INCREASE YOUR H2IQ

The #H2IQ Hour

Today's Topic:

Learn to use the GREET Model for Emissions Life Cycle Analysis

This presentation is part of the monthly H2IQ hour to highlight research and development activities funded by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE).

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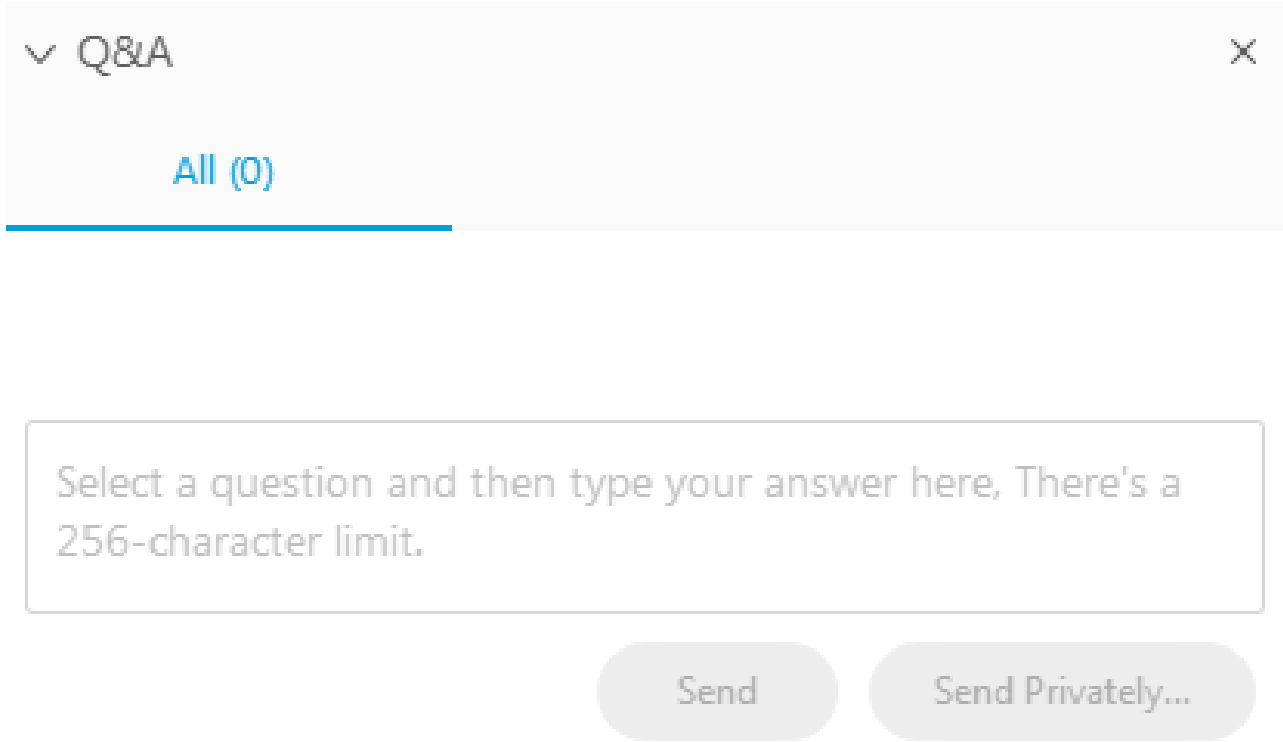
The #H2IQ Hour Q&A

Please type your questions into the **Q&A Box**



GREET® Model for Life Cycle Analysis of Greenhouse Gas Emissions

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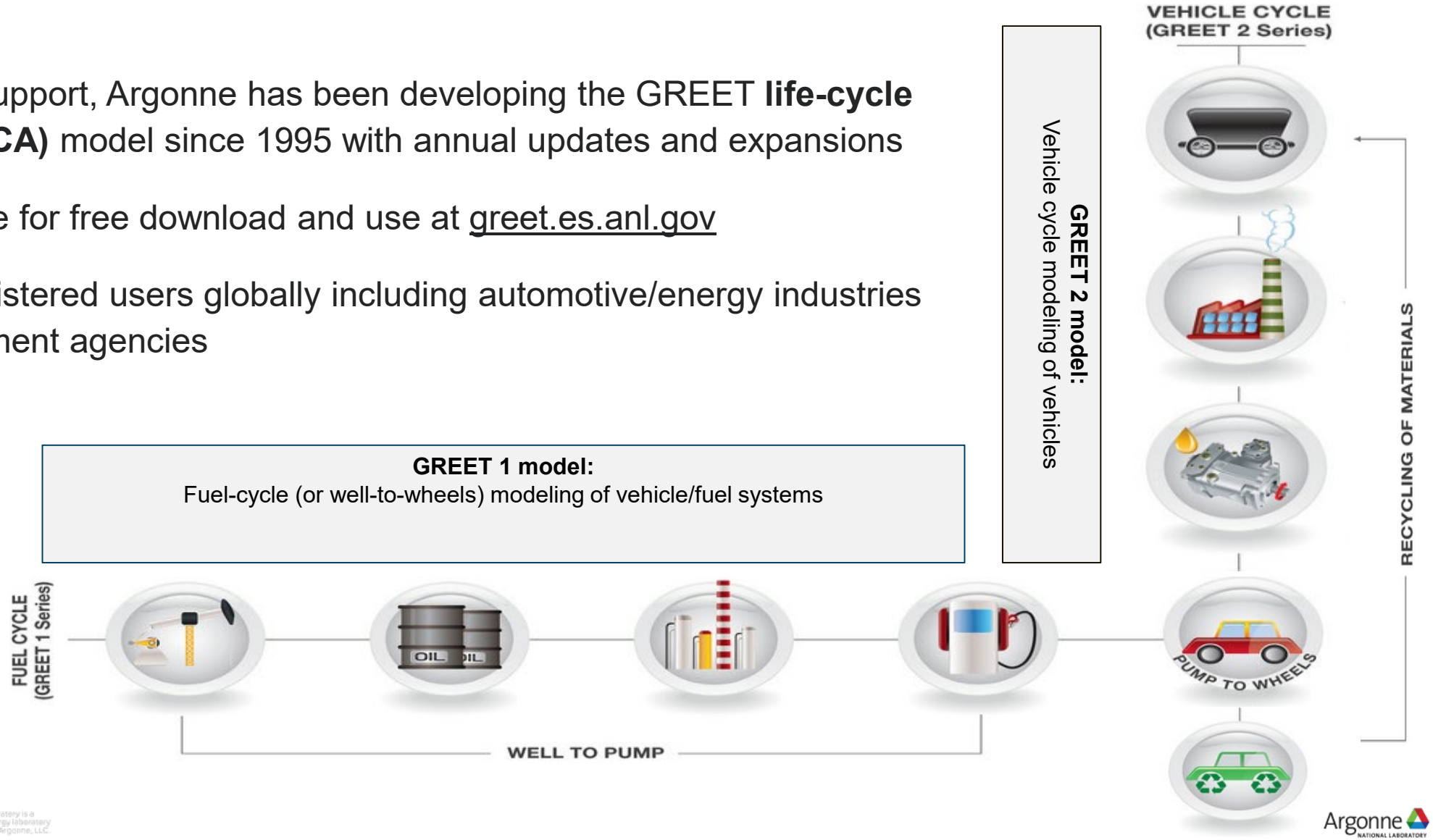
Argonne National Laboratory

Presentation at H2IQ

October 28, 2021

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

- With DOE support, Argonne has been developing the GREET **life-cycle analysis (LCA)** model since 1995 with annual updates and expansions
- It is available for free download and use at greet.es.anl.gov
- ~50,000 registered users globally including automotive/energy industries and government agencies



GREET includes a suite of models and tools

- GREET coverage
  - ✓ GREET1: fuel cycle (or WTW) model of vehicle technologies and transportation fuels
  - ✓ GREET2: vehicle manufacturing cycle model of vehicle technologies
- Modeling platform
  - ✓ Excel
  - ✓ .net
- GREET derivatives
  - ✓ ICAO-GREET by ANL, based on GREET1
  - ✓ China-GREET by ANL, with support of Aramco
  - ✓ CA-GREET by CARB, based on GREET1
  - ✓ AFLEET by ANL: alternative-fuel vehicles energy, emissions, and cost estimation
  - ✓ EverBatt by ANL: energy, emissions, and cost modeling of remanufacturing and recycling of EV batteries

GREET applications by agencies

California Environmental Protection Agency Air Resources Board CA-GREET3.0 built based on and uses data from ANL GREET

State of Oregon Department of Environmental Quality DEQ Oregon Dept of Environ. Quality Clean Fuel Program

EPA RFS2 used GREET and other sources for LCA of fuel pathways; GHG regulations

NHTSA National Highway Traffic Safety Administration (NHTSA) fuel economy regulation

FAA and ICAO AFTF using GREET to evaluate aviation fuel pathways

USDRIVE GREET was used for the US DRIVE Fuels Working Group Well-to-Wheels Report

MARAD Maritime Administration LCA of renewable marine fuel options to meet IMO 2020 sulfur regulations for the DOT MARAD

USDA US Dept of Agriculture: ARS for carbon intensity of farming practices and management; ERS for food environmental footprints; Office of Chief Economist for bioenergy LCA

Government of Canada Environment and Climate Change Canada for its Clean Fuel Standard

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

Energy use

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

Air pollutants

- VOC, CO, NOx, PM_{10}, $PM_{2.5}$, and SOx
- Estimated separately for total and urban (a subset of the total) emissions

Greenhouse gases

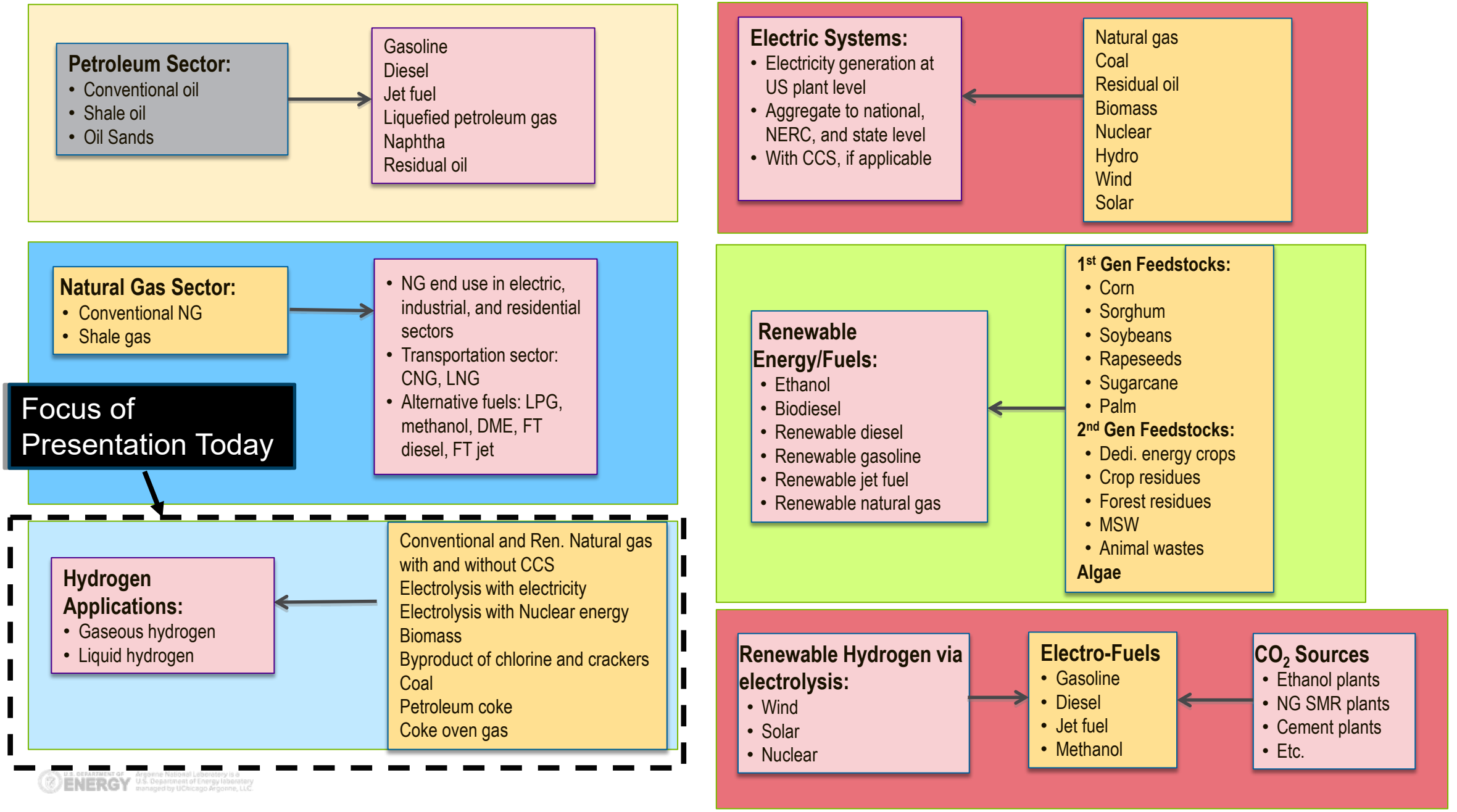
- CO_2, CH_4, N_2O, black carbon, and albedo
- CO_{2e} of the five (with their global warming potentials)

Water consumption

- Addressing water supply and demand (energy-water nexus)

- GREET LCA functional units
  - Per service unit (e.g., mile driven, ton-mile, passenger-mile)
  - Per unit of output (e.g., million Btu, MJ, gasoline gallon equivalent)
  - Per units of resource (e.g., per ton of biomass)

GREET covers many groups of energy systems



Global warming potentials (GWPs) of gases

- Allows comparisons of relative global warming impacts of different gases
- CO_2 is the reference gas with GWP=1
- GWP is mainly impacted by:
  - ✓ ability of gas to absorb energy
  - ✓ how long they stay in the atmosphere

GAS	GWP	Timeframe	Life in the atmosphere
CO_2	1	All	~100s of years
CH_4	30	100 years	~10-20 years
	85	20 Years	
N_2O	265	100 Years	~100 years

Greenhouse gases

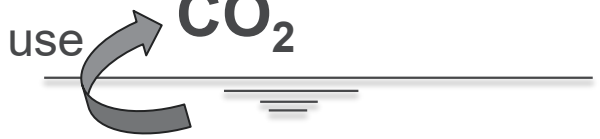
- CO_2, CH_4, N_2O, black carbon, and albedo
- CO_{2e} with their global warming potentials

- Focusing on reducing CH_4 emissions to meet GHG emissions reduction targets* using GWP20 may require abrupt reduction in CO_2 after 20 years to maintain GHG emissions reduction rate
  - ✓ most GHG emissions targets are set based on GWP100
- Reducing CO_2 from fossil sources will reduce associated CH_4 by default
  - ✓ the opposite is not necessarily true

*e.g., to limit $\Delta T < 1.5°C$ and 2°C above pre-industrial levels

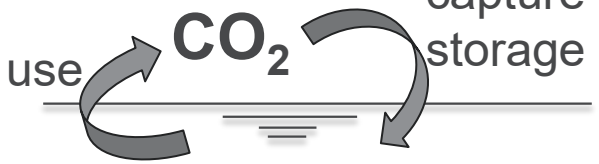
What really matters: carbon source and fate

1.



Carbon (e.g., fossil)

2.



Carbon (e.g., fossil)

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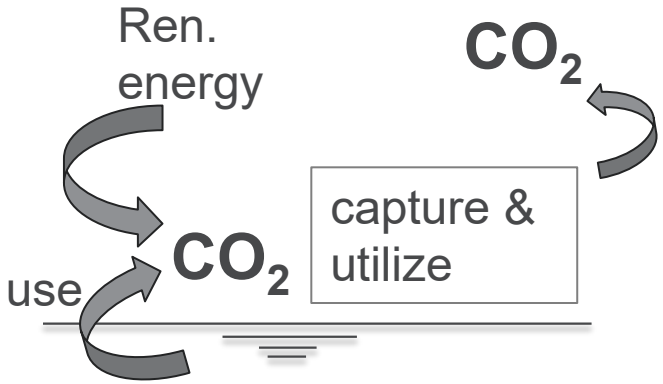

Carbon (e.g., fossil)

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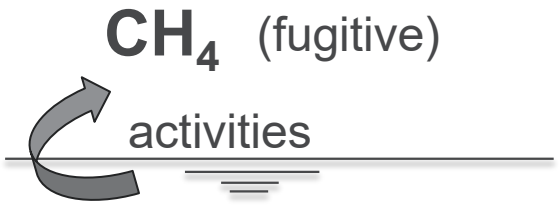
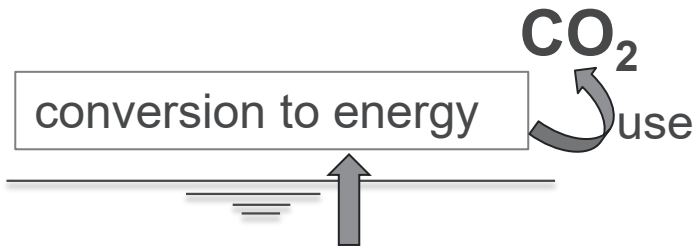


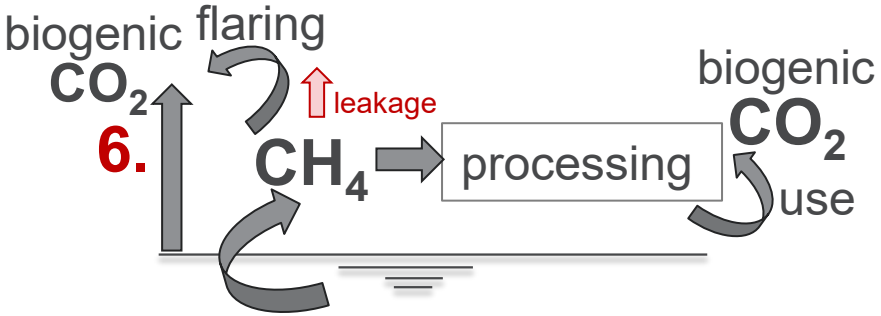
Carbon (e.g., fossil)

5.



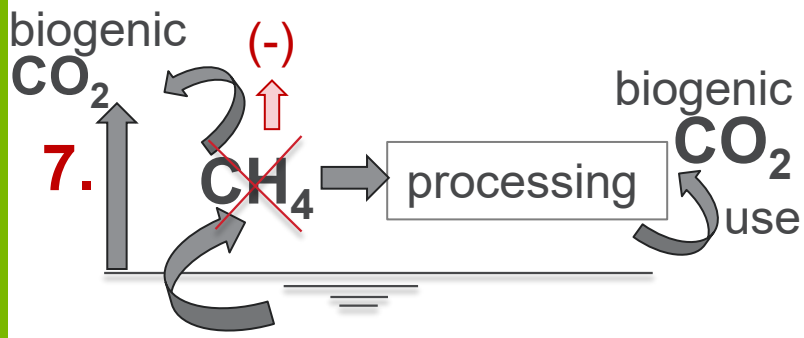
Landfill (inorganic waste)

6.



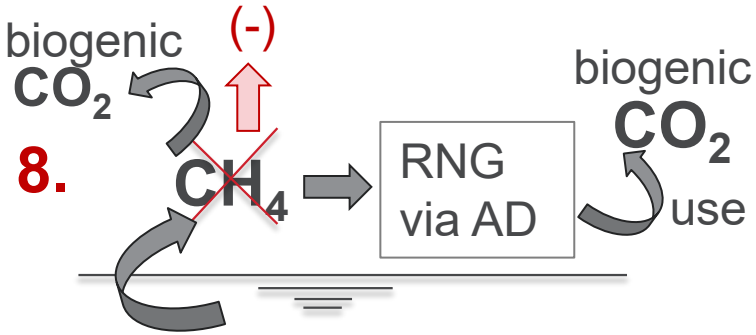
Landfill (organic waste)

7.



MSW (organic waste)

8.



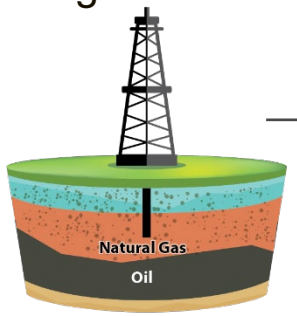
Animal waste lagoons

9.

Carbon (e.g., biomass)

Example hydrogen production pathway: Reforming w/ and w/o CCS

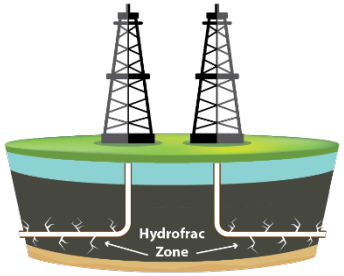
Conventional Gas Drilling & Recovery



NG Processing

NG Compression

Shale Gas Drilling & Recovery



NG Processing

NG Compression

CCS

CO_2 CO_2

combustion reformation

NG Transportation

H_2 + Steam

NG SMR Plant

Avoided GHG emissions from landfilled MSW

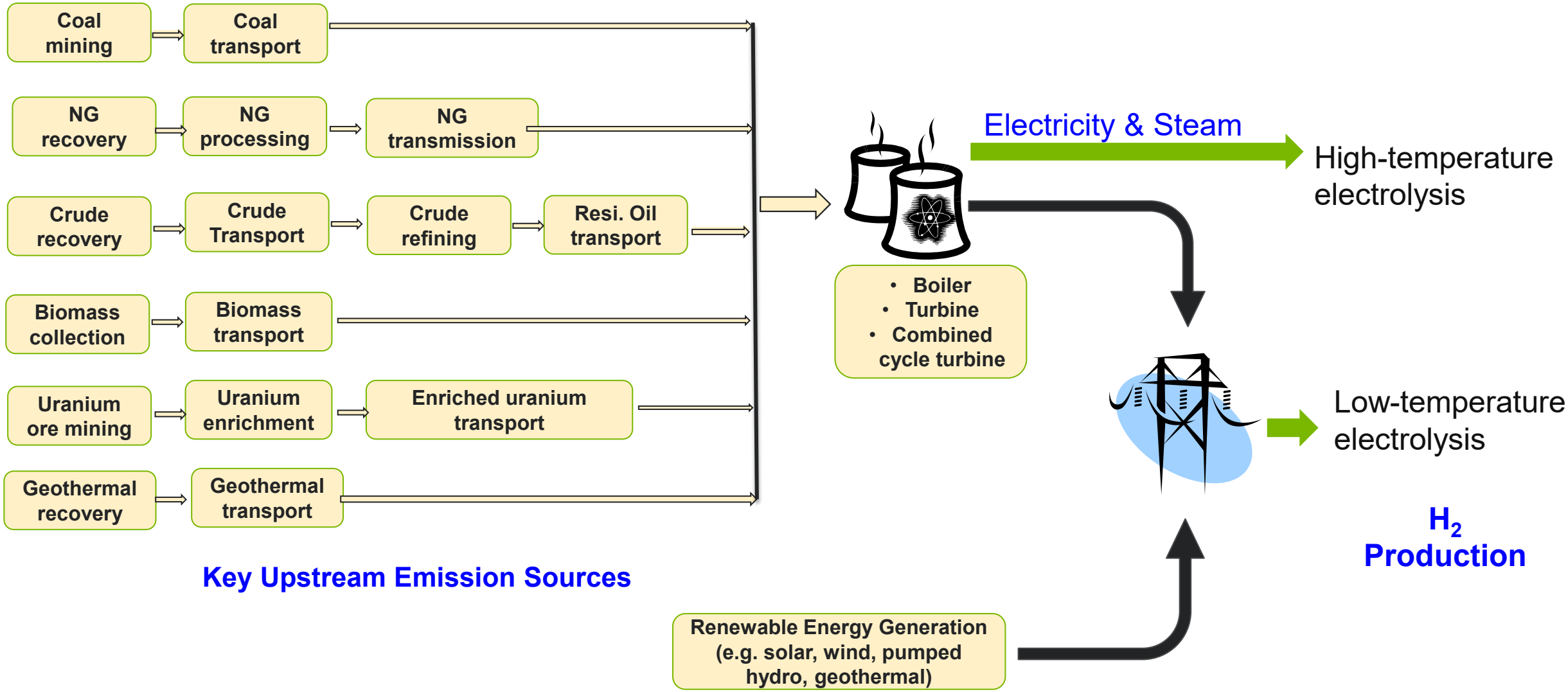
Landfilling

MSW

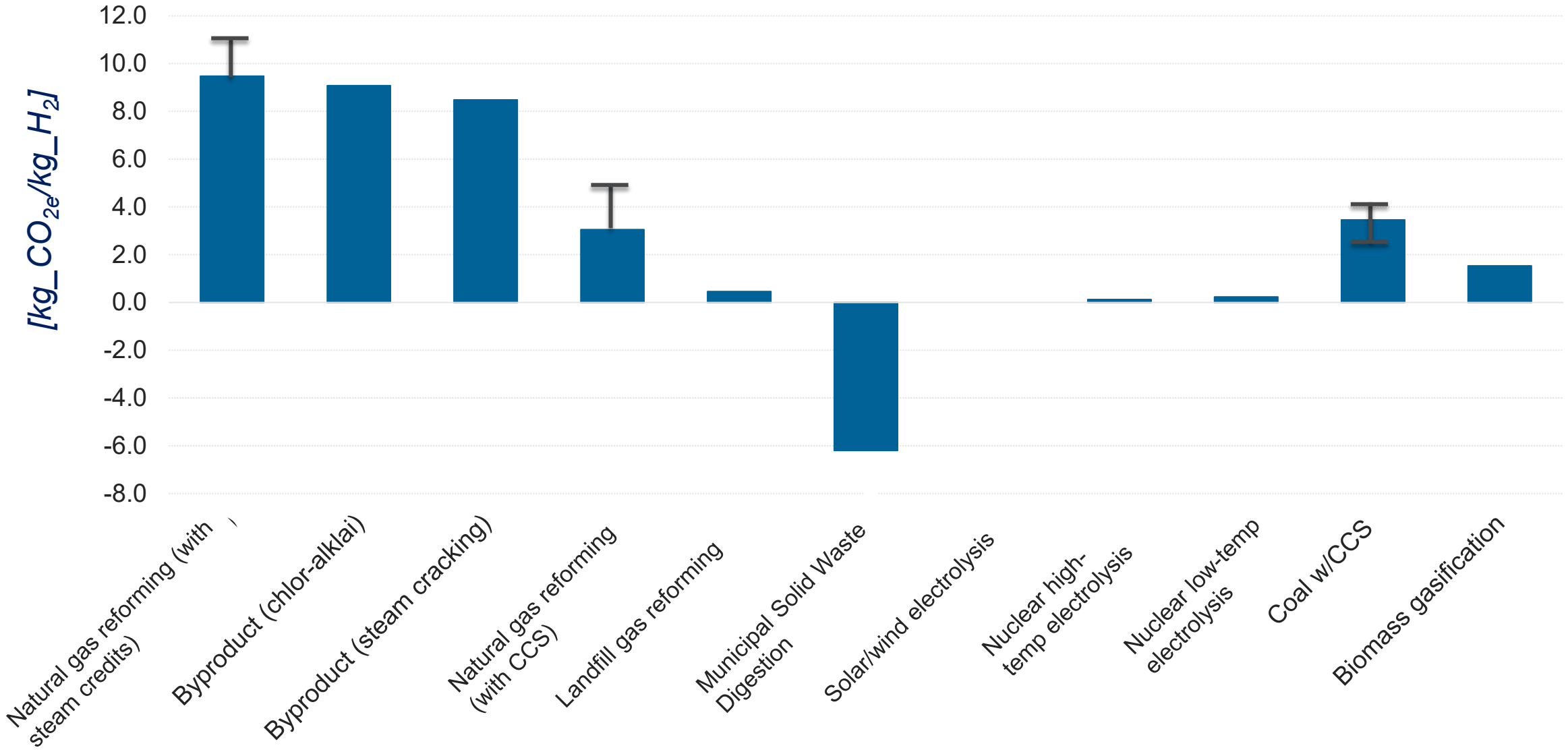
Anerobic Digestion

RNG

Example hydrogen production pathway: water electrolysis



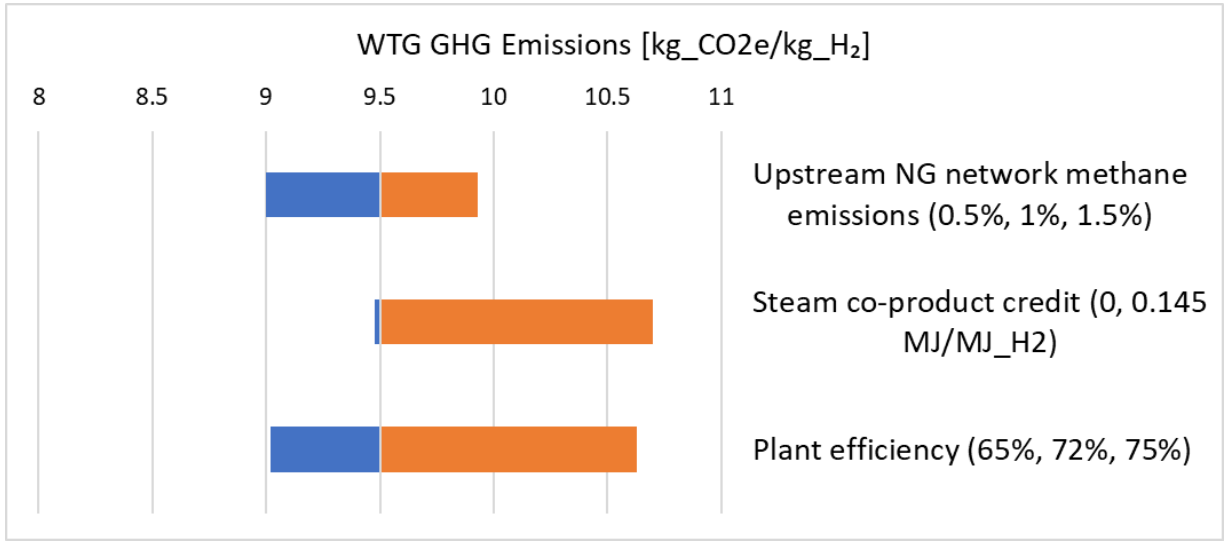
WTG GHG emissions of Key Hydrogen Production Pathways



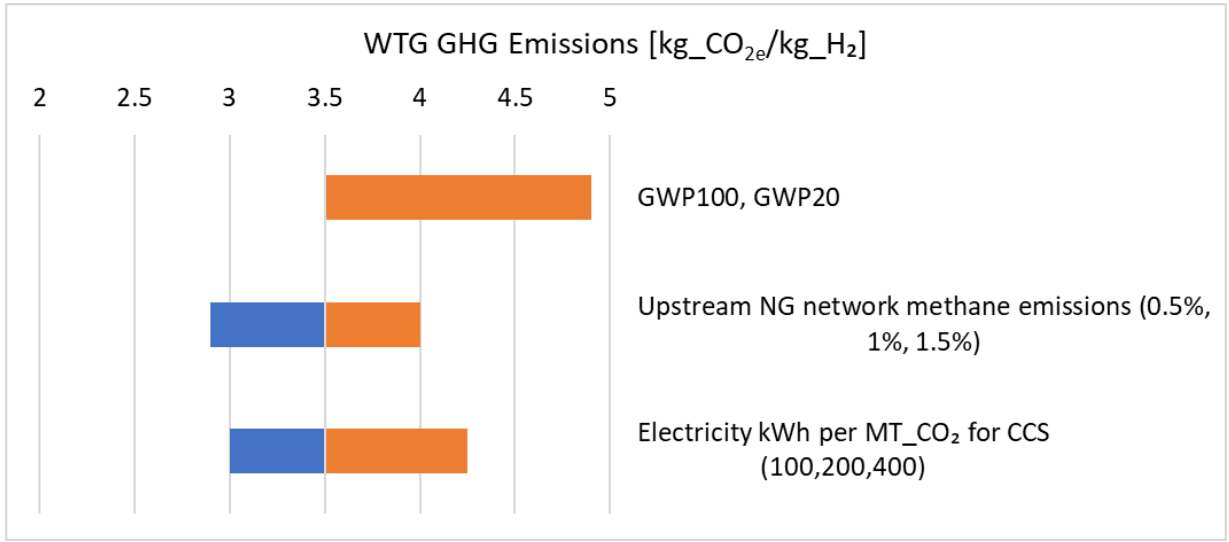
Ranges shown reflect potential variability in upstream methane leak rates, plant energy efficiency, and CO_2 capture rates. Baseline assumes 90% capture rate

Key parameters affecting WTG GHG emissions of SMR-Hydrogen production pathway

Grey Hydrogen (NG SMR)



Blue Hydrogen (NG SMR w/CCS)

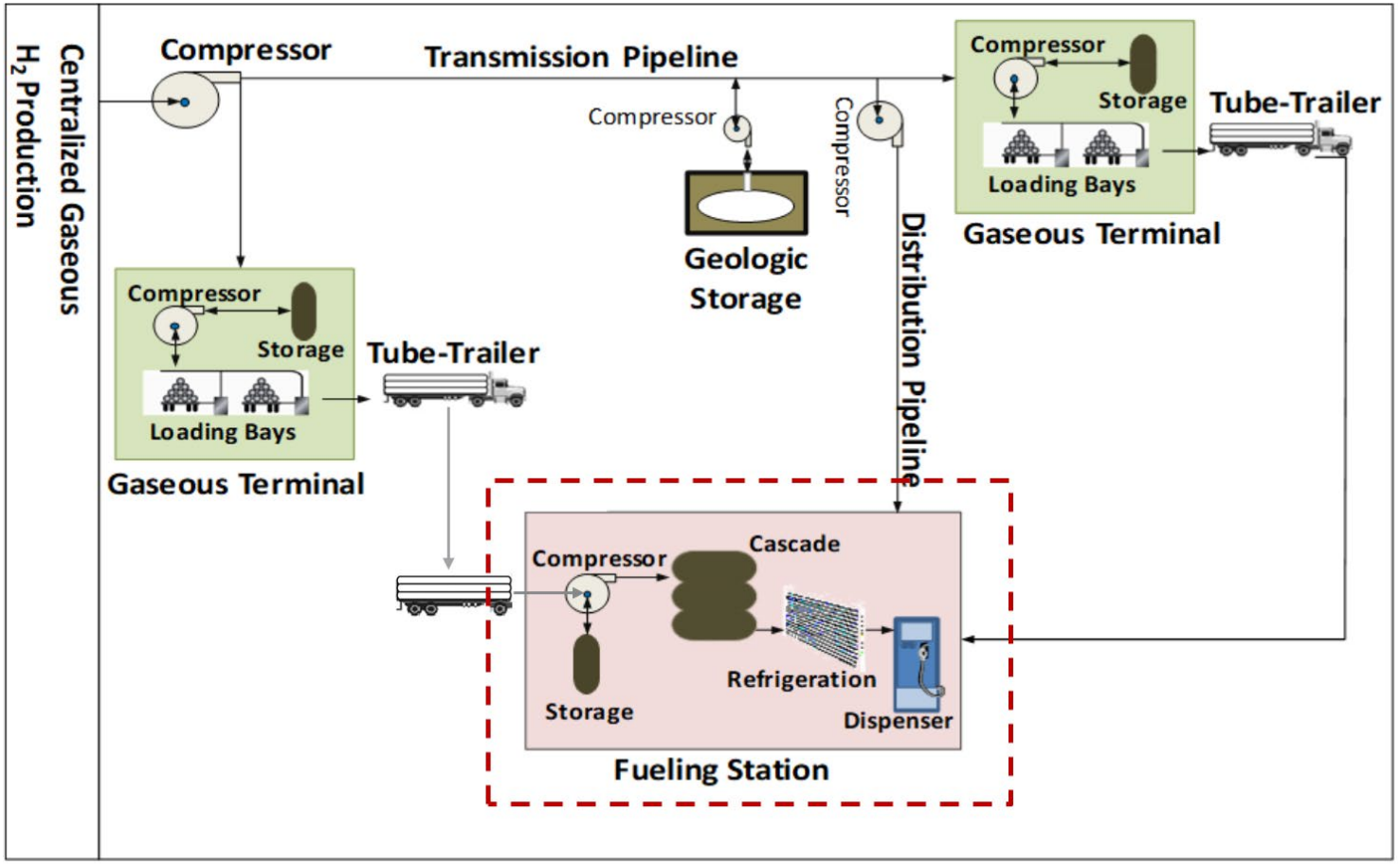


BREAK FOR LIVE DEMO OF GREET

Other analysis capabilities within GREET include…

- Hydrogen infrastructure emissions for diverse end uses
- Baseline petroleum fuels
- Biofuel production and use pathways
- Electricity for battery electric vehicles

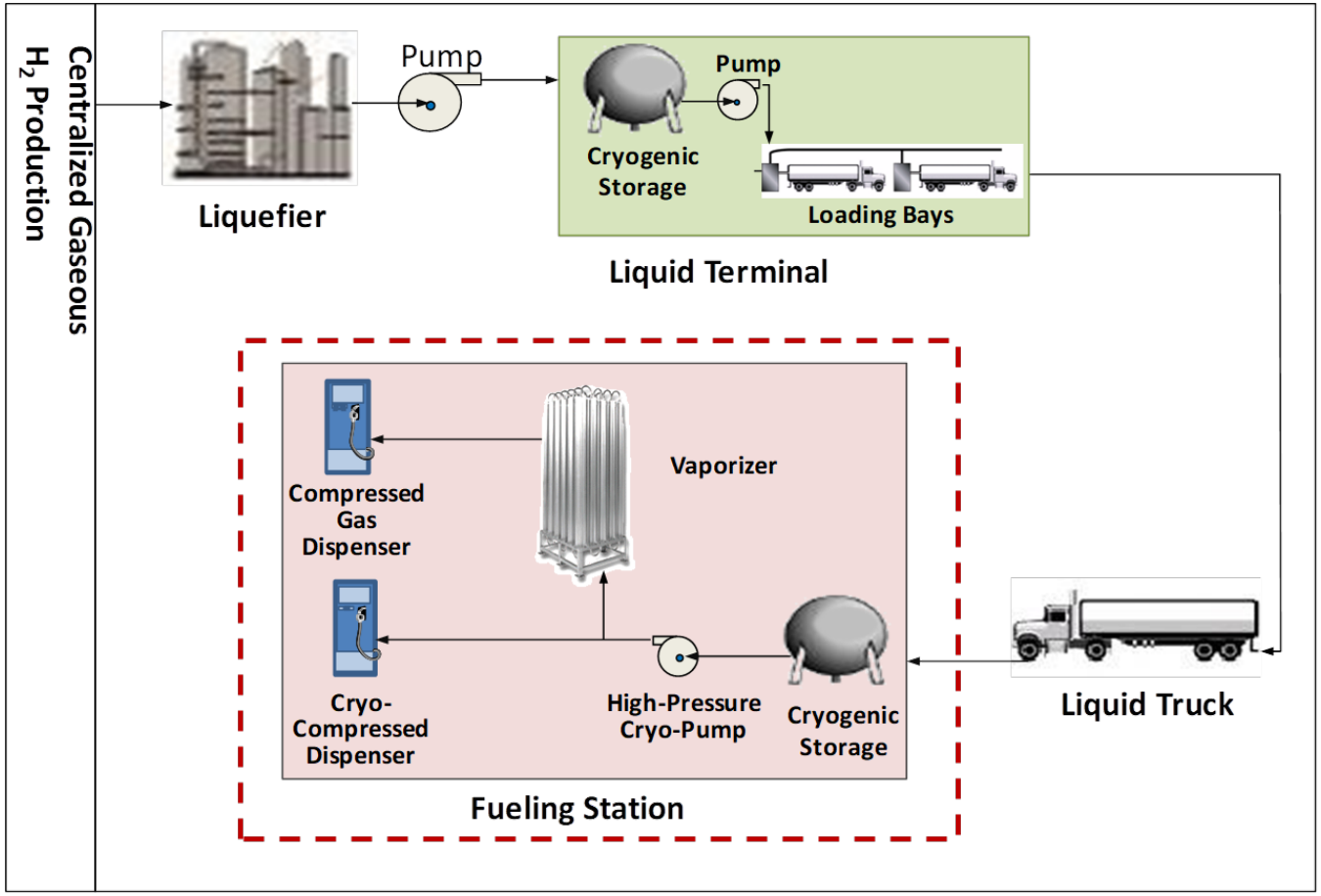
Infrastructure of gaseous hydrogen delivery: LCA perspective



Key factors for LCA results

- Feedstocks for H_2 production
- H_2 plant efficiency, co-products, and options for CCS
- H_2 transportation/distribution
- Compression/pre-cooling at fueling station

Infrastructure of liquid hydrogen delivery: LCA perspective

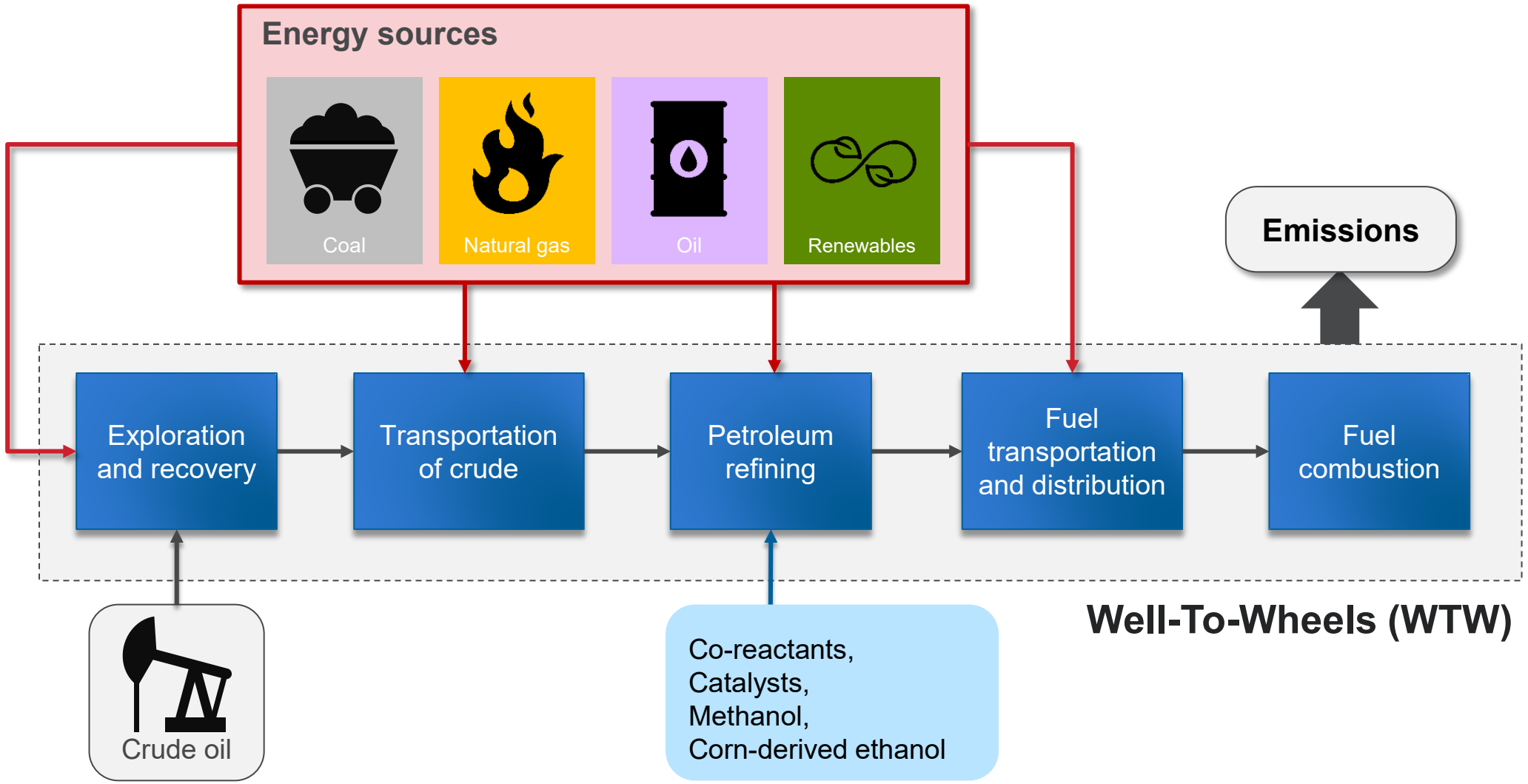


Key factors for LCA results

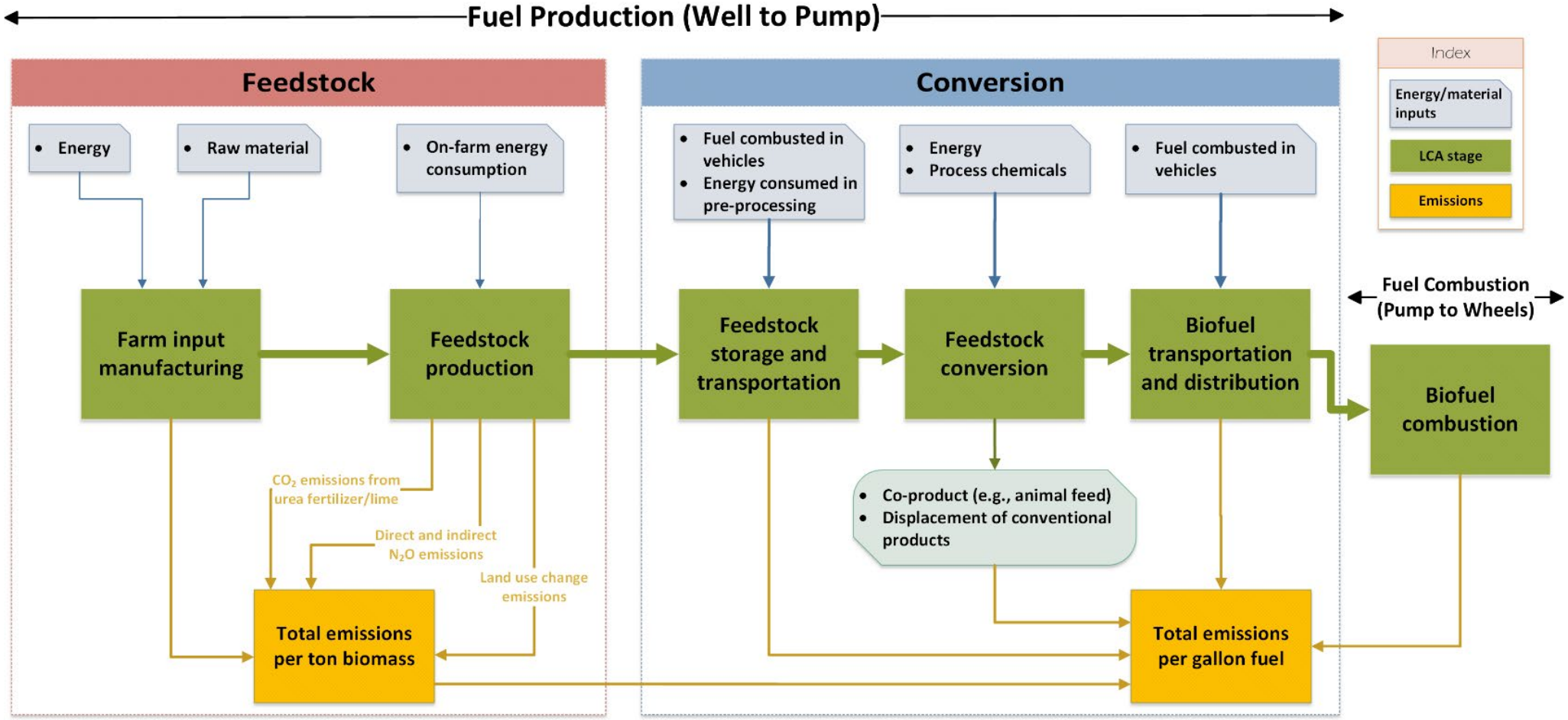
- Feedstocks for H_2 production
- H_2 plant efficiency, co-products and options for CCS
- H_2 liquefaction
- H_2 transportation/distribution
- Compression/pumping at fueling station

Life cycle of petroleum fuels

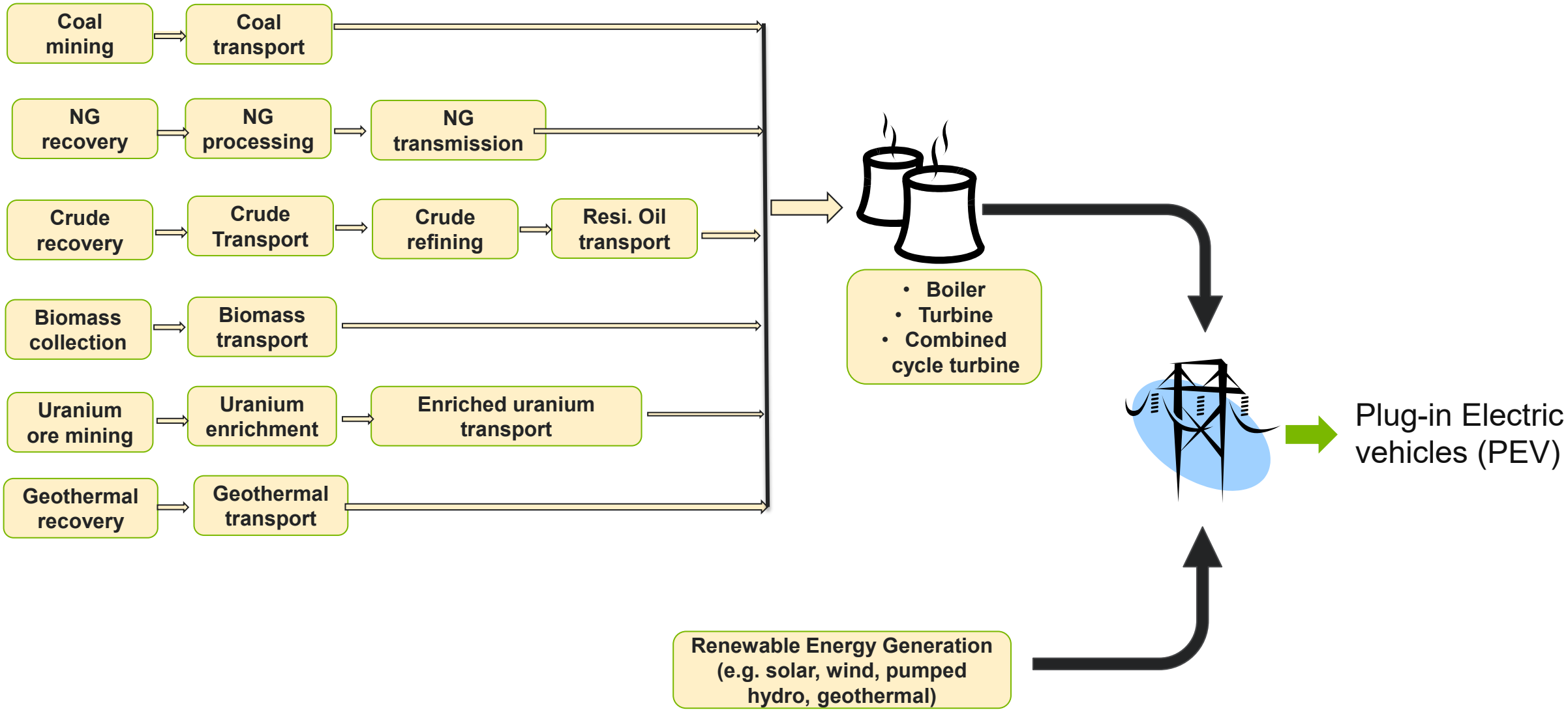
- GREET covers from petroleum recovery to fuel use (combustion) by including all energy inputs and emissions for each stage.



GREET includes details of both biofuel feedstock and conversion



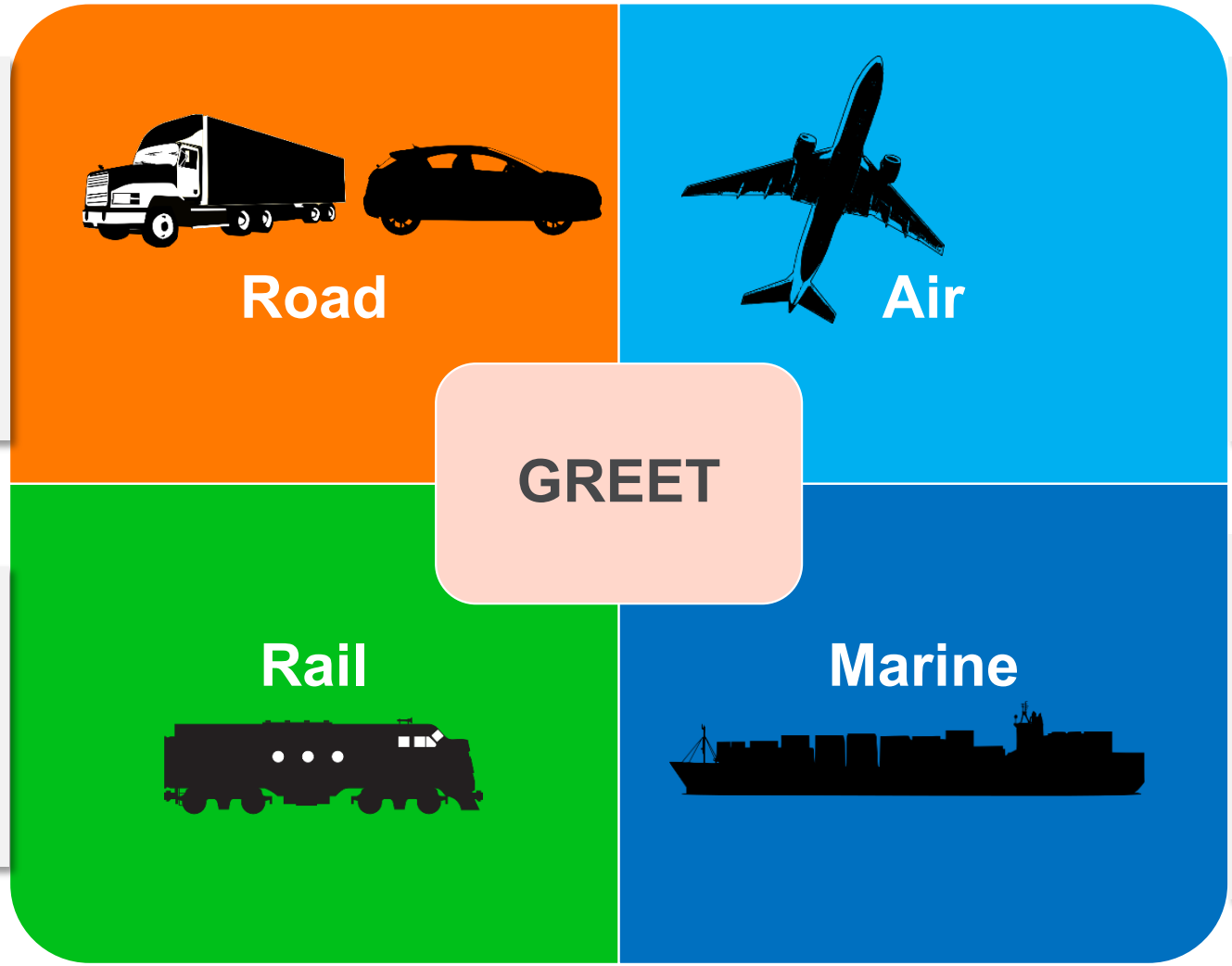
LCA of electricity and end use (plug-in electric vehicles, PEVs)



GREET includes all transportation subsectors for many fuels

- Medium-duty vehicles
- Heavy-duty vehicles
- Light-duty vehicles
- Various powertrains:
  - Internal combustion
  - Battery electric
  - Fuel cells

Freight transportation
GREET includes
- Diesel
- Electricity
- CNG/LNG
- Hydrogen



Globally, a fast growing sector with GHG reduction pressure. GREET includes
- Passenger and freight transportation of various alternative fuels blended with petroleum jet fuels

The sector is under pressure to reduce air emissions and GHG emissions. GREET includes
- Ocean and inland water transportation
- Baseline diesel and alternative marine fuels

Variability and uncertainty in LCA

- Technical variability of LCA results reflects
  - Variability of input data, which reflect variabilities in operations of a given facility, facility differences, regional differences, and temporal differences
    - Well defined scope of a LCA can help on data representation for targeted LCA for facilities, regions, or a given time period
    - Key inputs with variability that influence hydrogen production LCA include:
      - Upstream methane leak rates
      - Plant level energy efficiency
      - Emissions intensity of energy supply for electricity
      - Source of heat for high-temperature electrolysis
      - Creation of co-products
- Uncertainties
  - Sensitivity analysis to show importance of input parameters to inform stakeholders
  - Scenario analysis to show LCA results of different futures
  - Transparency is key to inform stakeholders

Thank You!

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Our models and publications are available at:

https://greet.es.anl.gov

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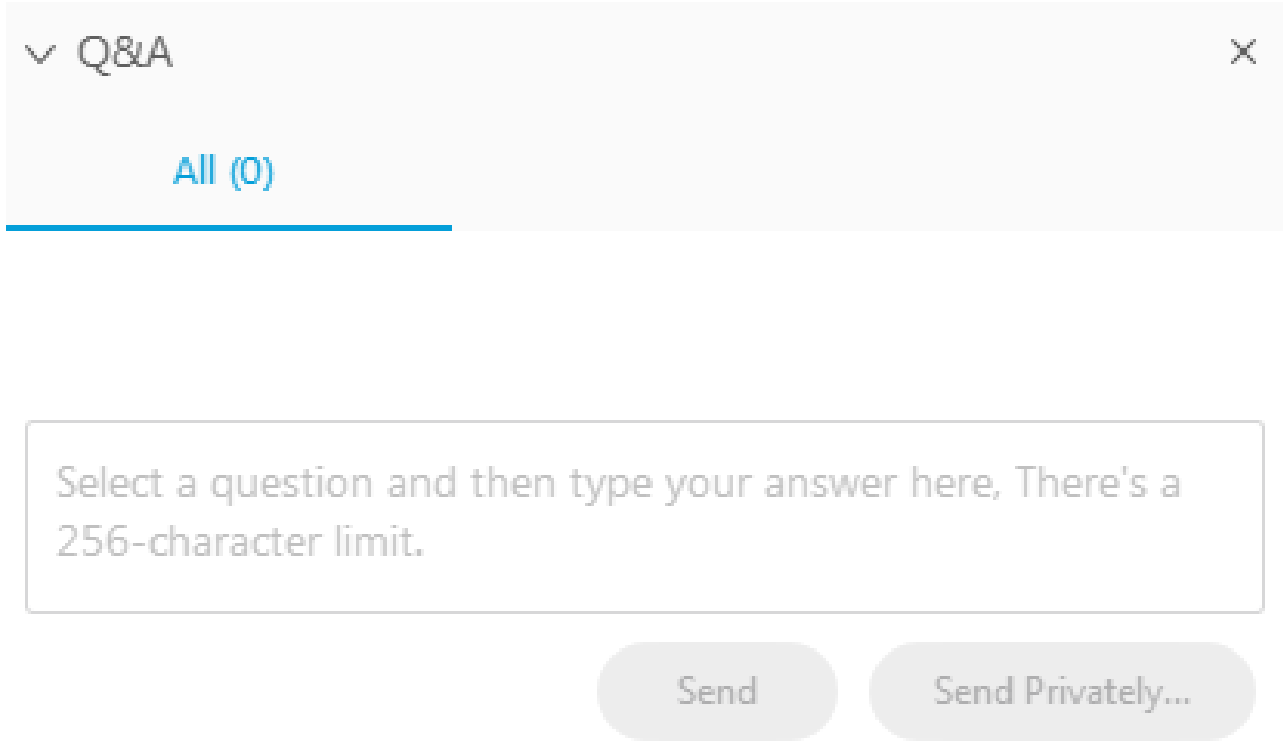

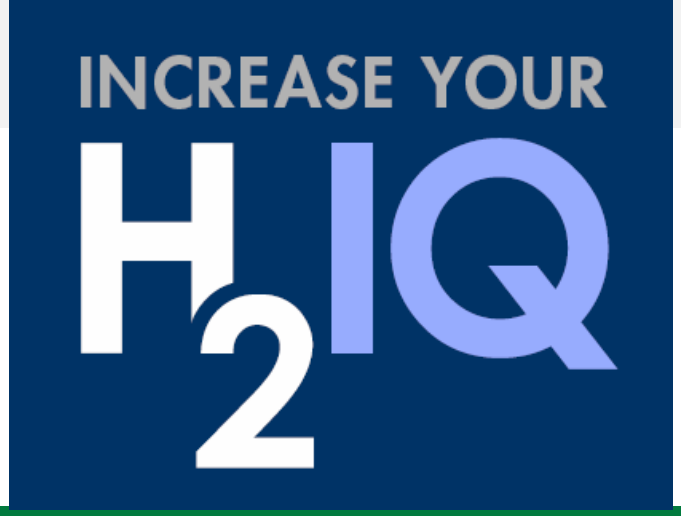

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Thank you for your participation!

Learn more:

energy.gov/fuelcells
hydrogen.energy.gov