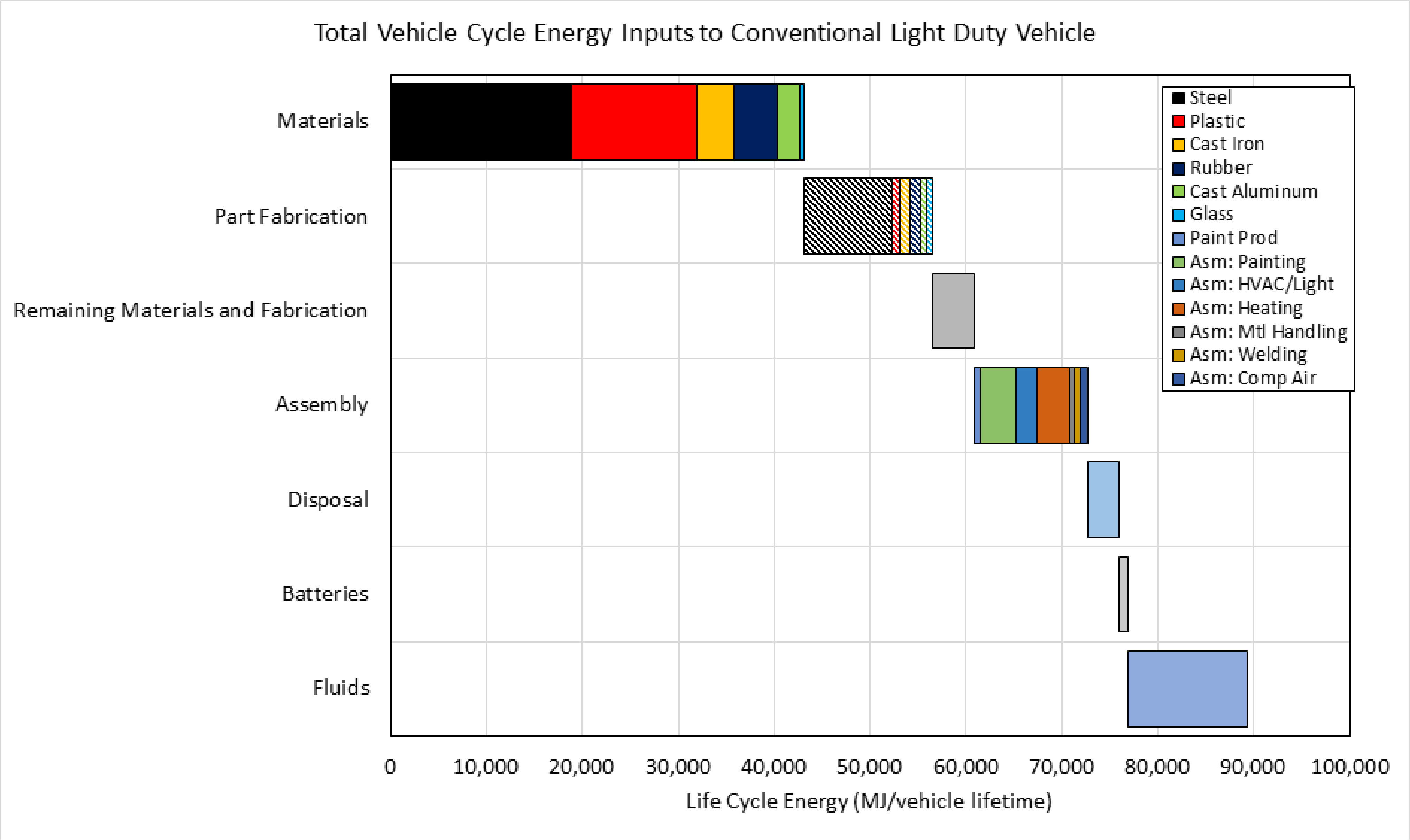

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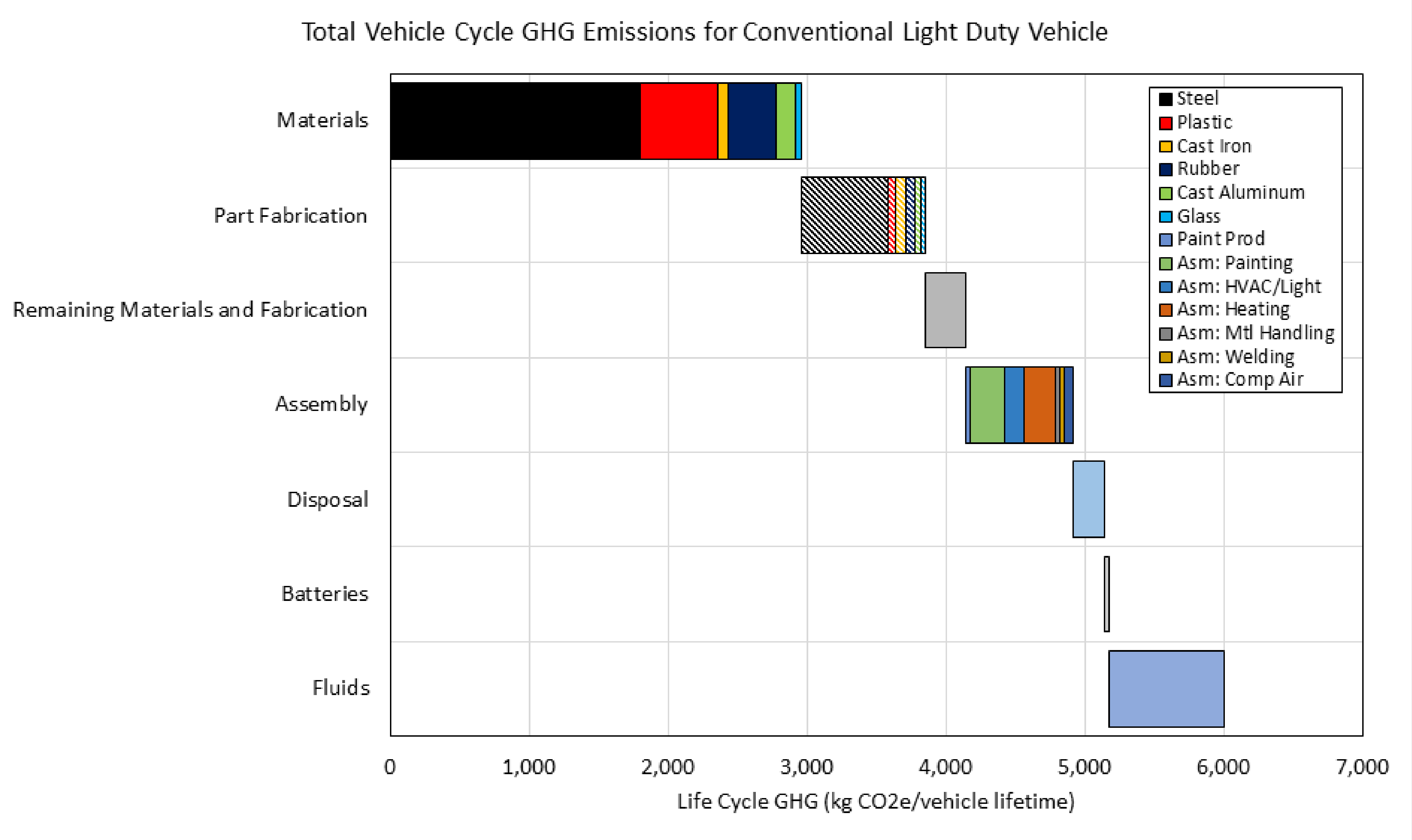
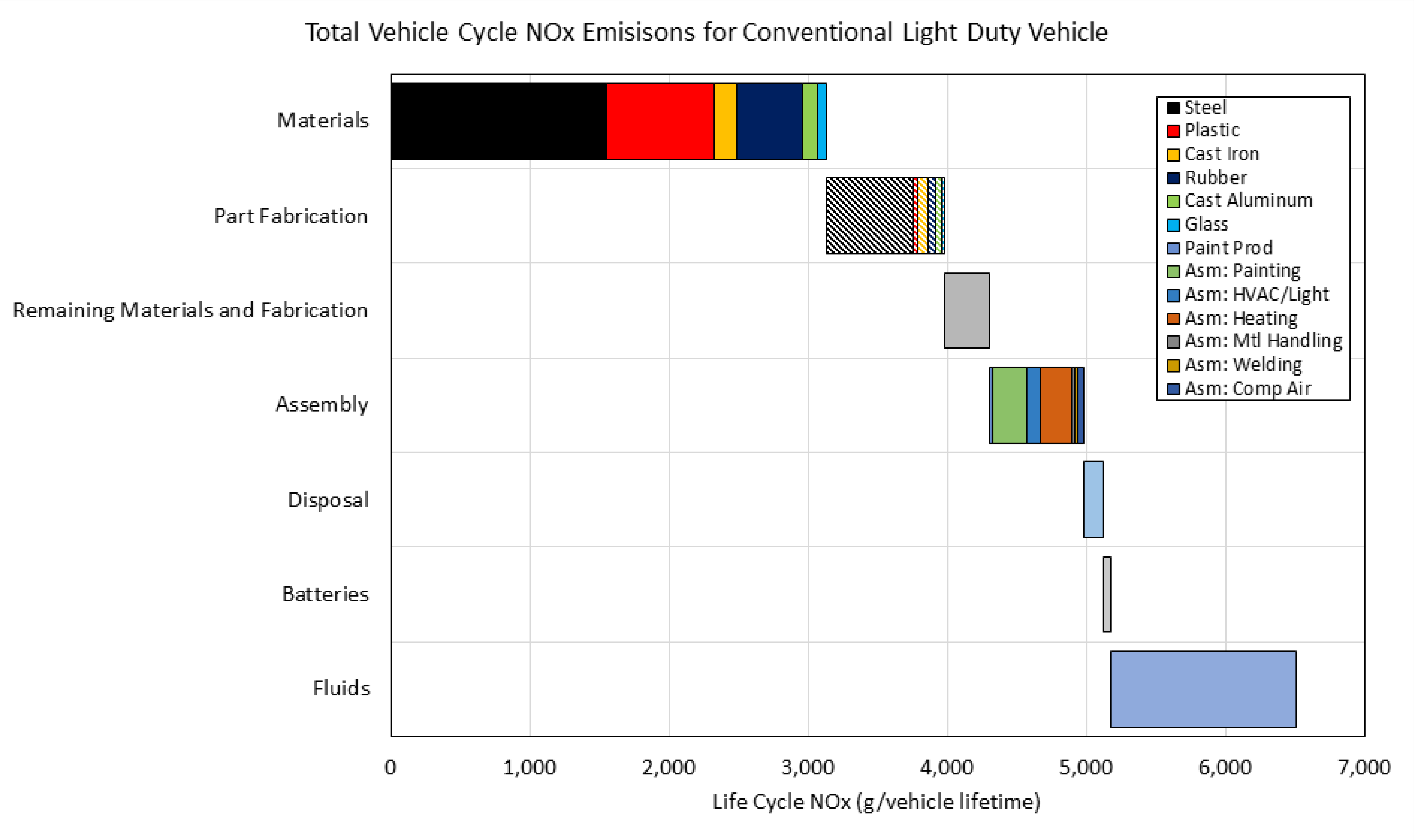
GREET 2 results: vehicle cycle GHG emissions



GREET 2 results: vehicle cycle NOx emissions



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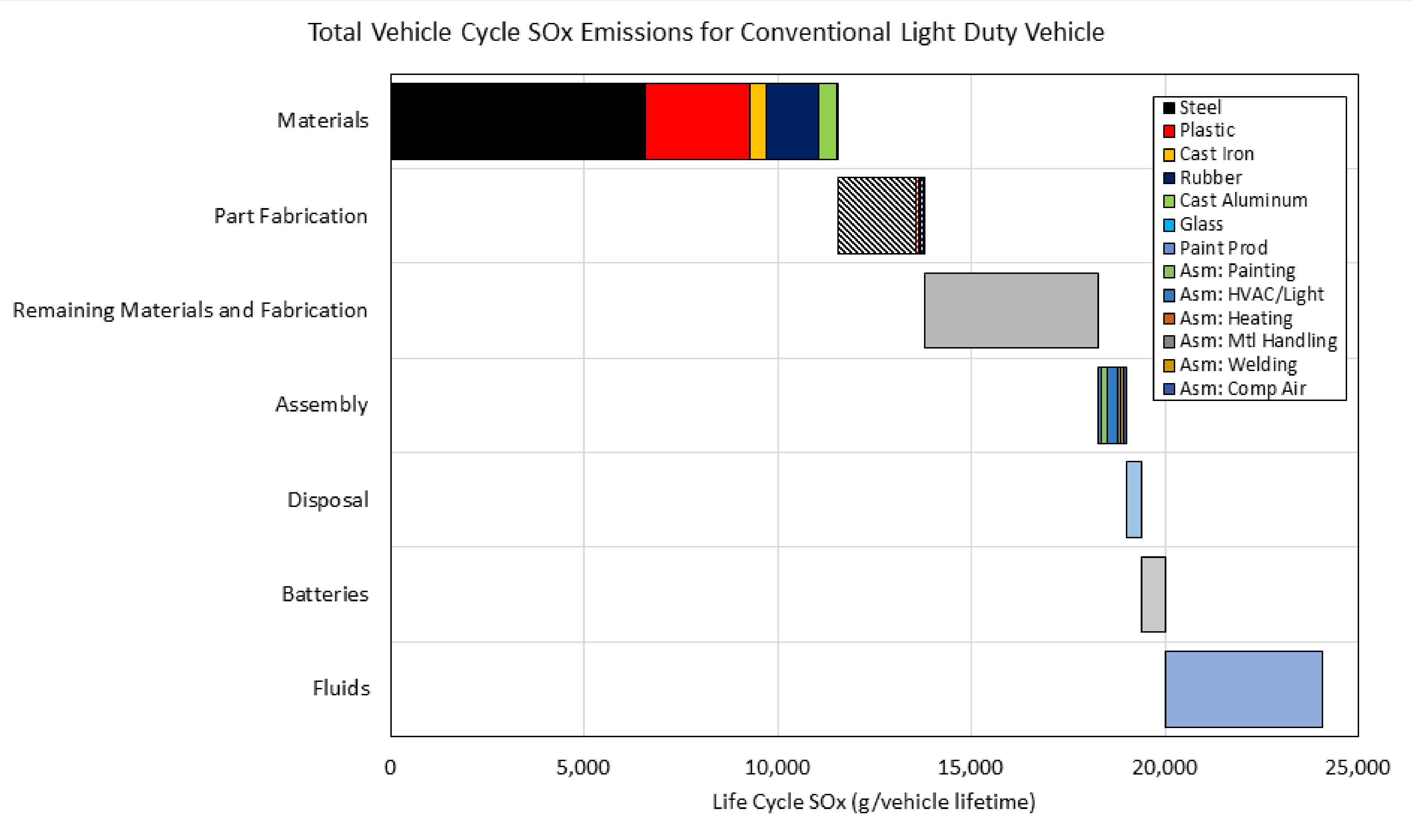
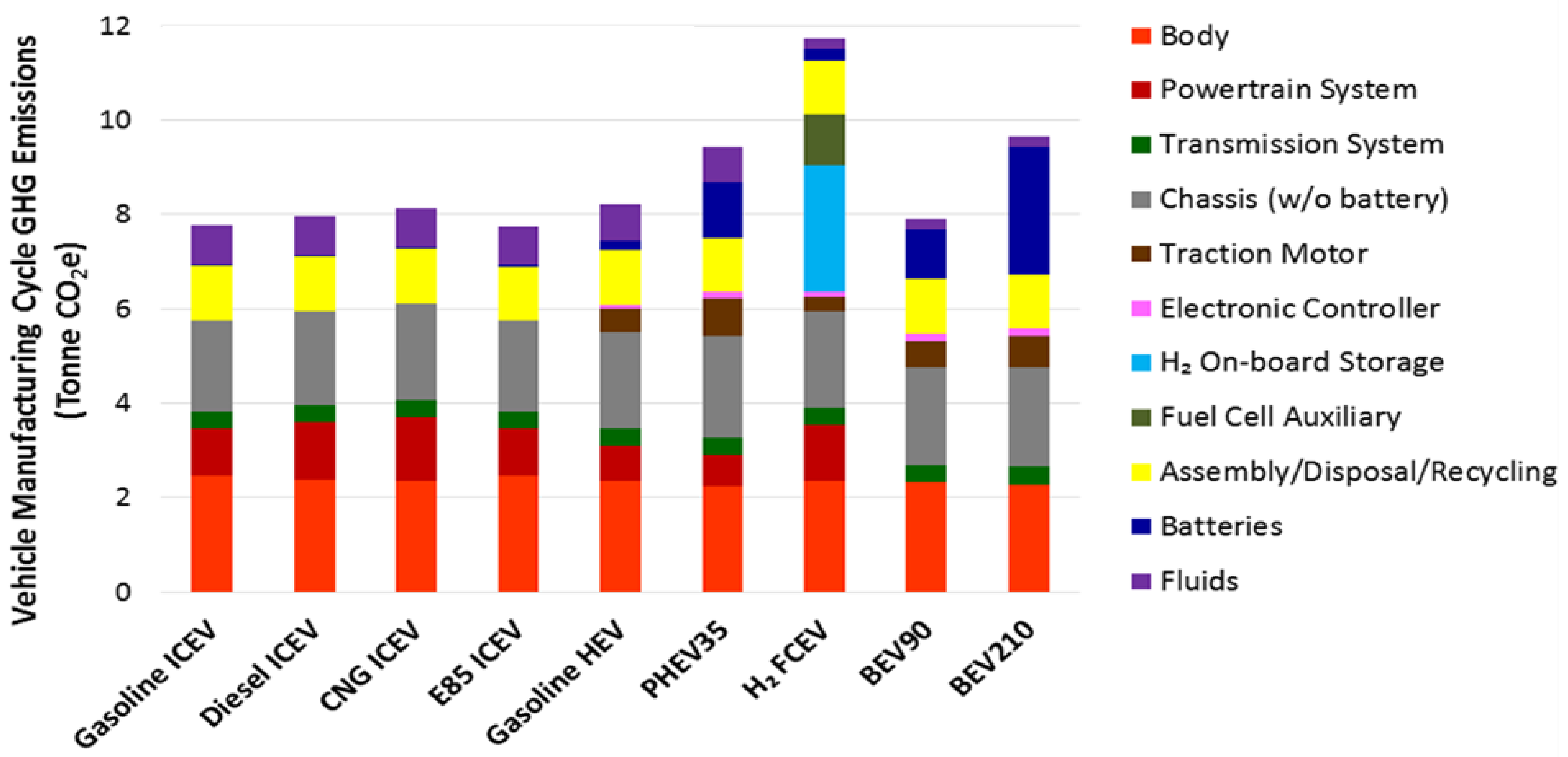
GREET 2 results: vehicle cycle SOx emissions



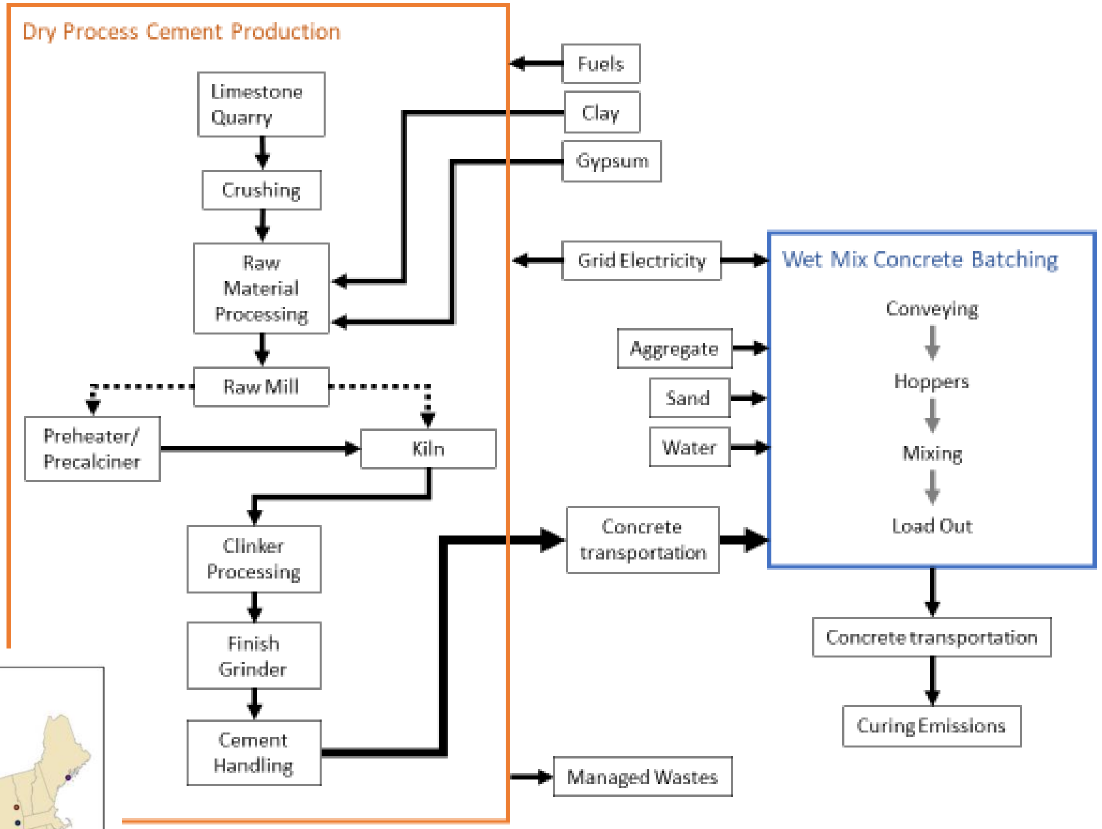
GREET 2 results for different powertrain technologies

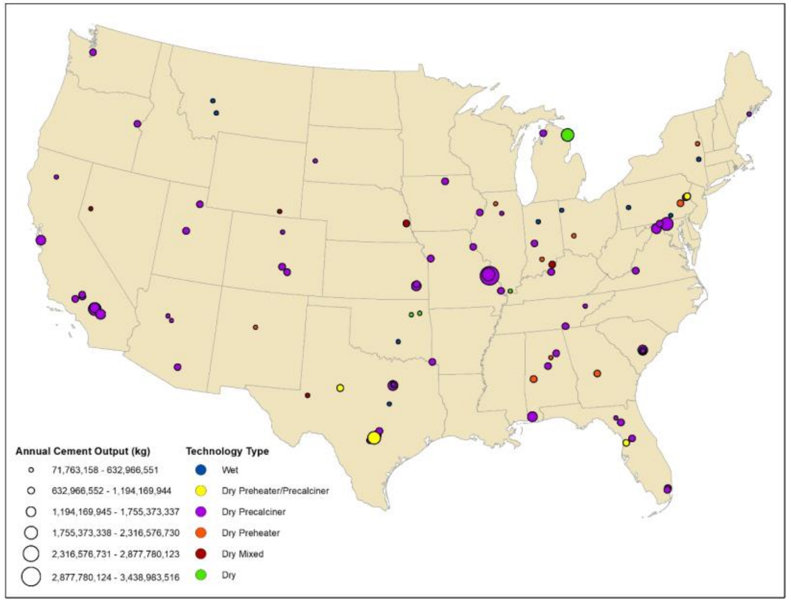


Expansion and Updating of Concrete and Asphalt LCI in GREET for Road Pavement LCA

Updated GREET cement/concrete LCI

- Incorporates publicly available data for 83 cement producers.
- Strong regional representativeness.





- Results parsed by technology: wet, dry, preheater, and precalciner.

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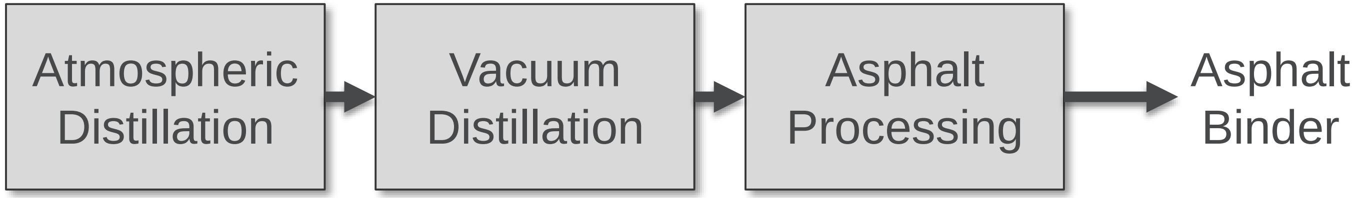
Coverage of asphalt producing refineries

- Dataset includes 11 refineries across U.S. PADD regions
- Asphalt binder production
  - Refineries in dataset represent 12 million tonnes
  - U.S. total was 21 million tonnes in 2017 and 22 million tonnes in 2010
  - Dataset includes ~52% of U.S. capacity
- Dataset includes two refineries using a solvent deasphalting unit and 9 that are not.

Input	Share of Input Energy
Natural gas	90.3%
Electricity	5.2%
Residual oil	4.1%
Butane	0.2%
Hydrogen	0.1%

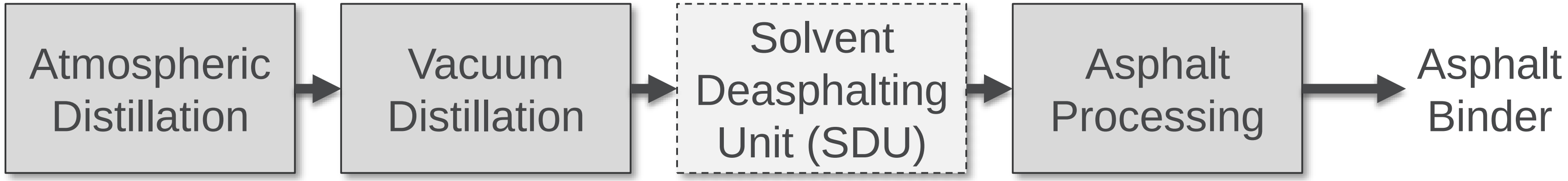
Asphalt follows a short path through the refinery

- Asphalt is the residual after fuels/lighter fractions are separated.
- In most cases, asphalt binder only passes through atmospheric distillation, vacuum distillation, and asphalt processing steps.



Using a solvent deasphalting unit at a couple refineries significantly increases impacts

- Two refineries in our sample included a solvent deasphalting unit (SDU) representing ~2% of asphalt production
- Purpose of SDU is to increase fuel production, the non-asphalt stream is fed back into the fluid catalytic cracker.
- The SDU consumes a significant amount of heat/steam.
- Potential challenge for allocation, asphalt is not an energy product, it is “along for the ride” throught the SDU.
  - SDU allocation by energy content: ~1/3 asphalt & ~2/3 FCC feed (used here)
  - SDU allocation by market value: ~1/6 asphalt & ~5/6 FCC feed, based on EIA 2018 annual average prices, asphalt: $7.30/mmBTU and vacuum gas oil: $15.20/mmBTU



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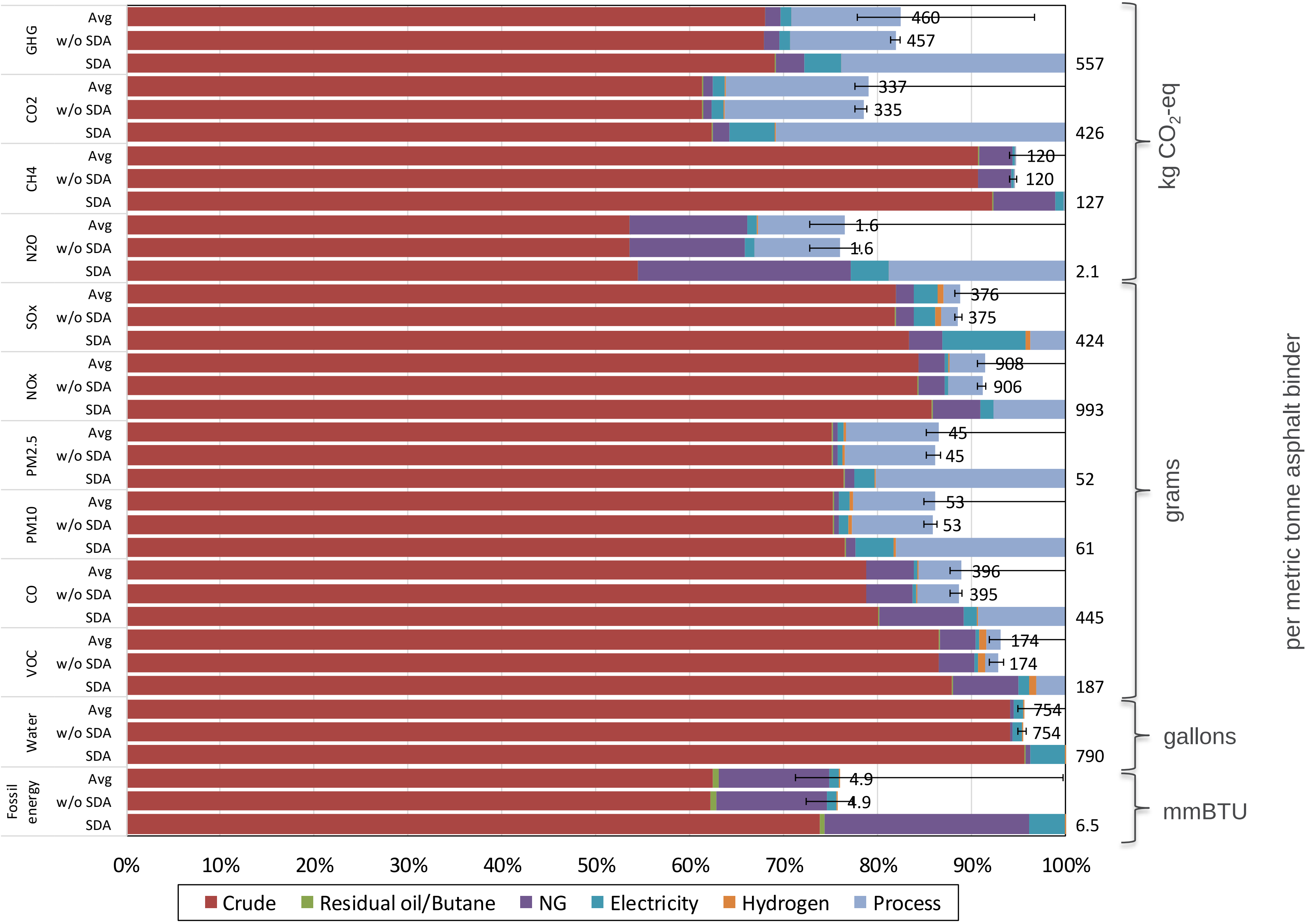
Asphalt binder: cradle-to-refinery gate draft results



Please visit http://greet.es.anl.gov for:

- ***GREET models***
- ***GREET documents***
- ***LCA publications***
- ***GREET-based tools and calculators***