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KOBE, JAPAN

Analysis of Current and Future Hydrogen Production and Utilization in the United States

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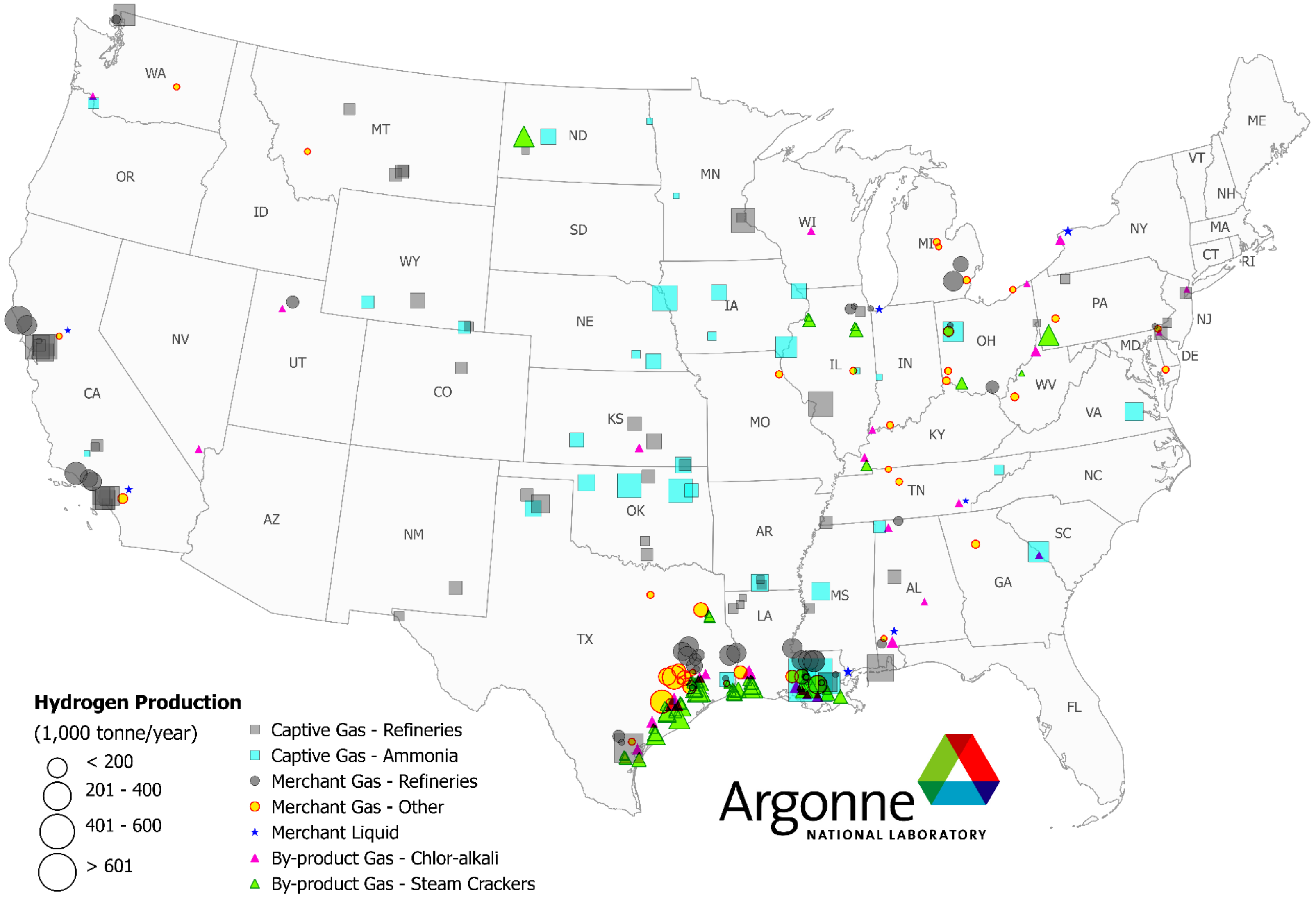
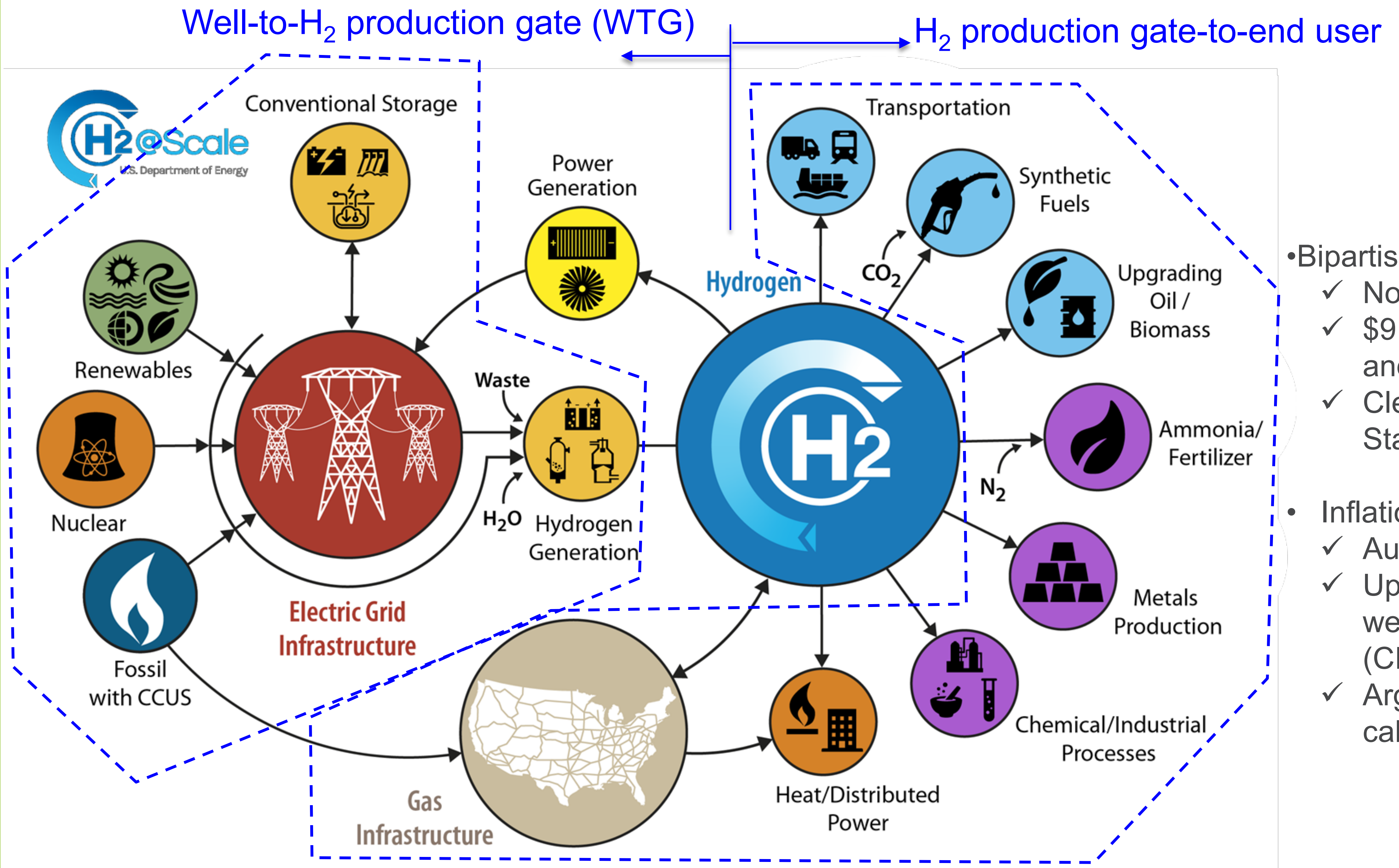
Today, more than 10M metric tons of hydrogen are produced in the U.S. annually, mainly from steam methane reforming of natural gas



H2@Scale: a DOE initiative for a hydrogen economy



- Bipartisan Infrastructure Law (BIL)
  - ✓ November 2021
  - ✓ \$9.5B for clean H_2 production and deployment
  - ✓ Clean Hydrogen Production Standard (<4 $kgCO_{2e}/kg_{H2}$)

- Inflation Reduction Act (IRA)
  - ✓ August 2022
  - ✓ Up to \$3/kg credit based on H_2 well-to-gate carbon intensity (CI)
  - ✓ Argonne GREET model for CI calculations

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Current status and trends of hydrogen deployment in the USA

Hydrogen Program

Coordinated across DOE on **research, development, demonstration, and deployment** (RDD&D) to address:

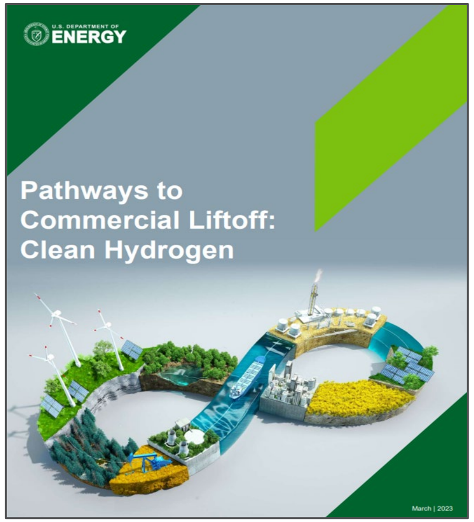
- **The entire H_2 value chain** from production through end use
- **H_2 production from all resources** (renewables, nuclear, and fossil + CCS)

U.S. clean hydrogen market is poised for rapid growth

Annual clean hydrogen production for domestic demand has the potential to scale from < 1 to ~10 M metric tons by 2030

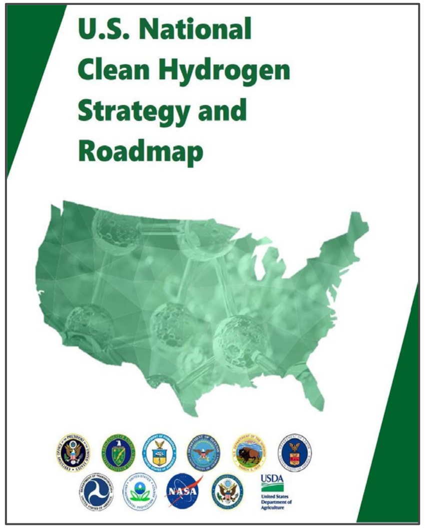
Scaling the market will require continuing work to address demand-side challenges

March 2023: Market Liftoff of Clean Hydrogen



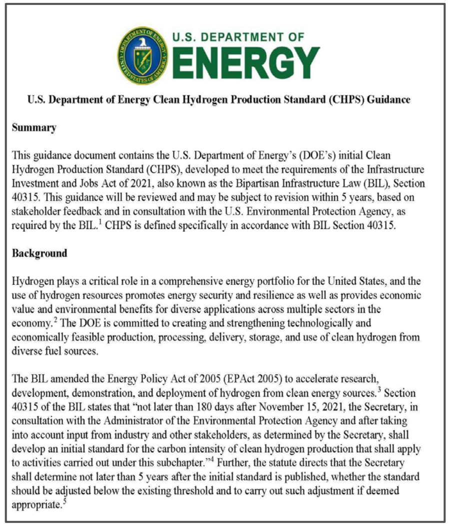
https://liftoff.energy.gov/clean-hydrogen/

June 2023: Multiagency strategy and roadmap



https://www.hydrogen.energy.gov/clean-hydrogen-strategy-roadmap.html

June 2023: DOE Production standard guidance


U.S. DEPARTMENT OF ENERGY

U.S. Department of Energy Clean Hydrogen Production Standard (CHPS) Guidance

Summary

This guidance document contains the U.S. Department of Energy's (DOE's) initial Clean Hydrogen Production Standard (CHPS), developed to meet the requirements of the Infrastructure Investment and Jobs Act of 2021, also known as the Bipartisan Infrastructure Law (BIL), Section 40315. This guidance will be reviewed and may be subject to revision within 5 years, based on stakeholder feedback and in consultation with the U.S. Environmental Protection Agency, as required by the BIL.[1] CHPS is defined specifically in accordance with BIL Section 40315.

Background

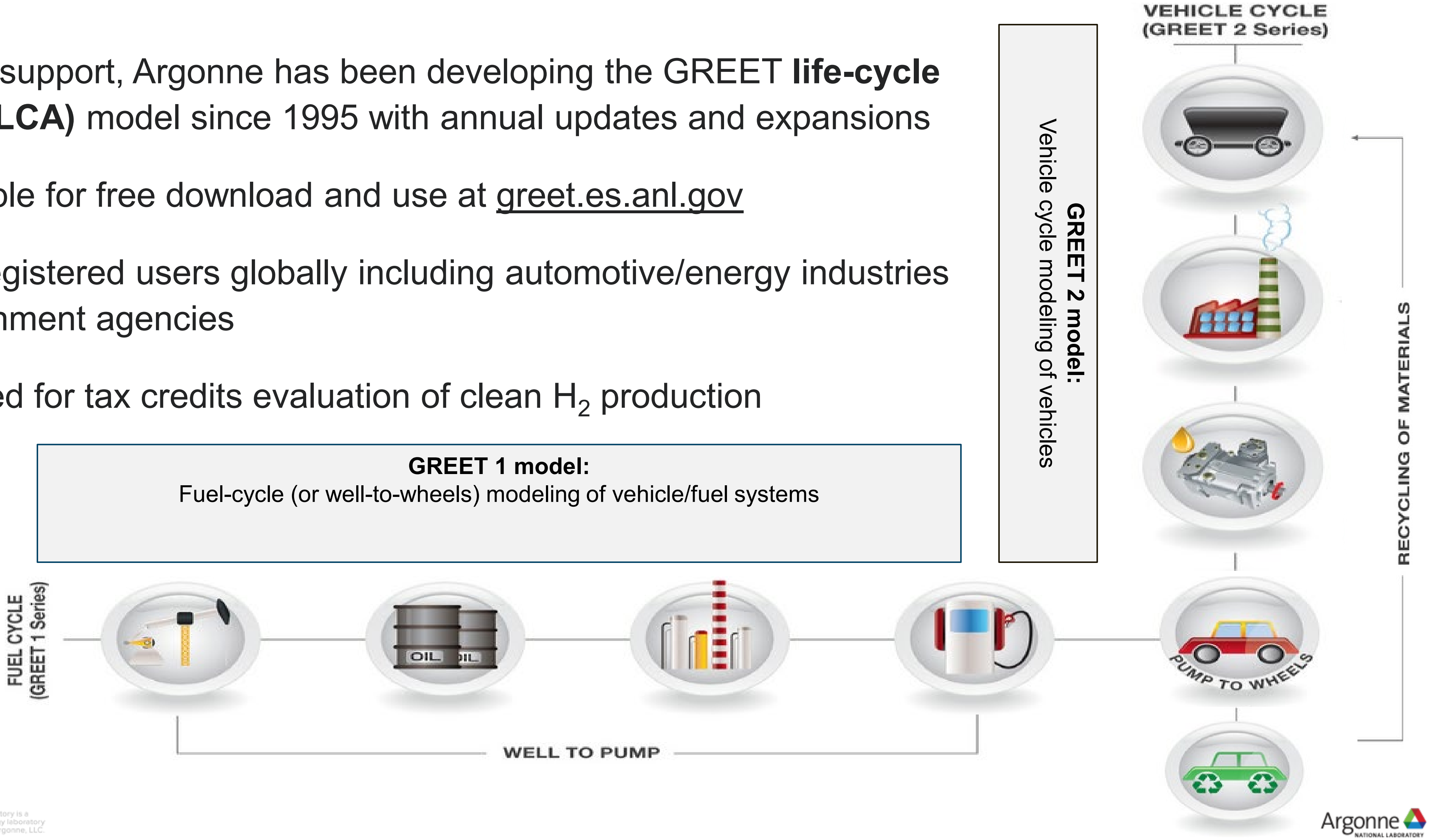
Hydrogen plays a critical role in a comprehensive energy portfolio for the United States, and the use of hydrogen resources promotes energy security and resilience as well as provides economic value and environmental benefits for diverse applications across multiple sectors in the economy.[2] The DOE is committed to creating and strengthening technologically and economically feasible production, processing, delivery, storage, and use of clean hydrogen from diverse fuel sources.

The BIL amended the Energy Policy Act of 2005 (EPAct 2005) to accelerate research, development, demonstration, and deployment of hydrogen from clean energy sources.[3] Section 40315 of the BIL states that "not later than 180 days after November 15, 2021, the Secretary, in consultation with the Administrator of the Environmental Protection Agency and after taking into account input from industry and other stakeholders, as determined by the Secretary, shall develop an initial standard for the carbon intensity of clean hydrogen production that shall apply to activities carried out under this subchapter."[4] Further, the statute directs that the Secretary shall determine not later than 5 years after the initial standard is published, whether the standard should be adjusted below the existing threshold and to carry out such adjustment if deemed appropriate.[5]

https://www.energy.gov/eere/fuelcells/articles/clean-hydrogen-production-standard

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
- >55,000 registered users globally including automotive/energy industries and government agencies
- Will be used for tax credits evaluation of clean H_2 production



GREET sustainability metrics include energy use, criteria air pollutants, GHG, 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

Resource availability and energy security

Air pollutants

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

Human health and environmental justice

Greenhouse gases

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

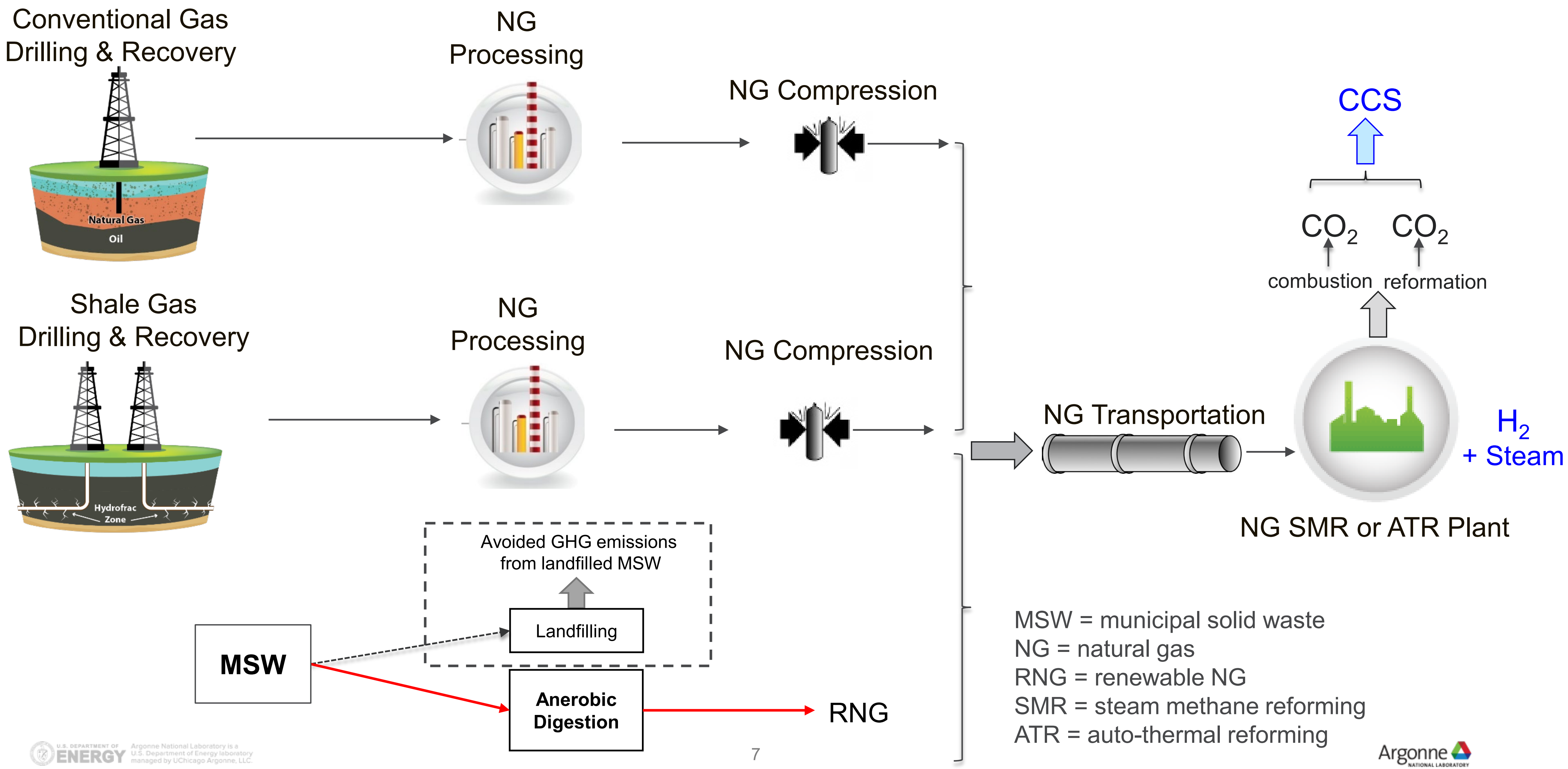
Global warming impacts

Water consumption

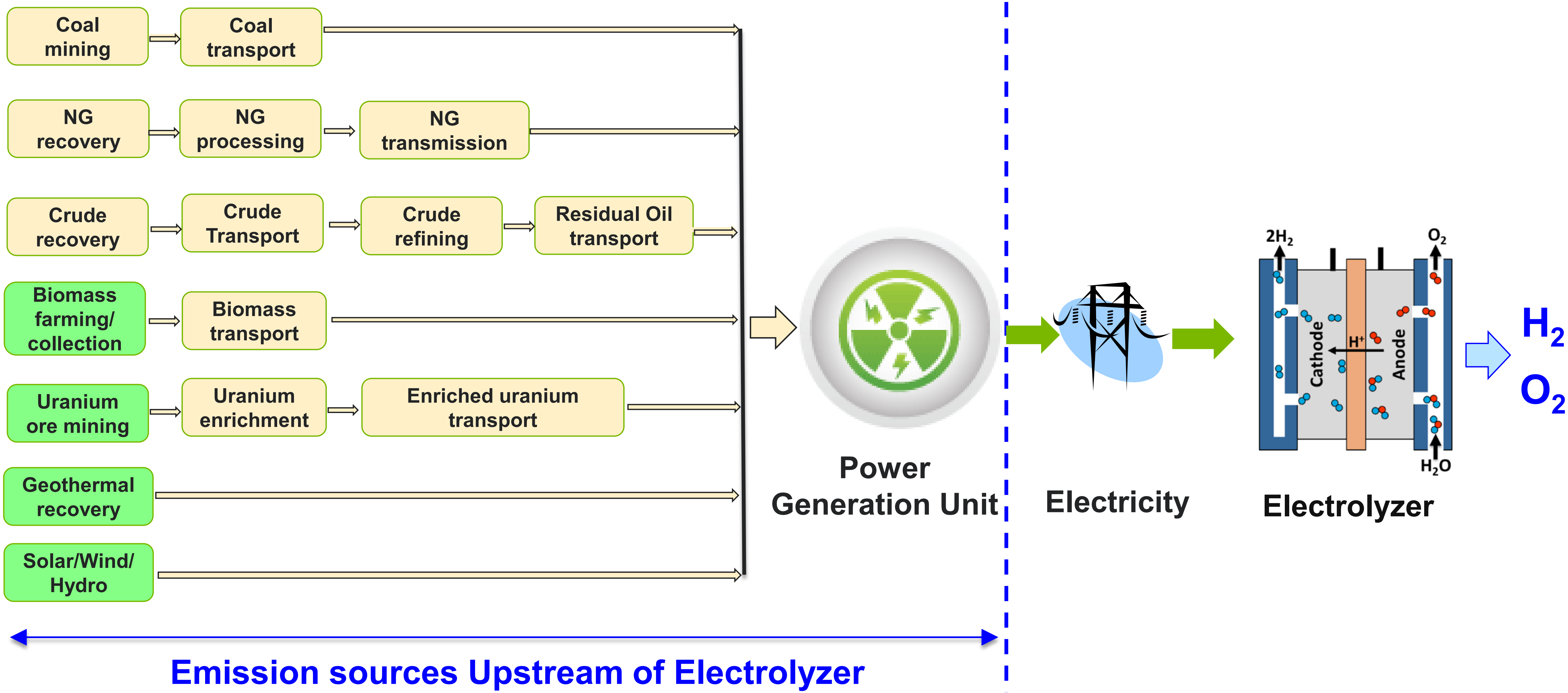
- Addressing water supply and demand (energy-water nexus)

Regional/seasonal water stress impacts

Hydrogen production via CH_4 reforming, w/ and w/o CCS

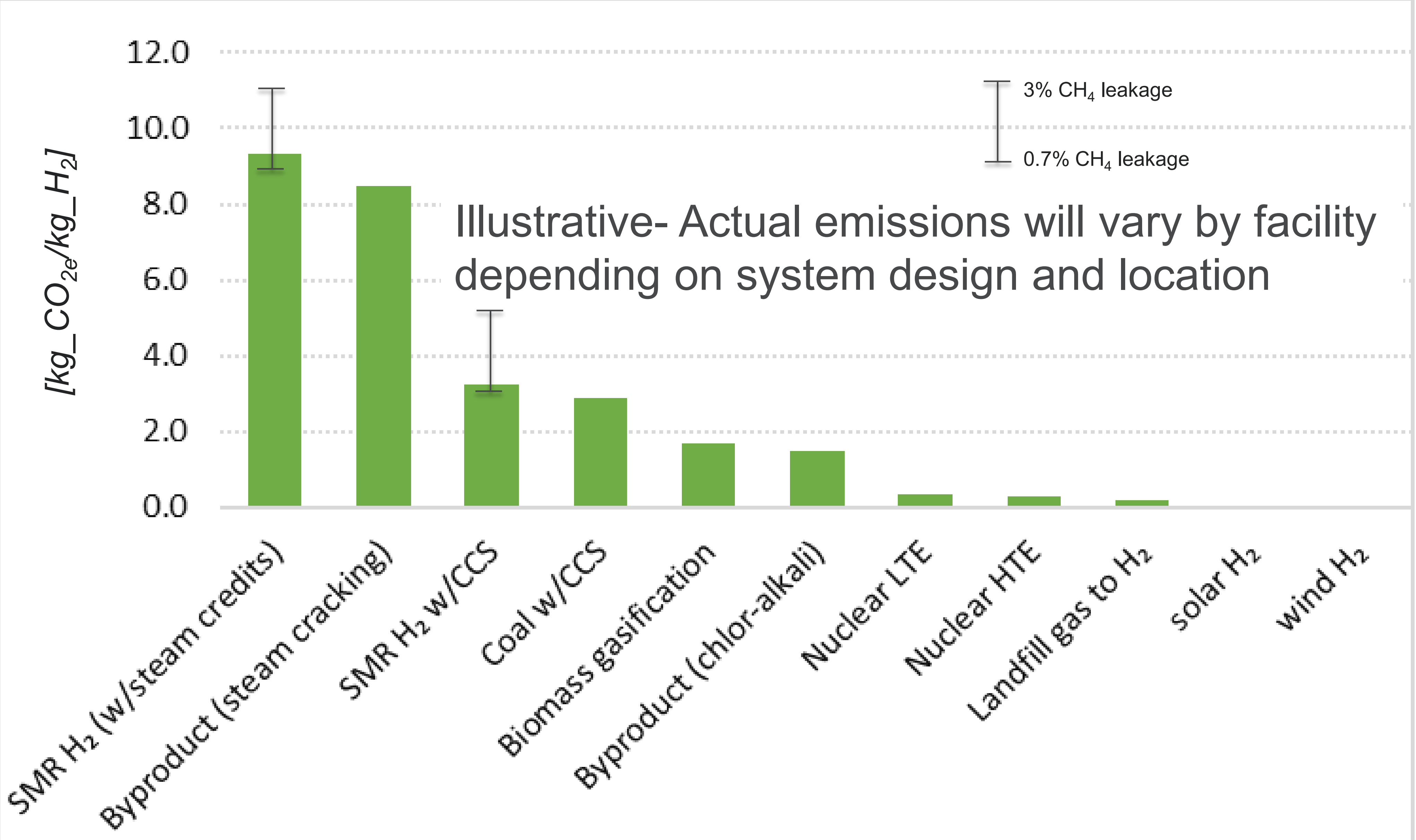


Hydrogen production via water electrolysis



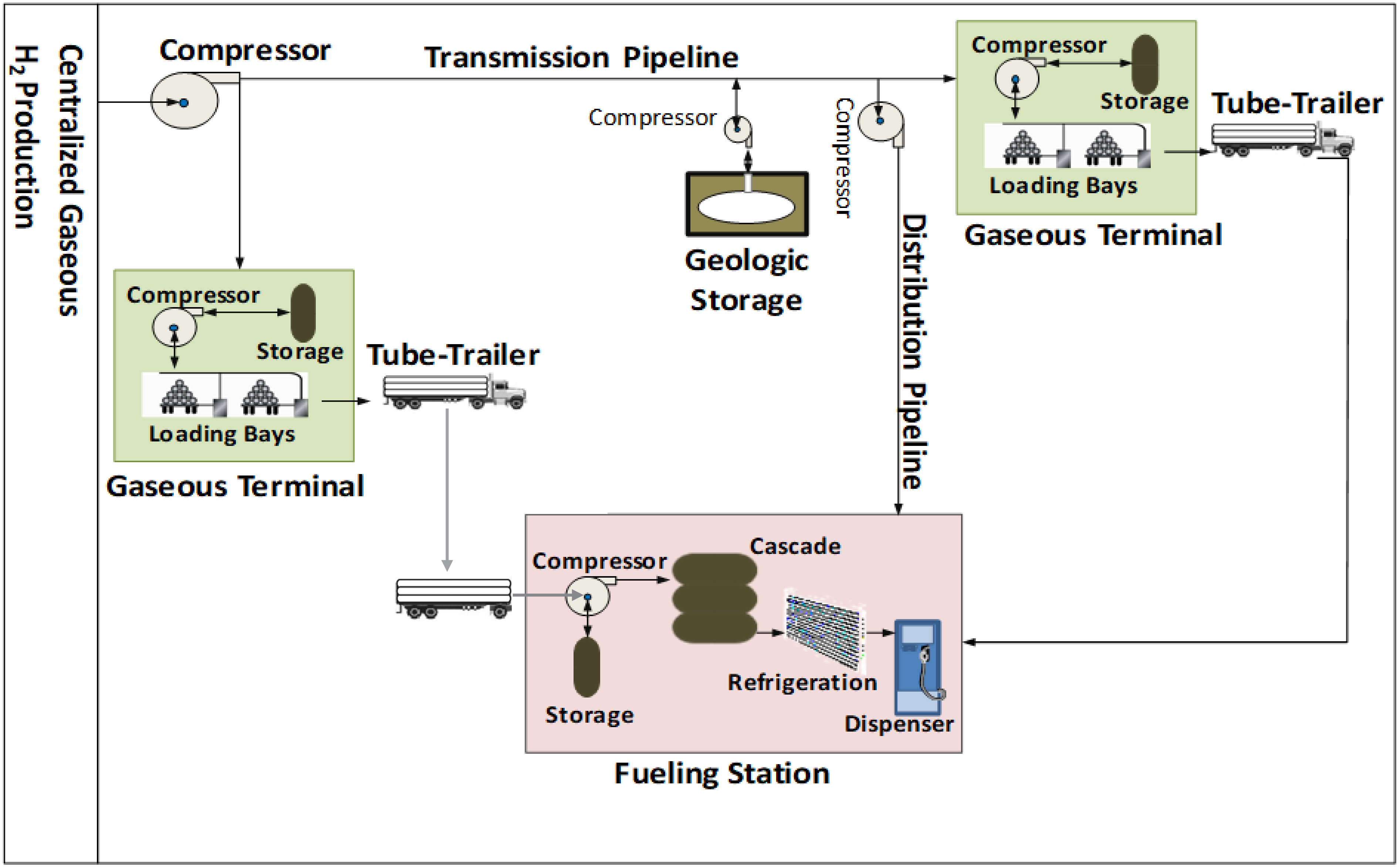
Well-to-gate (WTG) GHG emissions of hydrogen production pathways

SMR= Steam Methane Reforming;
CCS=Carbon Capture and Sequestration;
LTE=Low-Temp Electrolysis;
HTE=High-Temp Electrolysis;
LFG=Landfill Gas

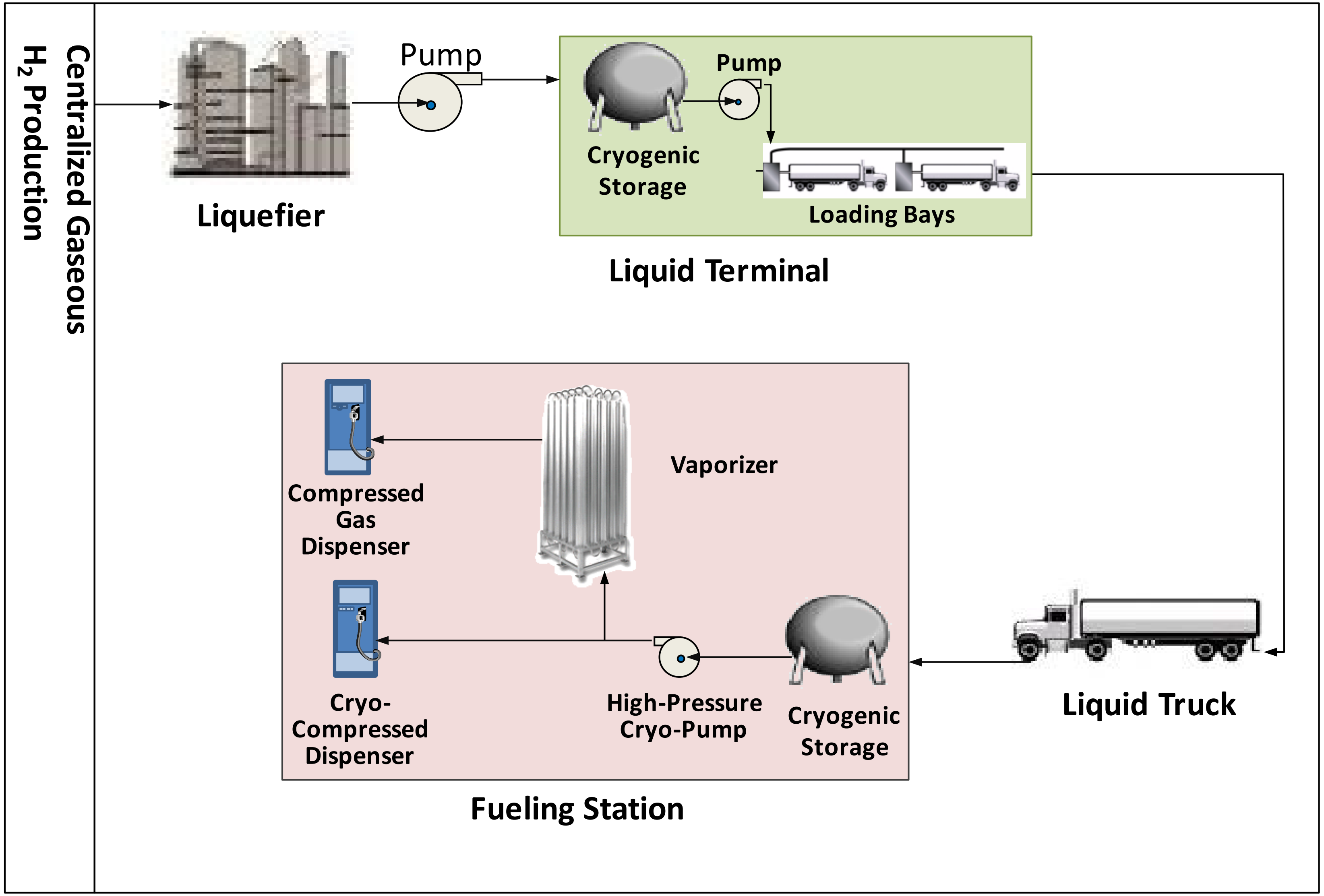


https://greet.es.anl.gov/files/hydrogenreport2022

Infrastructure options for gaseous hydrogen (GH2) delivery

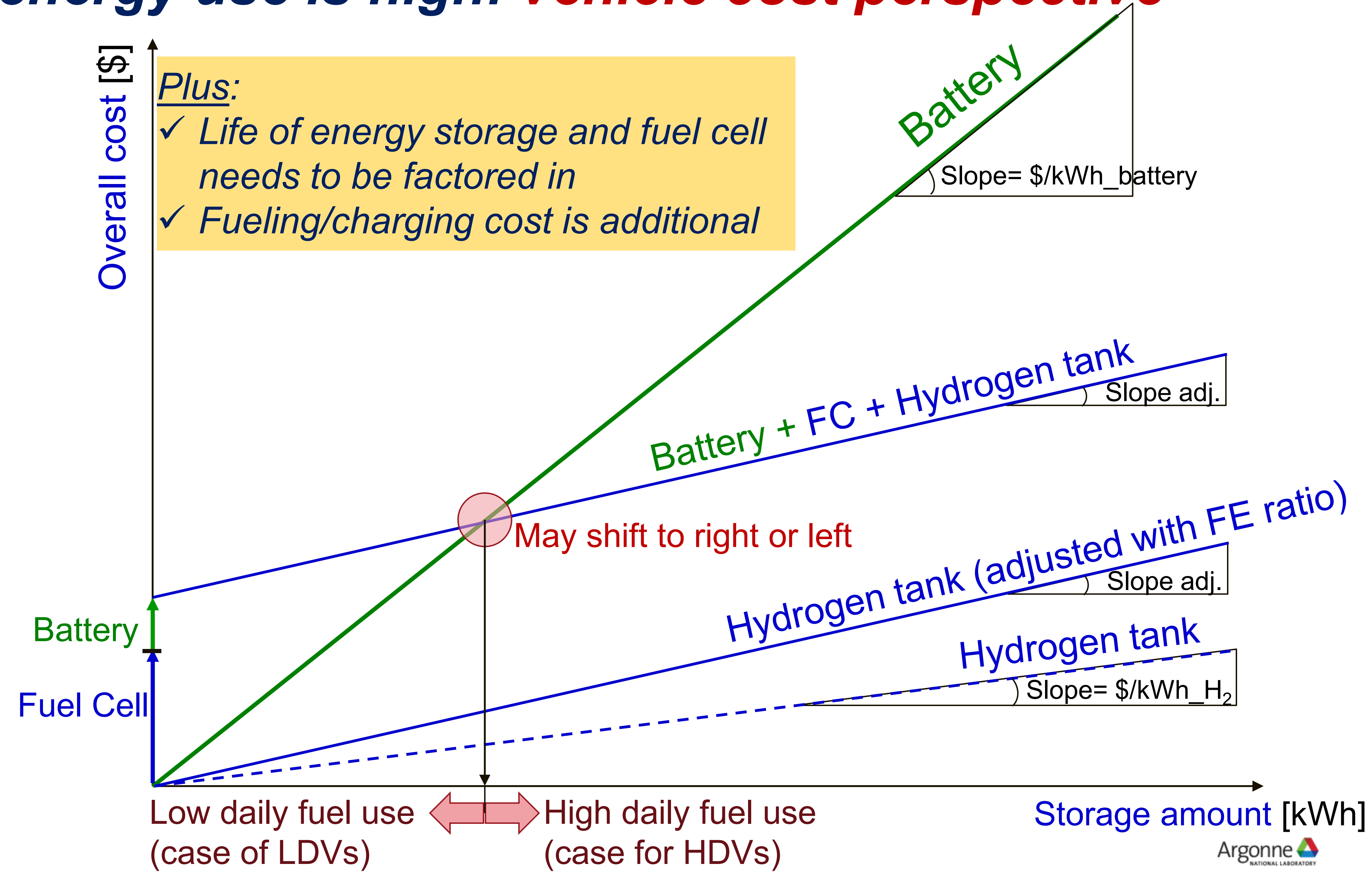


Infrastructure of liquid hydrogen (LH2) delivery



H_2 fuel cell electric vehicles are attractive zero-emission options when daily energy use is high: vehicle cost perspective

Plus:
- ✓ *Life of energy storage and fuel cell needs to be factored in*
- ✓ *Fueling/charging cost is additional*



✓FC: Fuel Cell
✓FE: Fuel Economy
✓LDV: Light-Duty Vehicle
✓HDV: Medium- and Heavy-Duty Vehicle

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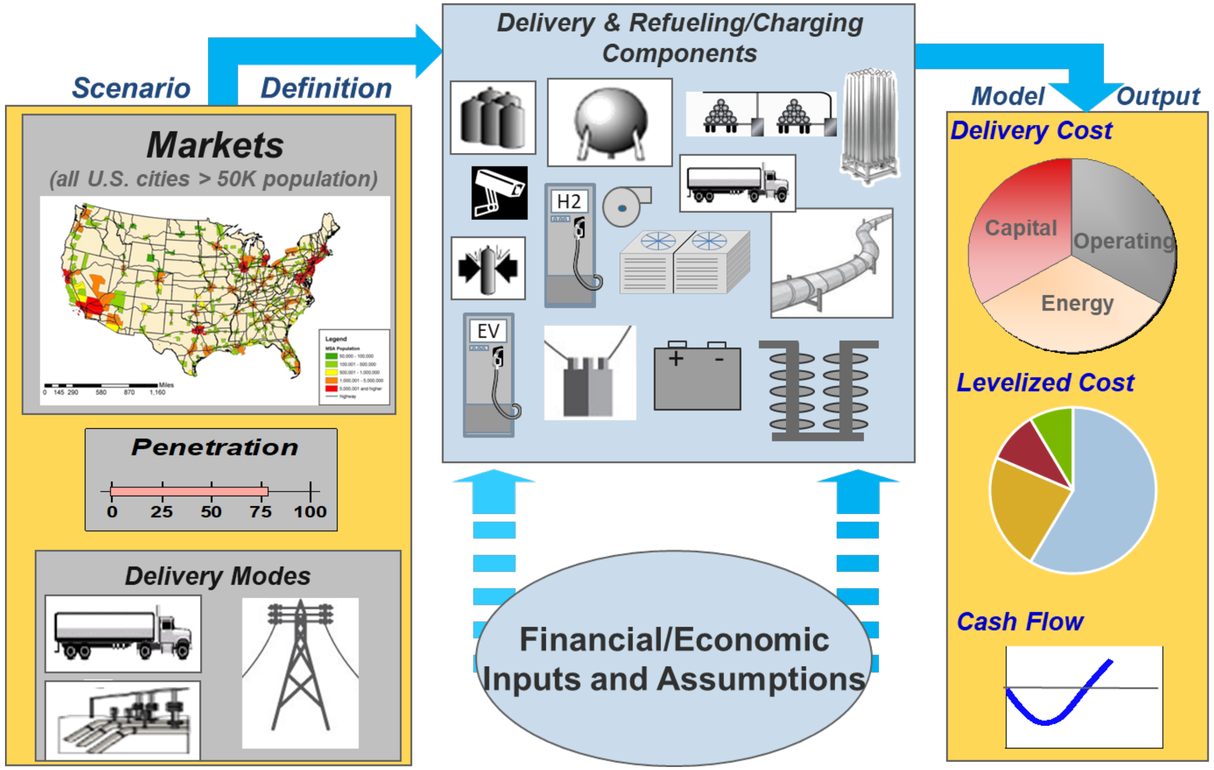
Hydrogen Delivery Scenario Analysis suite of Models (HDSAM)

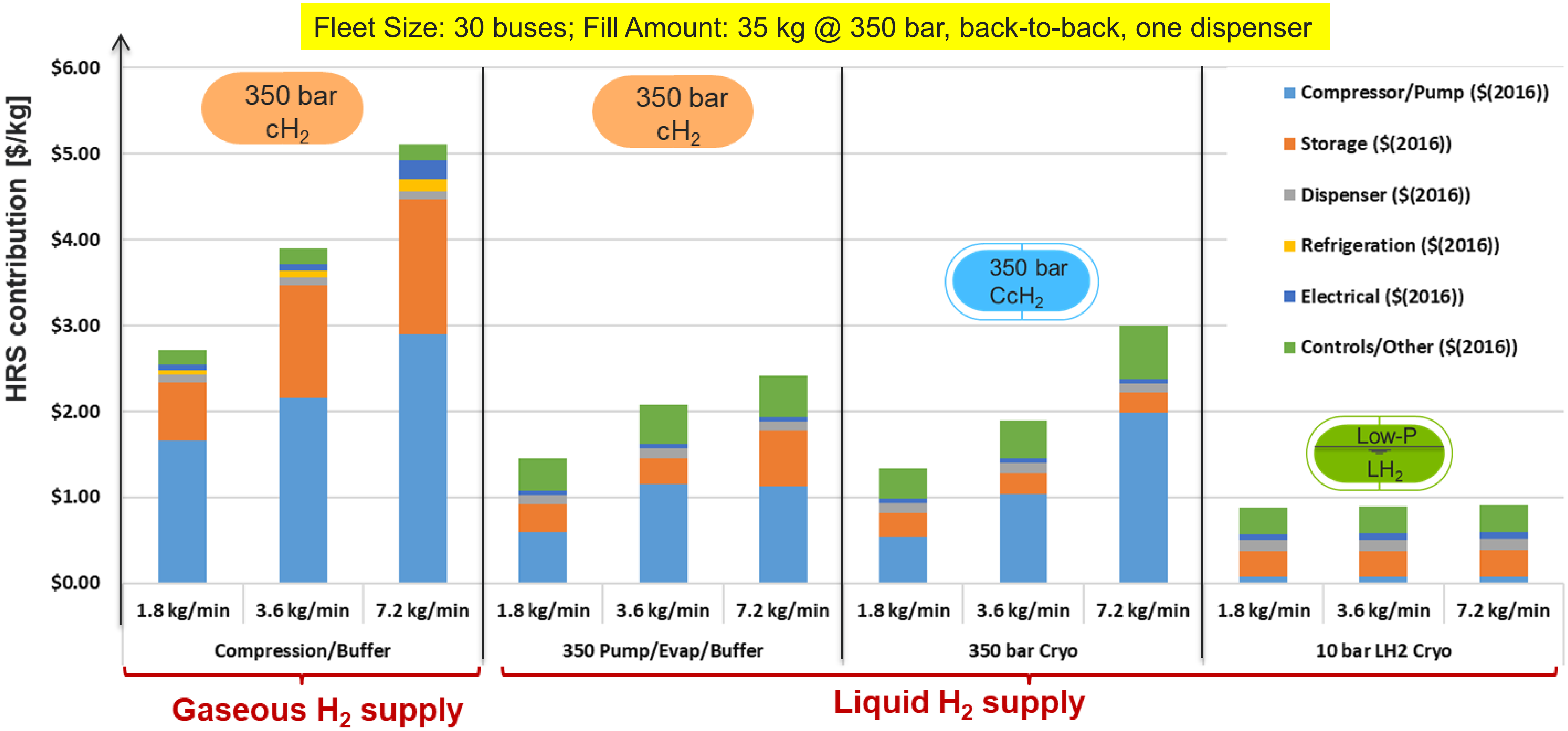
Argonne's HDSAM and its derivatives evaluate the economic performance and market acceptance of hydrogen delivery technologies and fueling infrastructure for FCEVs

- Publicly available with >5,000 users, including major gas and energy companies, in more than 25 economies
- Supported by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) since 2004



https://hdsam.es.anl.gov/

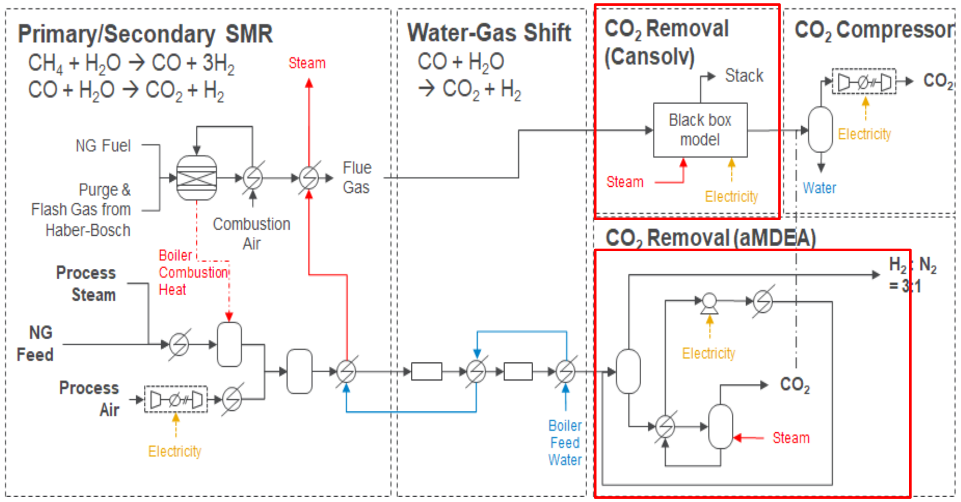
H_2 supply form and onboard storage technology strongly impact H_2 refueling station (HRS) cost



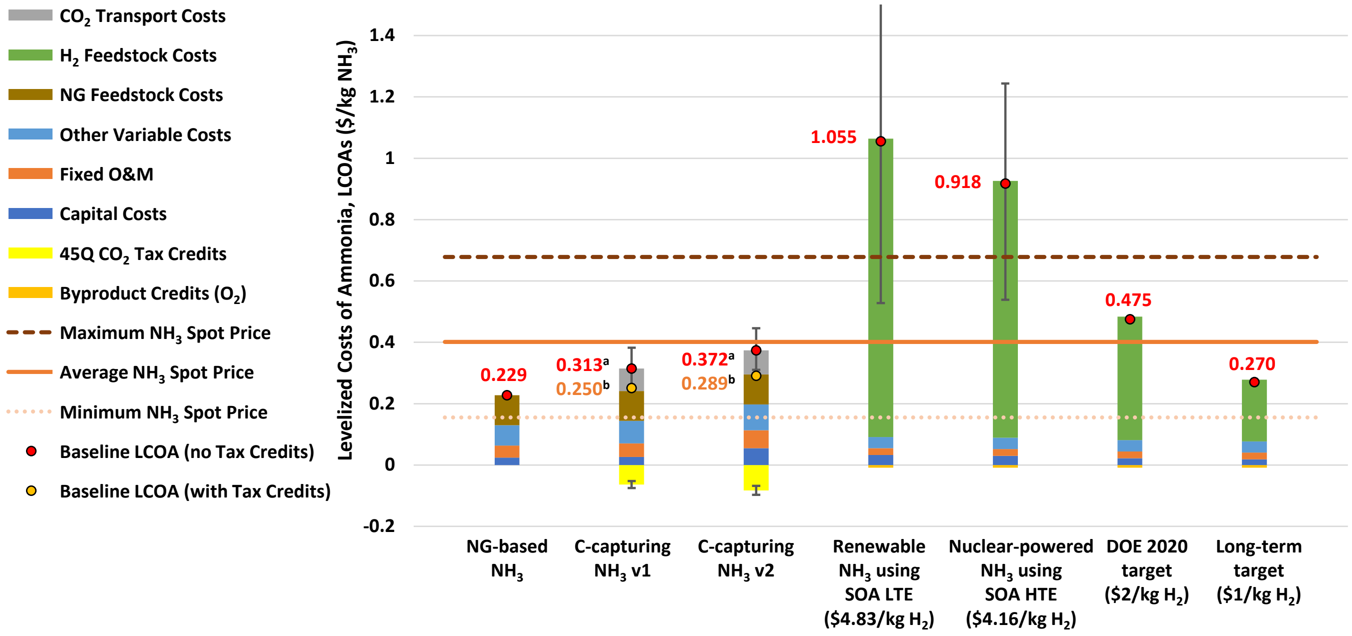
➢ Cost of H_2 delivered to the station is additional

Ammonia as fertilizer, fuel and H_2 carrier

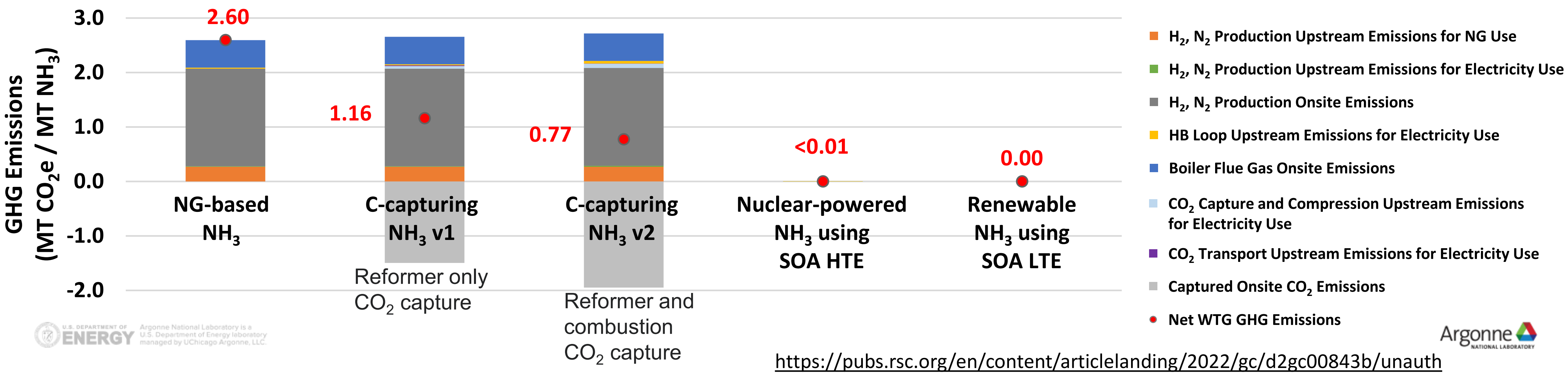
- Ammonia production process modeling



- Techno-economic analysis



- Well-to-gate emissions

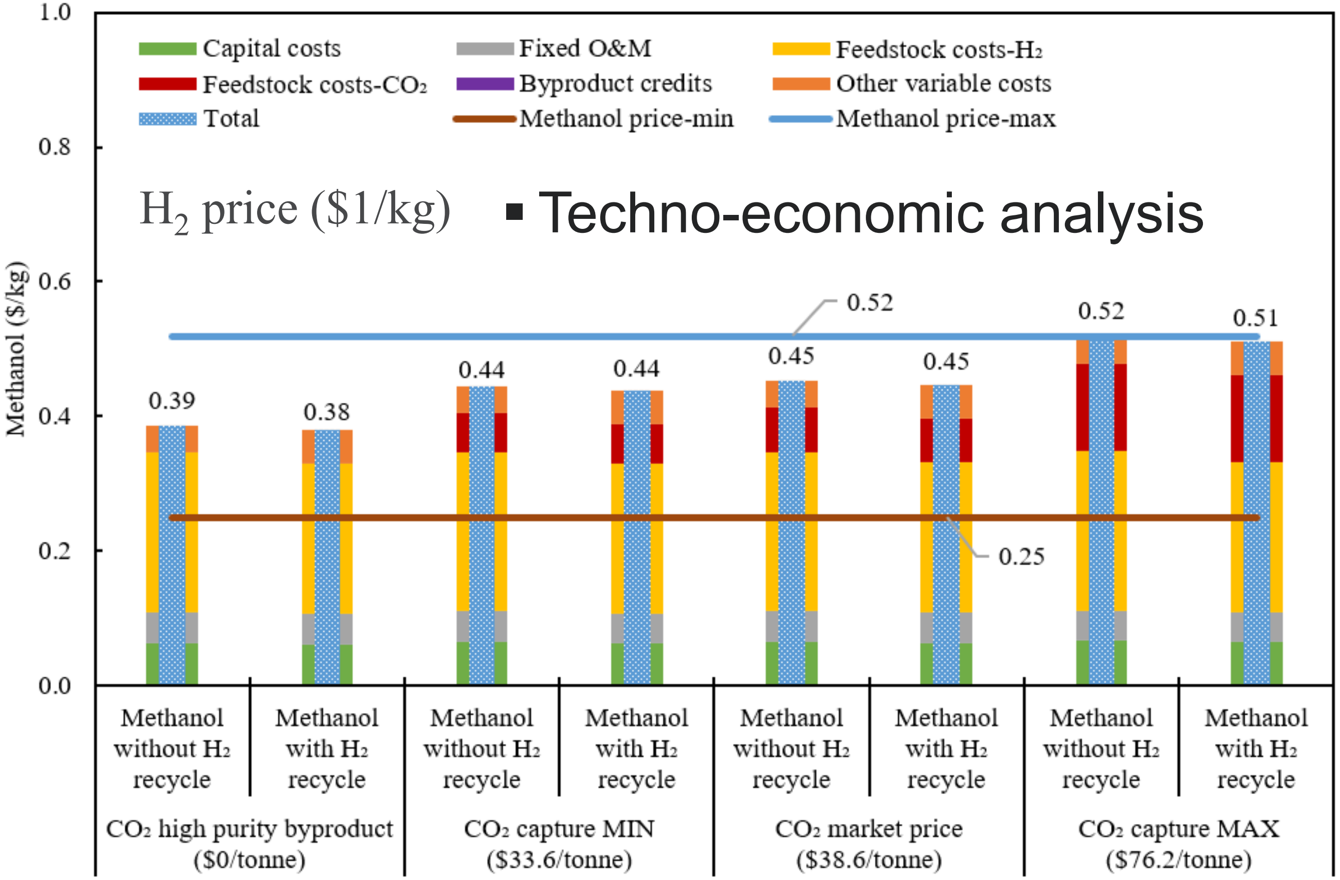


https://pubs.rsc.org/en/content/articlelanding/2022/gc/d2gc00843b/unauth

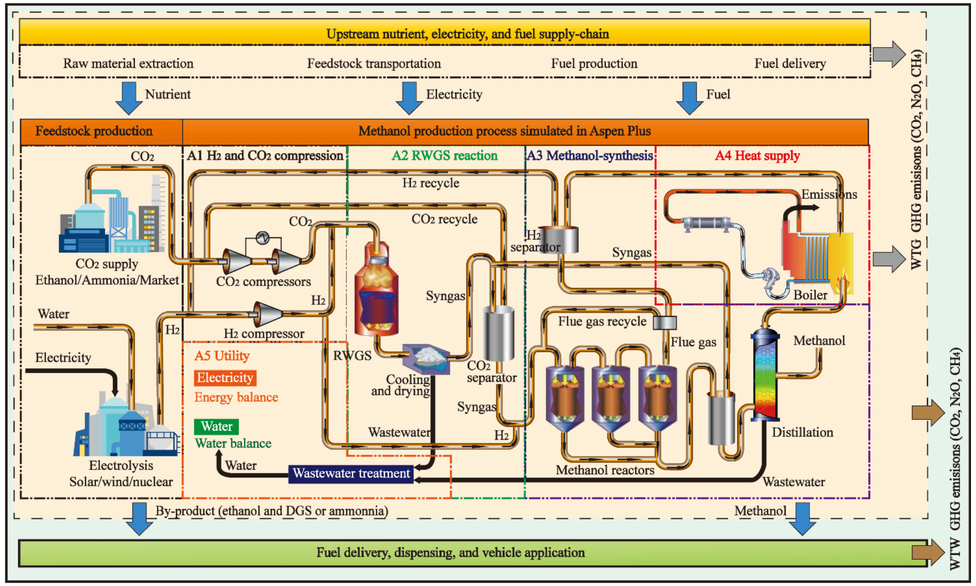
e-methanol as chemical, fuel, H_2 carrier

- Methanol can be synthesized by using CO_2 and H_2 via RWGS and methanol reaction
- $CO_2 + H_2 \rightarrow$ syngas $\rightarrow$ methanol

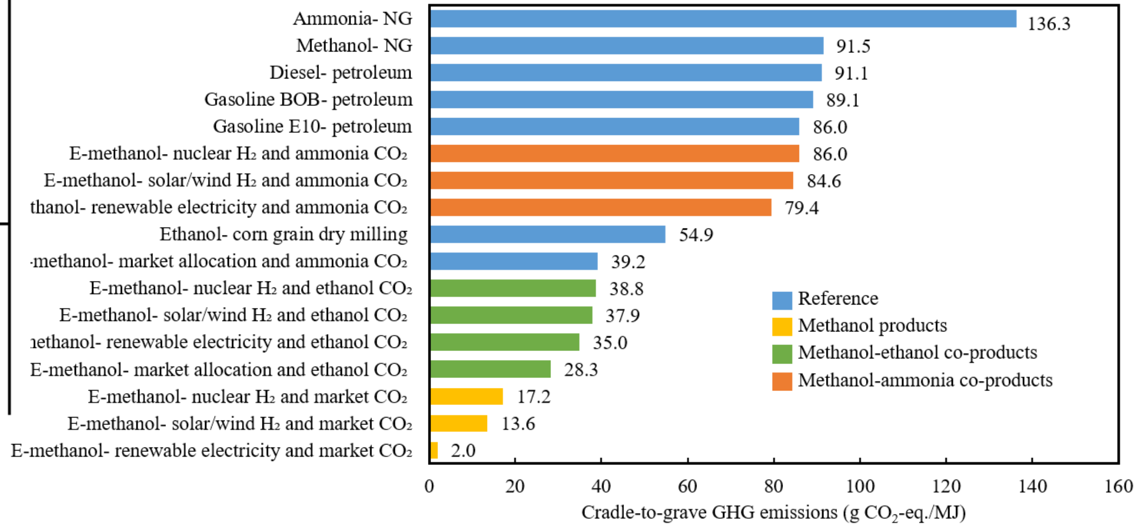
▪ Techno-economic analysis



▪ Conversion process modeling



▪ Well-to-gate GHG emissions

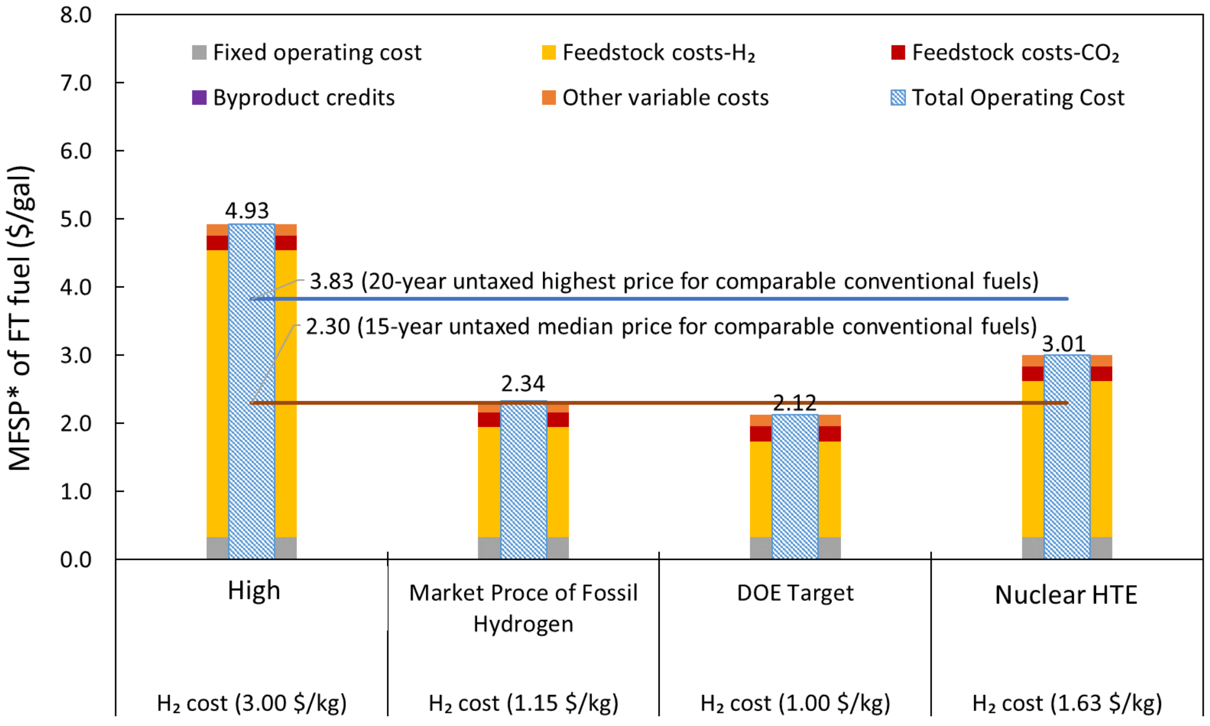


https://pubs.acs.org/doi/10.1021/acs.est.0c08237

E-fuels via Fischer-Tropsch (FT) process using H_2 + CO_2

- FT fuels can be synthesized by using CO_2 and H_2 via RWGS and FT reaction
- CO_2 + H_2→ syngas→ FT fuels

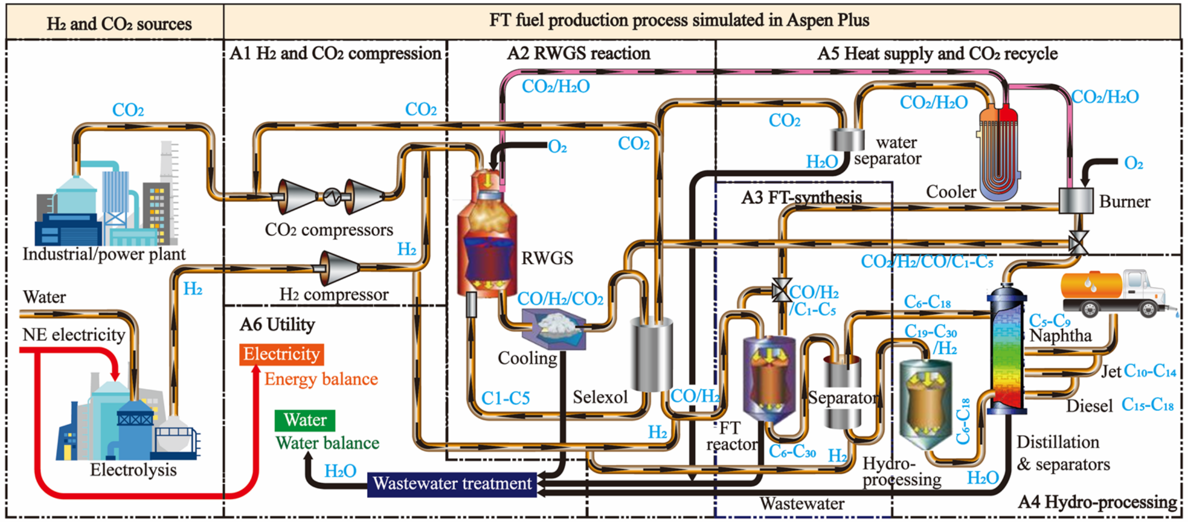
▪ Techno-economic analysis



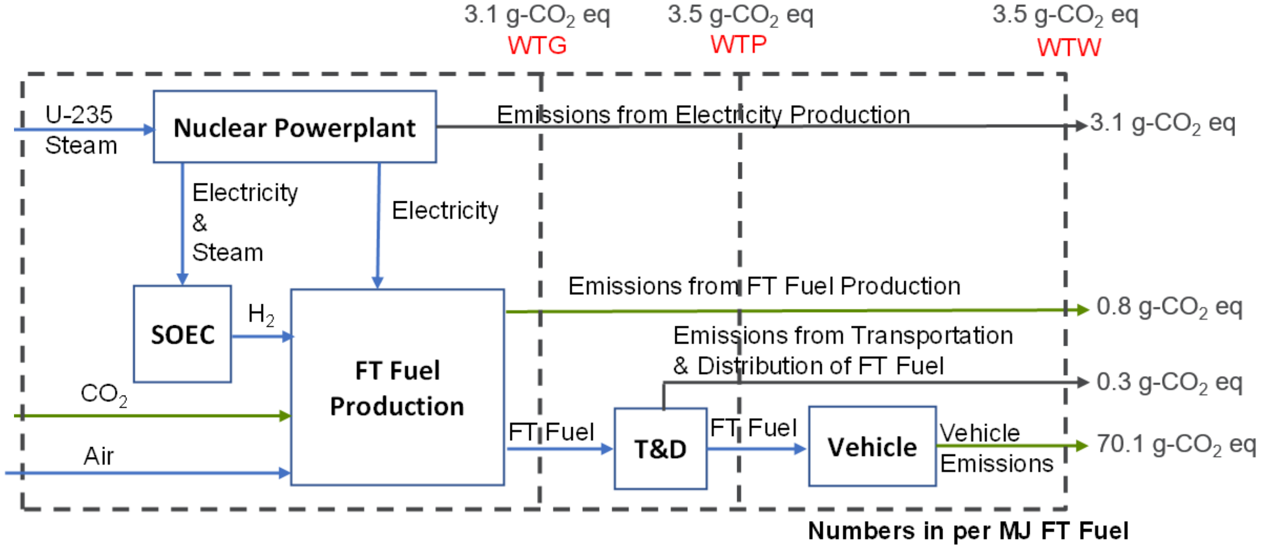
*MSFP=minimum fuel selling price

https://www.osti.gov/biblio/1868524

▪ Conversion process modeling



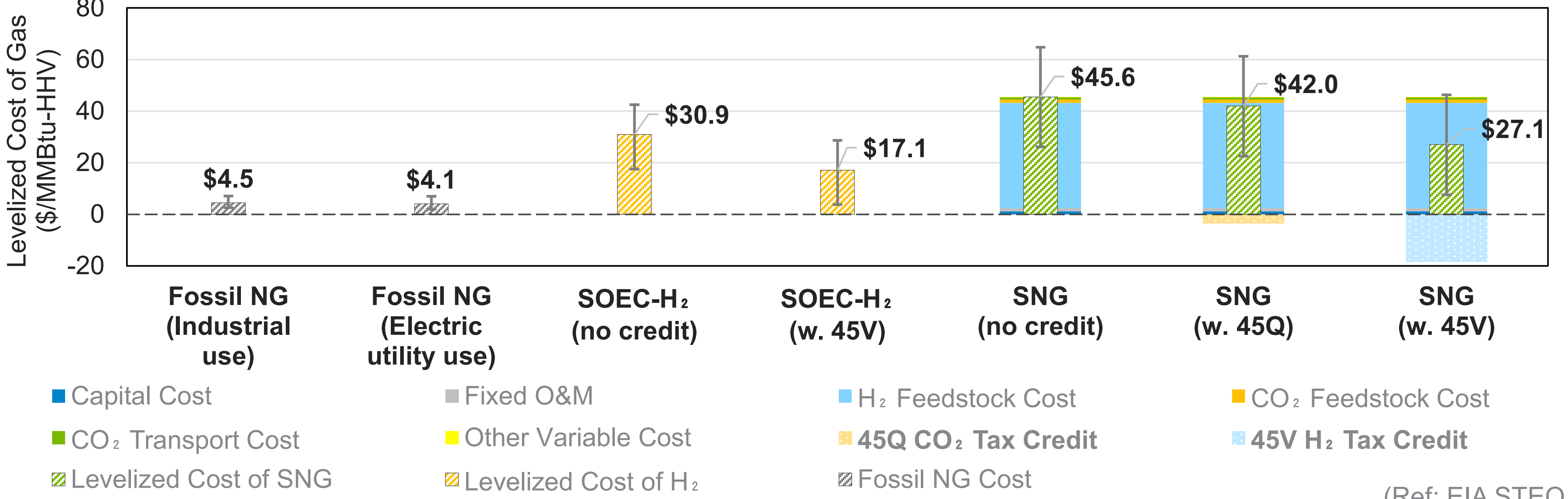
▪ Well-to-gate emissions



SNG Production Cost – w/ and w/o IRA Tax Credits

- Ethanol-CO_2 supply

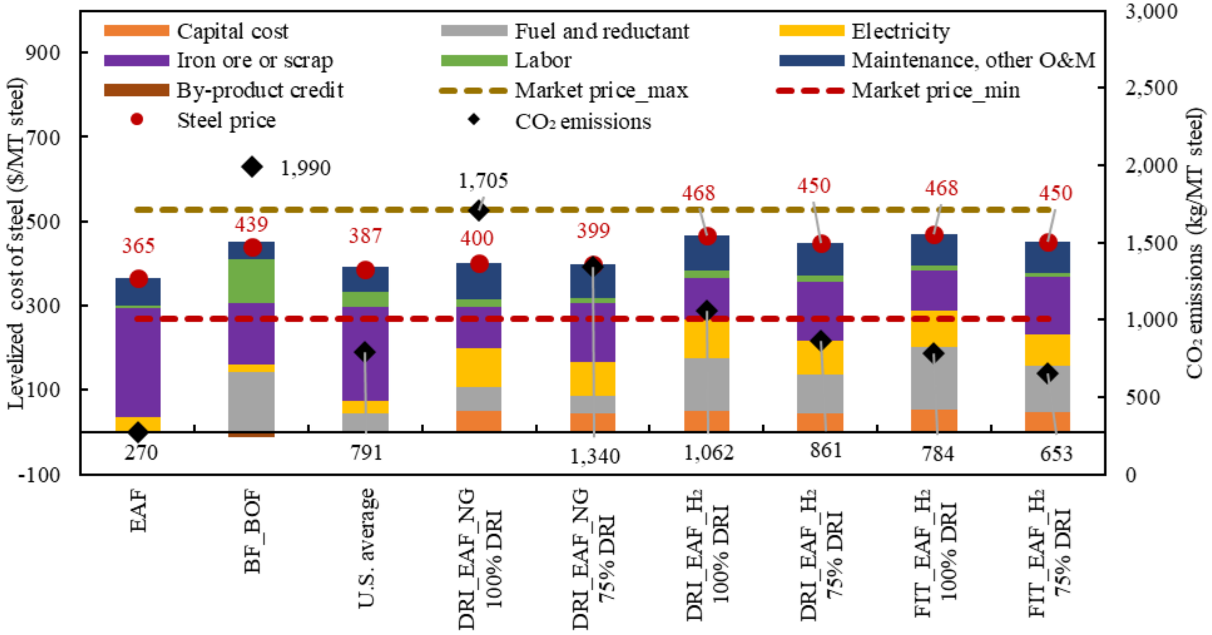
- SOEC = solid oxide electrolyzer cell

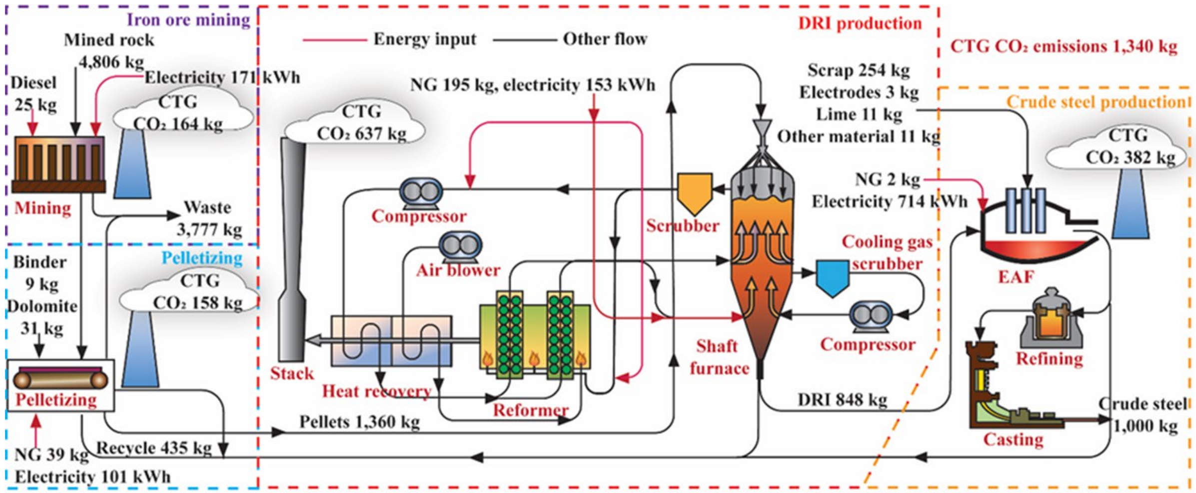


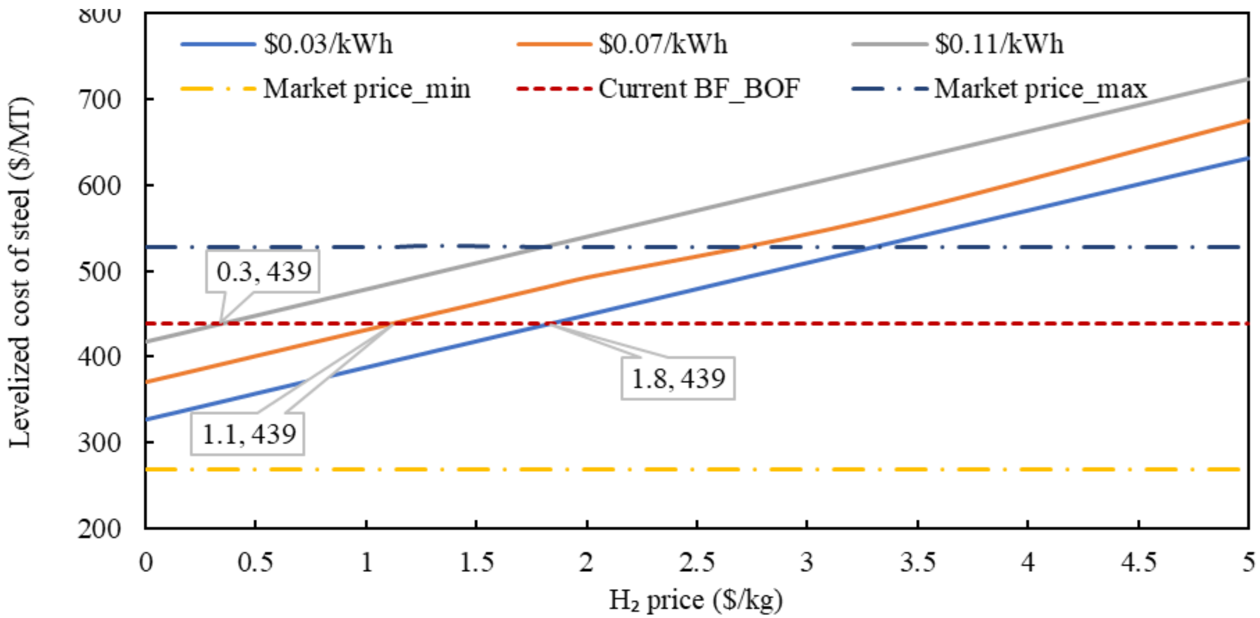
(Ref: EIA STEO 2022)

TEA Parameter	Unit	Low-Cost Value	Baseline Value	High-Cost Value	Reference
Nuclear electricity price	¢/kWh	3	**7**	11	DOE 2020 Record
SOEC-H_2 price (no credit)	\$/kg-H_2	2.4	**4.2**	5.7	DOE 2020 Record
SOEC-H_2 price (with 45V PTC)	\$/kg-H_2	0.5	**2.3**	3.9	This work
Ethanol-CO_2 price	\$/MT-CO_2	17.7 (minimum)	**25.2 (weighted average)**	33.4 (maximum)	This work and NETL, 2014
CO_2 transport distance	mi	50	**100**	500	This work
Byproduct steam	-	Export	**No export**	No export	This work

Steel production using hydrogen in DRI technology







- NG=$3.7/GJ, Elec =$0.07/kWh, H_2=$1.3/kg
- The production cost with DRI-NG-EAF is similar with that of BF-BOF
- DRI-H_2 is more costly, and sensitive to H_2 price
- For DRI-H_2 steel to reach price parity with market price, H_2 cost needs to be $1-2/kg H_2
- IRA 45V incentivize DRI with H_2

Cost and Life Cycle Analysis for Deep CO2 Emissions Reduction for Steel Making: Direct Reduced Iron Technologies - Zang - steel research international - Wiley Online Library

Acknowledgment

Hydrogen TEA and LCA at Argonne have been supported by DOE's Office of Energy Efficiency and Renewable Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) for over two decades

Thank You!

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Our models, tutorials and publications are available at:

https://greet.es.anl.gov/

https://hdsam.es.anl.gov/