DOE Gasification Technology Status and Pathways for Net-Zero Carbon Economy Workshop (virtual)

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LCA Methods and Challenges of Biomass, Plastics, and Combined Feedstocks for Gasification

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Consistent LCA methodologies will help compare technologies and identify drivers for environmental improvements

- LCA approaches and related system boundary
  1. Process-based LCA (sometimes the so-called attributional LCA): the entire supply chain of products/technologies: with process level details; **cycle-based approach**; mass and energy balances are key
  2. Emissions of the three scopes of enterprise operations along the supply chains of their products/operations
  3. Economic input-output (EIO) approach: economic linkages among activities, emission co-efficients to economic activities are key
  4. Consequential analysis (sometimes the so-called consequential LCA): global, economy-wide effects of regulations/programs – **web-based approach;** usually with changes in **multiple** societal outputs (functional units in LCA terms; without attribution of environmental burdens among them)
- Co-product methods in LCA (related to Approach 1 and 2 above)
  - Displacement (system boundary expansion)
  - Process level allocation based on purposes of processes within a facility
  - Mass allocation
  - Energy allocation
  - Market revenue allocation
- Functional units: for comparative purposes
  - Per unit of output: MJ, kg, mile, ton-mile, etc.: comparison of products providing identical/similar services to consumers and society
  - Per unit of inputs: per bbl of oil, per-ton of biomass: best of use of limited resources

LCA is data intensive; data needs to represent technologies under evaluation

- Background vs. foreground data: in relation to specific technology under LCA
  - Background data:
    - ✓ Improvements of the rest of economy on specific technology under LCA
    - ✓ Consistency is key
  - Foreground data
    - ✓ Representation of specific technology under LCA
    - ✓ Geographic and temporal differences
    - ✓ Verification is key
- Primary vs. secondary data: related mainly to foreground data
  - Primary data: data from facility operations (surveys, etc.)
  - Secondary/proxy:
    - ✓ Simulations with process engineering modeling (techno-economic analysis)
    - ✓ Literature data
    - ✓ Approximation
    - ✓ Mass and energy balance can help verification
- Confusing terminologies: LCI data vs. LCA results
  - Life-cycle inventory data:
    - ✓ Energy/mass balance of individual process/facility
    - ✓ Embodied energy/emissions of input energy and materials (LCA results of them): LCA models help
- Data quality:
  - Quality rating is usually subjective
  - Technologies at different TRLs affect data availability, thus data quality

LCA execution and LCA result reliability

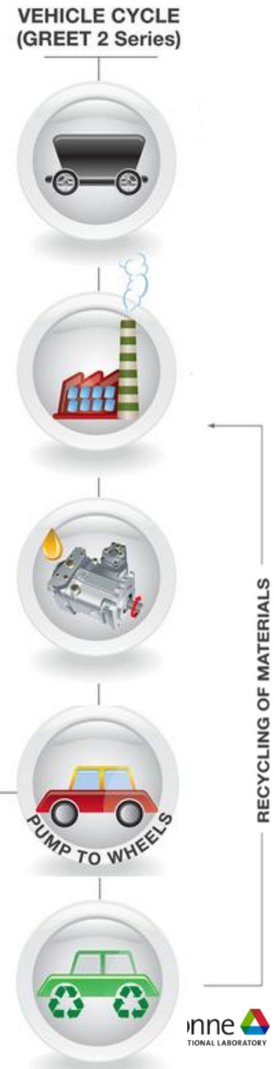
- Point estimation modeling
  - Perceived precision is a major problem
  - Users of LCA results usually want point estimates
- Stochastic methods in LCA
  - Probability distribution function (PDF)-based parameters result in PDF-based results
  - Objective vs. subjective PDFs
- Scenario analysis of alternative technology performances
- Sensitivity analysis to test importance of input parameters: tornado charts

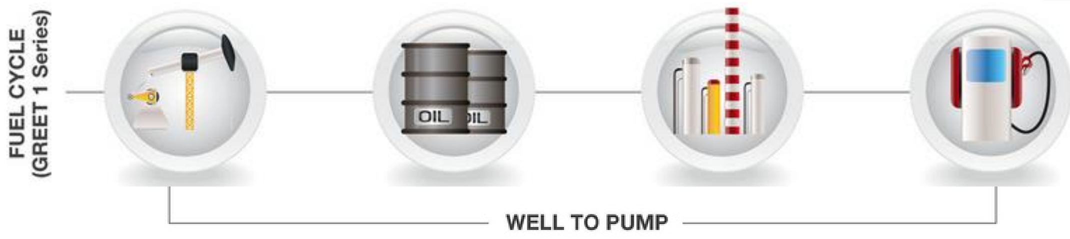
GREET Model Framework

- Fuel Cycle:
  - Environmental evaluation of **energy inputs** to the vehicle system
- Vehicle Cycle
  - Environmental analysis of the **material inputs** to the vehicle system
- First version released in 1995, annual release now; It is available at greet.es.anl.gov

GREET 1 model:
Fuel-cycle (well-to-wheels) modeling of vehicle/fuel systems

GREET 2 model:
Vehicle cycle modeling for vehicles





GREET LCA modeling framework and objectives

- Build LCA modeling capacity
- Build a consistent LCA platform with reliable, widely accepted methods/protocols
- Address emerging LCA issues
- Accessible to data sources and conduct detailed analysis
- Maintain openness and transparency of LCAs by making GREET and its documentation publicly available
- Primarily process-based LCA approach; some consequential effects are incorporated (e.g., land use change, albedo effects, animal feeds effects, etc.)

GREET relies on a variety of data sources

Baseline technologies and systems: background data

- Energy Information Administration: data and its Annual Energy Outlook projections
- EPA: eGrid for electric systems, MOVES, NEI, etc.
- US Geology Services: water data

Field operation data: foreground data

- Oil sands and shale oil operations
- Ethanol plants energy use
- Farming data from USDA

Simulations with models: foreground data

- ASPEN Plus for fuel production
- ANL Autonomie for vehicle fuel economy
- LP models for petroleum refinery operations
- Electric utility dispatch models for marginal electricity analysis

Collaborations with other organizations and Industries

- National labs
- Universities
- Fuel producers and technology developers on fuels
- Automakers and system components producers on vehicles

GREET covers many groups of energy systems

Petroleum Sector:
- Conventional oil
- Shale oil
- Oil Sands

→

Gasoline
Diesel
Jet fuel
Liquefied petroleum gas
Naphtha
Residual oil

Natural Gas Sector:
- Conventional NG
- Shale gas

→

- NG end use in electric, industrial, and residential sectors
- Transportation sector: CNG, LNG
- Alternative fuels: LPG, methanol, DME, FT diesel, FT jet

Hydrogen Economy:
- Gaseous hydrogen
- Liquid hydrogen
- With CCS, if applicable

←

Natural gas
Biomass
Coal
Petroleum coke
Coke oven gas
Electrolysis with electricity
Nuclear energy

Electric Systems:
- Electricity generation at US plant level
- Aggregate to national, NERC, and state level
- With CCS, if applicable

←

Natural gas
Coal
Residual oil
Biomass
Nuclear
Hydro
Wind
Solar

Renewable Energy/Fuels:
- Ethanol
- Biodiesel
- Renewable diesel
- Renewable gasoline
- Renewable jet fuel
- Renewable natural gas

←

1st Gen Feedstocks:
- Corn
- Sorghum
- Soybeans
- Rapeseeds
- Sugarcane
- Palm

2nd Gen Feedstocks:
- Dedicated energy crops
- Crop residues
- Forest residues
- MSW
- Animal wastes

Algae

Renewable Hydrogen via electrolysis:
- Wind
- Solar
- Nuclear

→

Electro-Fuels
- Gasoline
- Diesel
- Jet fuel
- Methanol

←

CO_2 Sources
- Ethanol plants
- NG SMR plants
- Cement plants
- Etc.

GREET also includes material production pathways

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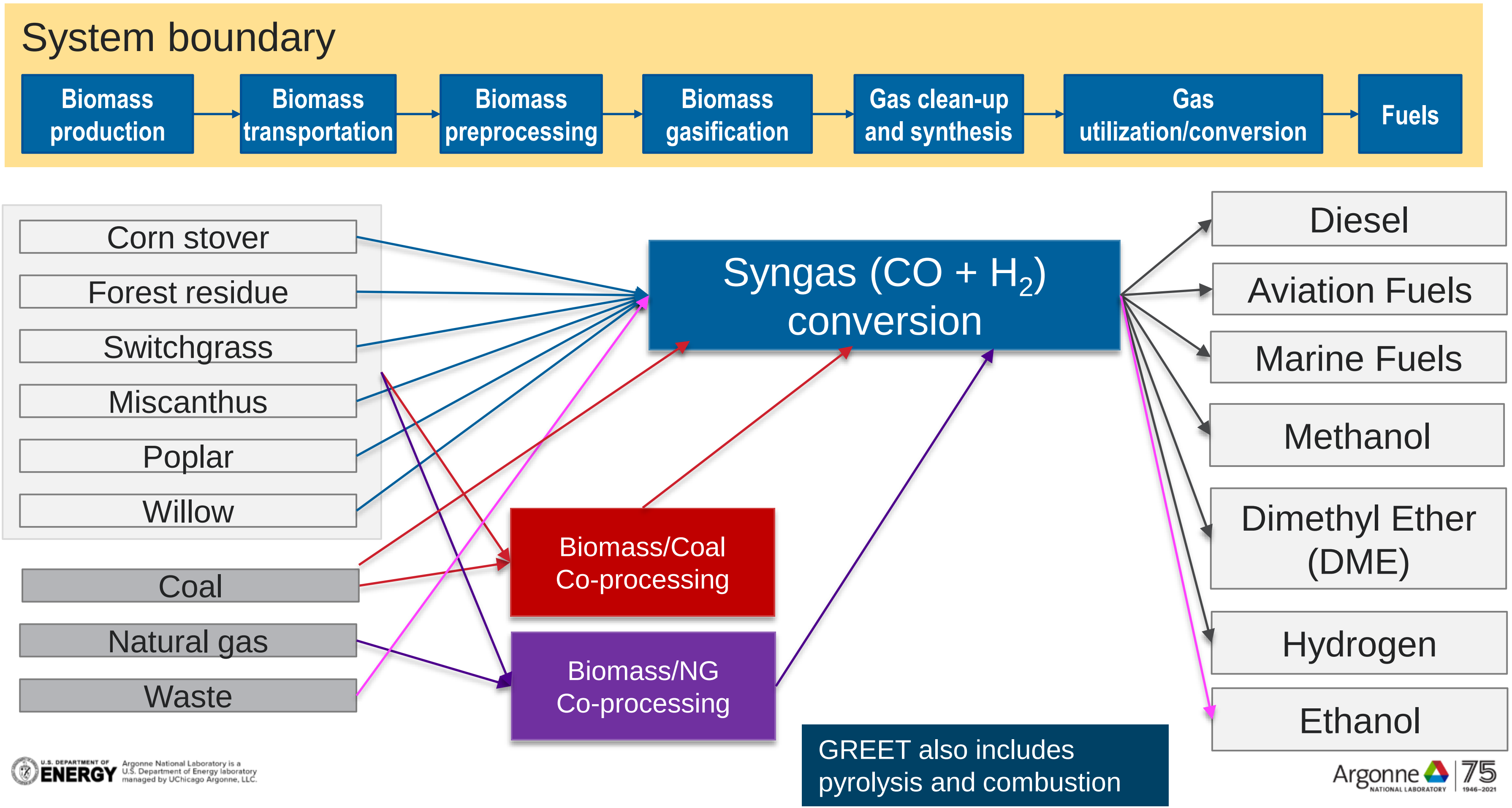
Gasification pathways in GREET



Cellulosic biomass types are categorized and handled accordingly in GREET

Dedicated/purposely grown biomass

- Switchgrass
- Miscanthus
- Poplar trees
- Willow trees

Residue biomass

- Agricultural residues: corn stover, wheat straw, rice straw
- Forestry residues

By-product biomass

- Tree tops
- Barks
- Sawdust

Waste biomass

- Biogenic, non-recycled municipal solid waste
- Organic wastes such as wastewater sludge

Biomass production supply chain

Potential LUC Impacts

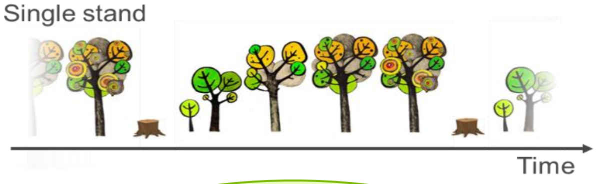
Biomass collection & transportation

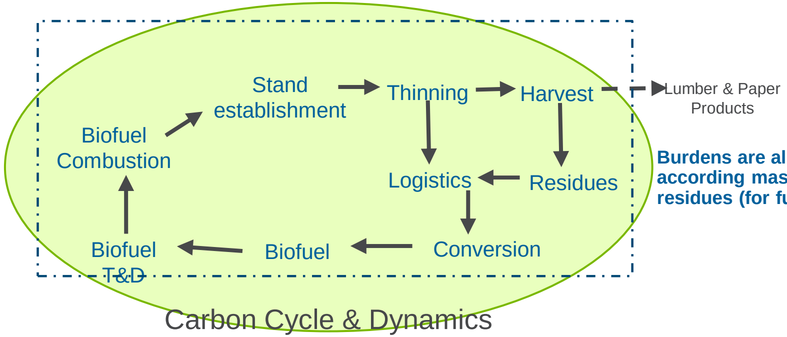
Counterfactual scenario impacts

Forest carbon dynamics and impacts on carbon neutrality are addressed

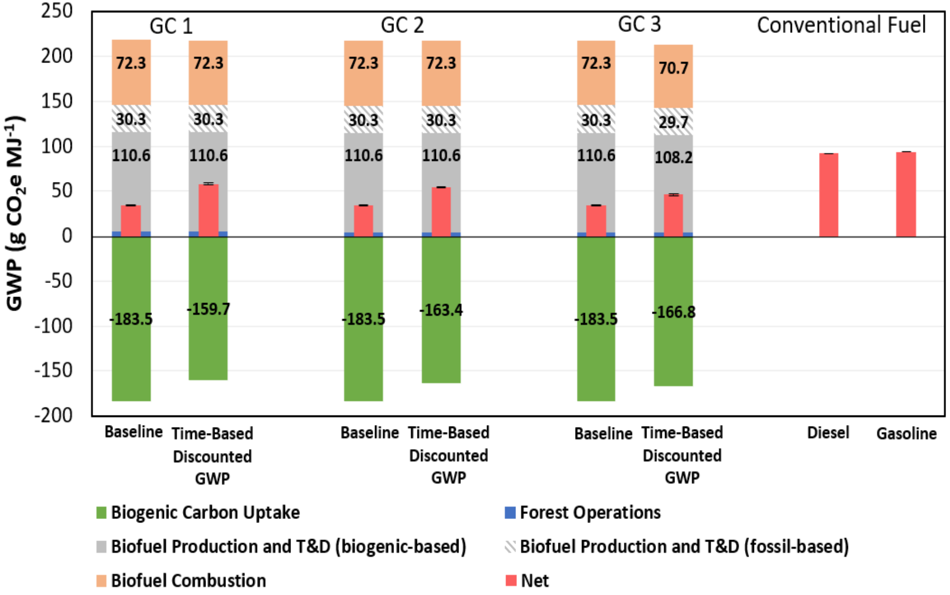
Various species, temporal effects, whole tree and residuals

- GREET wood feedstocks include Pine, Douglas-Fir, Spruce/Fir, Eucalyptus, Poplar, Willow.
- Calculations based on growth cycles address temporal effects on C balance.





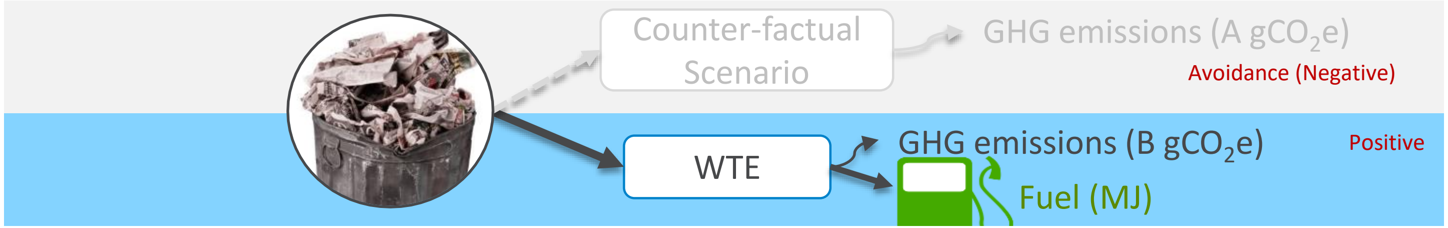
Burdens are allocated according mass in timber and residues (for fuels)



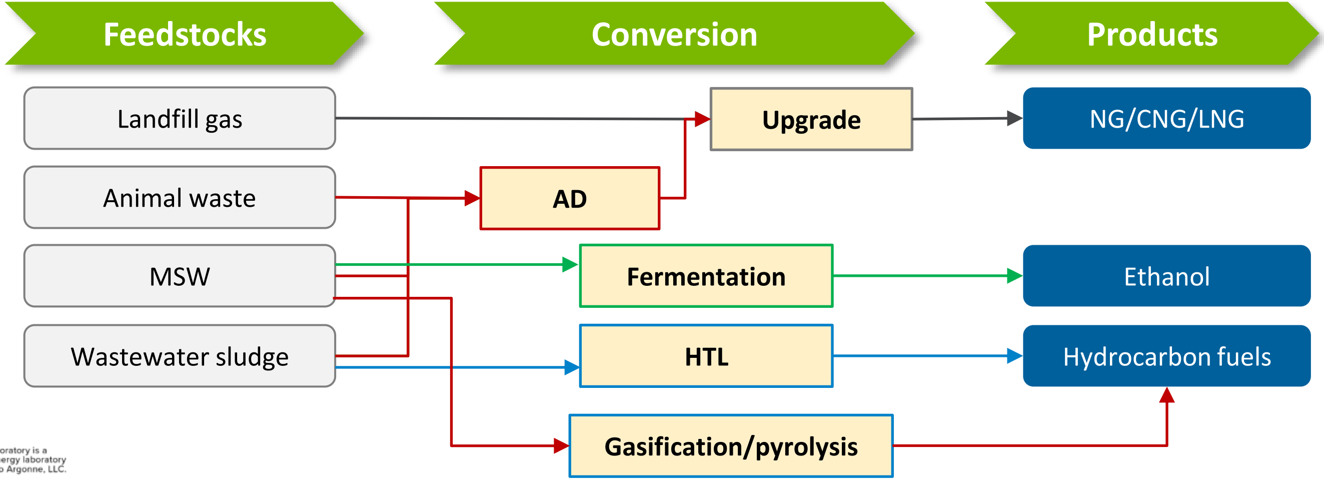
(Lan, Ou et al., 2021)

LCA of Waste-to-Energy (WTE) Pathways Shows Significant GHG Reductions

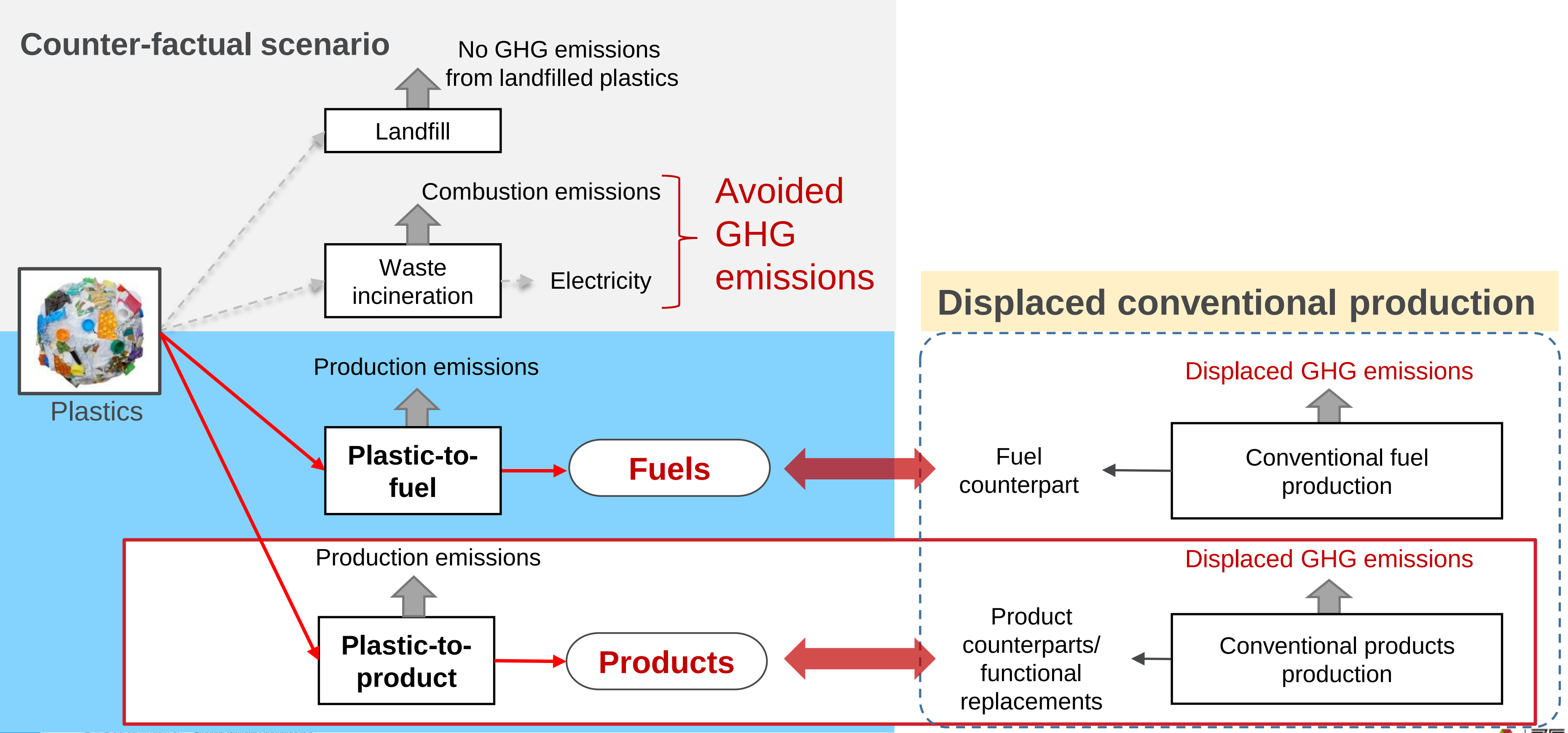
- LCA of WTE pathways includes emissions associated with counter-factual scenario of waste management to account for avoided emissions.



Pathways in GREET

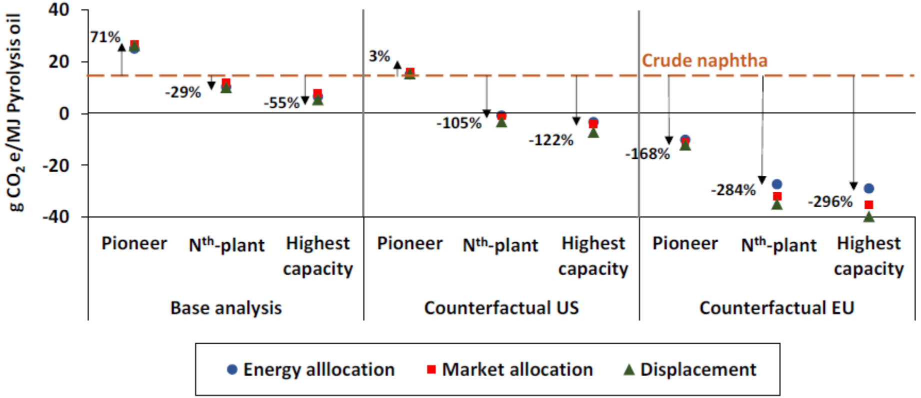


LCA framework for waste plastic-based fuels and products via pyrolysis: GHG is shown as example

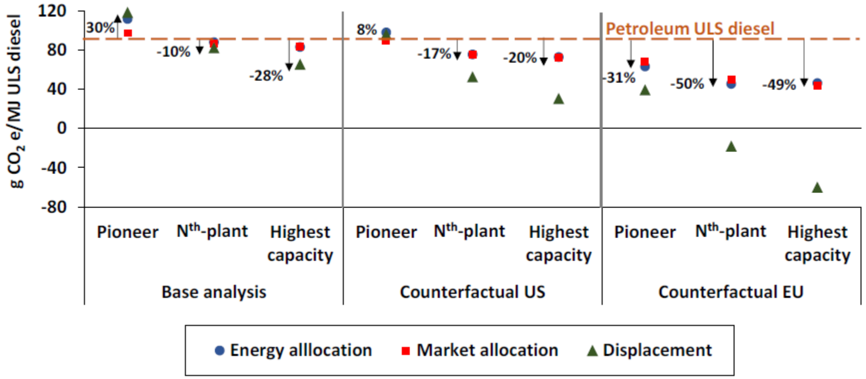


LCA results: waste plastic-based pyrolysis oil and diesel fuel

Pyrolysis oil



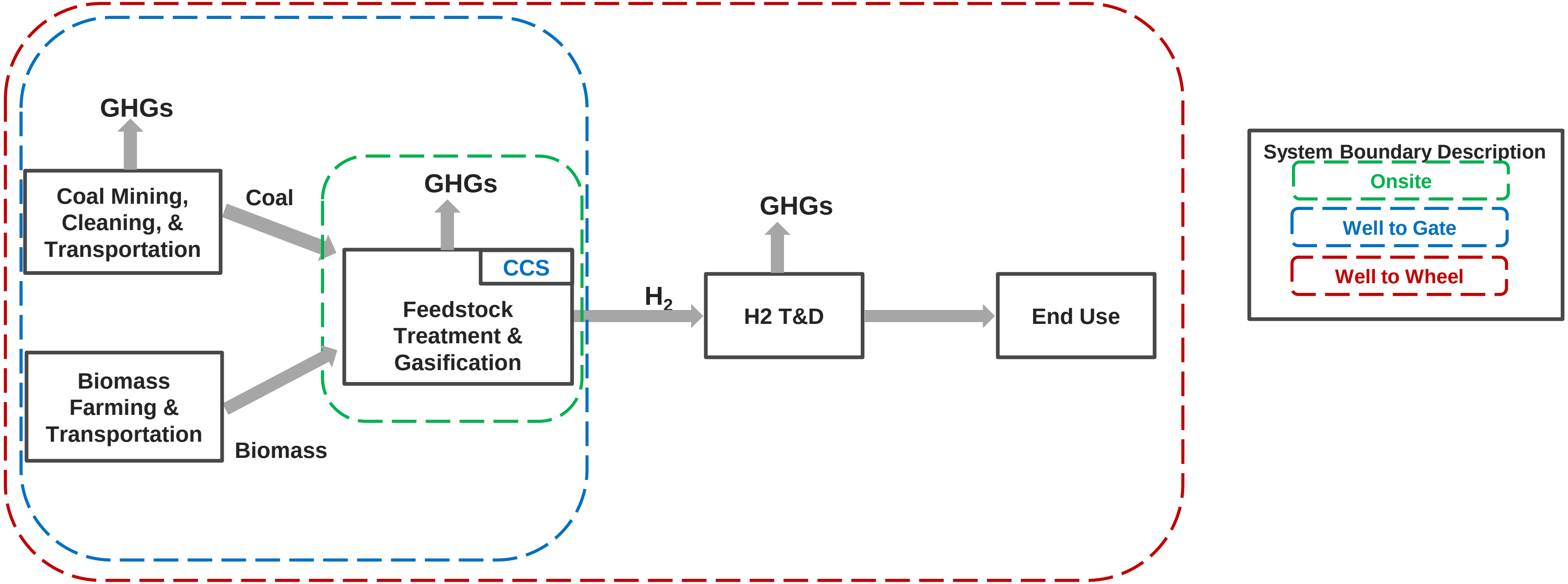
Ultra-low sulfur diesel



- Industry data was collected and processed to characterize environmental benefits of and tradeoffs of waste plastic conversion pathways via pyrolysis
- Included production of intermediate product such as pyrolysis oil and fuel such as ultra-low sulfur (ULS) diesel
- Presented the data for different types of plant capacities: pioneer, Nth-plant, highest capacity
- Nth-plants and the highest-capacity facility showed greater benefits (e.g., lower GHG, fossil energy and water consumption) compared to the baselines

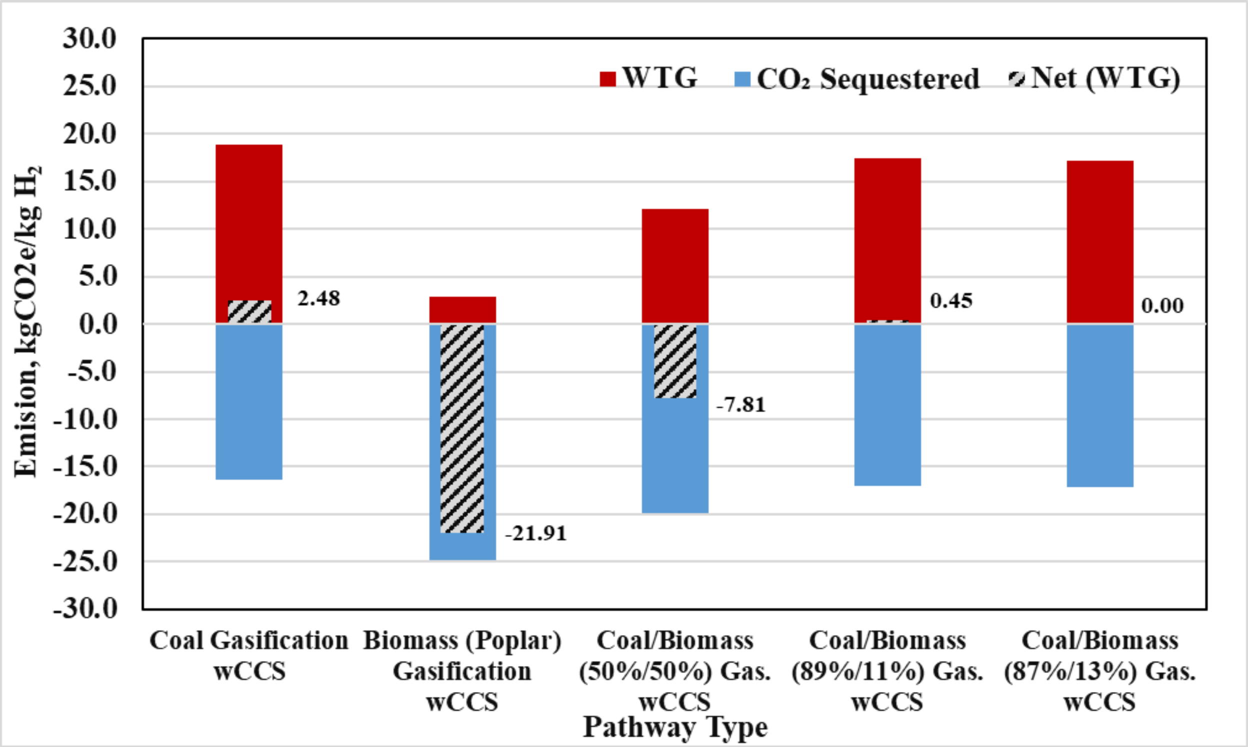
Benavides P.T. et al., 2022. Life-cycle Analysis of Conversion of Post-Use Plastic via pyrolysis with the GREET model. https://www.osti.gov/biblio/1885570

Coal and biomass gasification configuration in GREET: H2 production as the example



- Currently GREET has separate coal gasification and biomass gasification pathways
- An estimate is made by combining the two pathways
- Tested process data would allow more accurate evaluation

Results: Co-Feeding Coal/Biomass for Gasification



- Current GREET does not include Co-feed Coal/Biomass gasification pathway. Therefore the co-feeding GHG was estimated by using linear combination.
- Poplar is considered as the Biomass feedstock in all cases.
- CO_2 Capture rate of 95% is considered in all cases.
- CCS electricity in the biomass pathway is assumed to be 357 kWh/ton C captured, the same as that from coal pathway.
- Coal gasification results are influenced by type of coal assumed, grid electricity CI (for CO2 compression), output H2 pressure, etc.

Reference: 1. https://www.nrel.gov/hydrogen/assets/docs/current-central-biomass-gasification-v3-2018.xlsm
2. Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies. DOE/NETL-2022/3241. Pittsburgh, PA: National Energy Technology Laboratory, 2022. https://doi.org/10.2172/1862910

Observations: LCA results are subject to variations and uncertainties

- LCA system boundary depends on scope of LCA
- Attributional and consequential LCA address different questions and have completely different boundaries
- Co-product methods in LCA can be subjective and affect LCA results significantly
- Data availability and representation
  - ✓ Temporal variation
  - ✓ Geographic/spatial variation
  - ✓ Data uncertainty (e.g., sources of process energy/chemicals, methane emissions, land use changes from biofuels)
- Limitations of comparative results from LCA
  - ✓ Current vs. uncertain future
  - ✓ Different technology readiness levels (TRLs) across processes and pathways
  - ✓ Resource and infrastructure availability
  - ✓ Economics, production scalability, and market acceptance/competitiveness

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