OVERVIEW OF HYDROGEN DELIVERY SCENARIO ANALYSIS MODEL (HDSAM)

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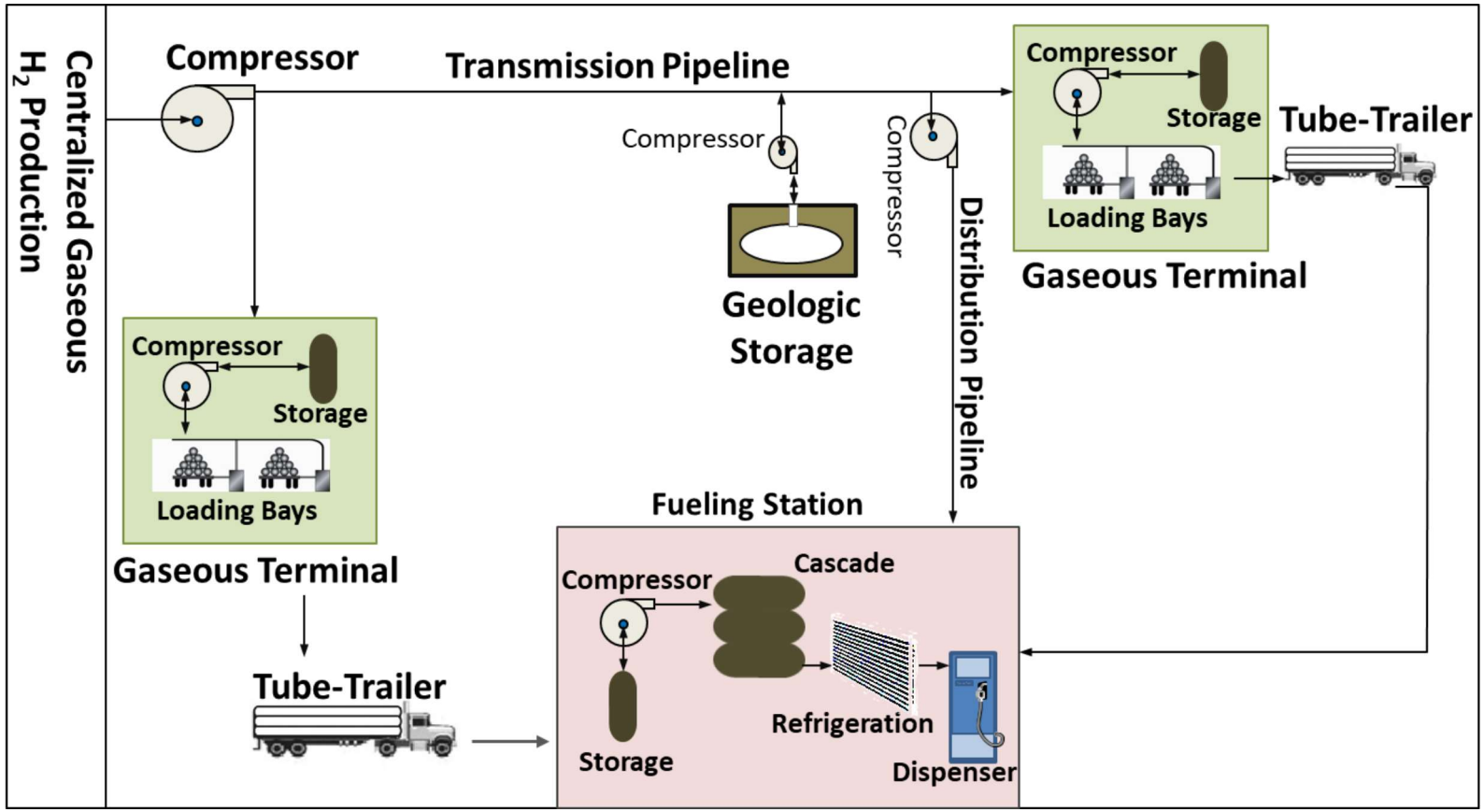
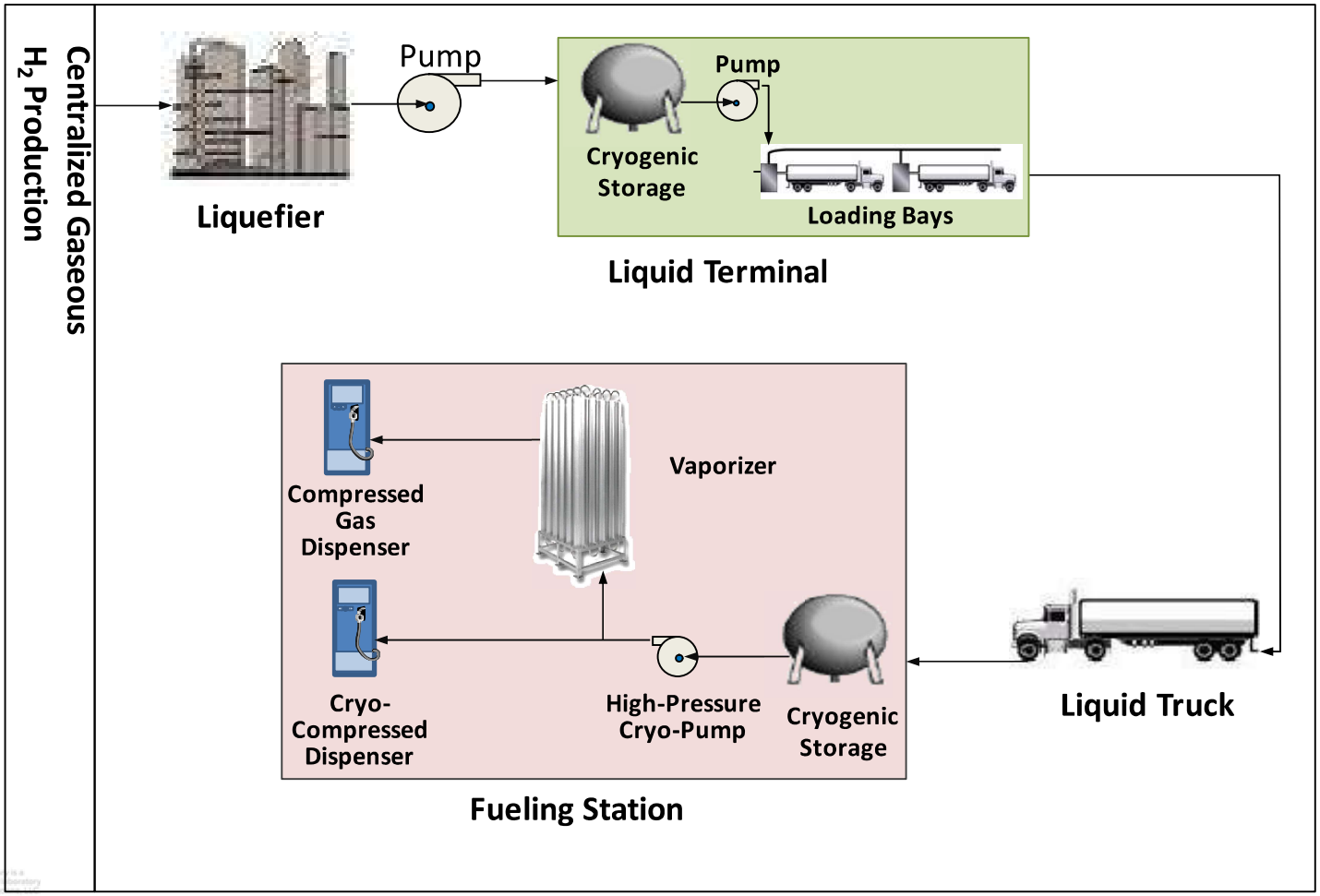
The Gulf Coast Hydrogen Ecosystem: Opportunities and Solutions

Technology - Hydrogen Supply Chain and Distribution

Infrastructure of gaseous hydrogen delivery and storage



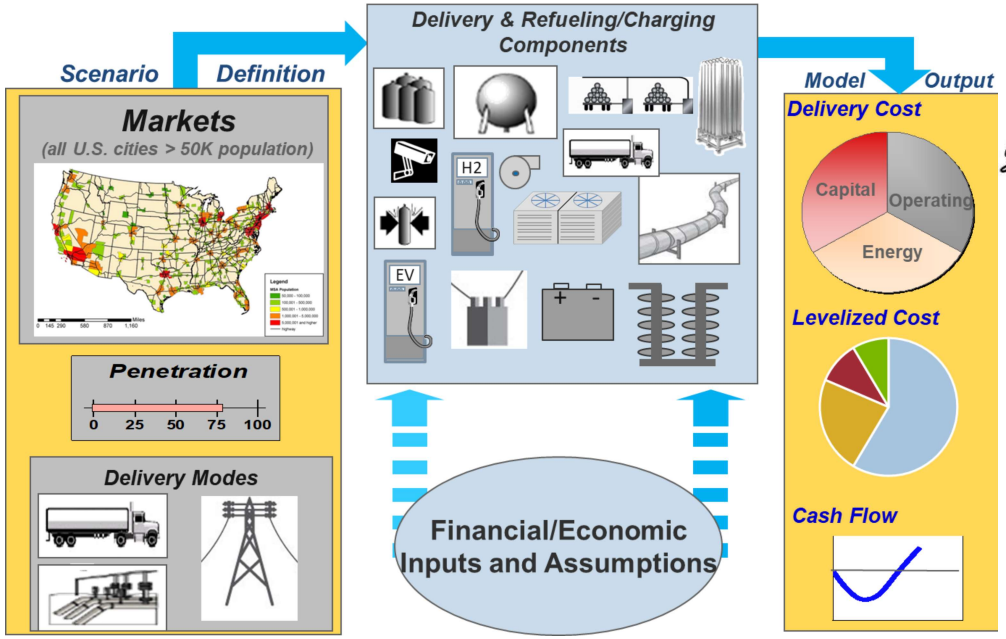
Infrastructure of liquid hydrogen delivery and storage



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 >6,000 users, including major gas and energy companies, in more than 25 countries
- Supported by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) since 2004

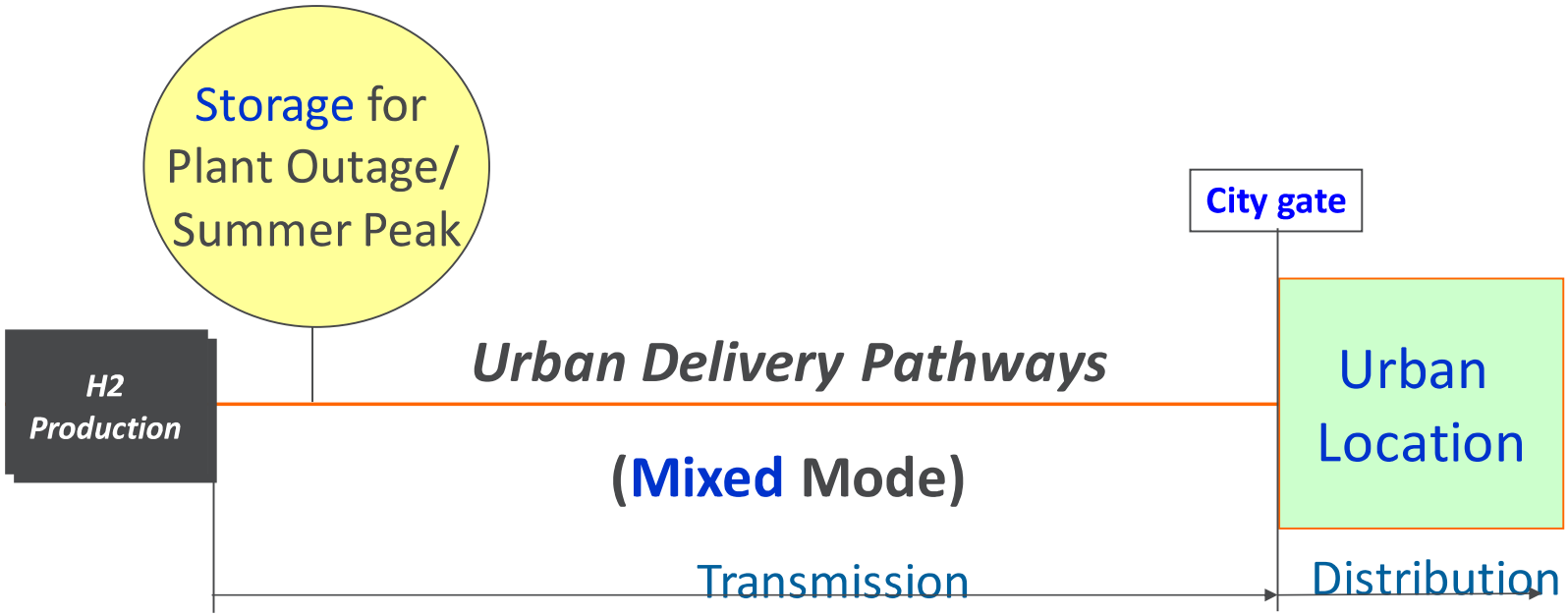


https://hdsam.es.anl.gov/

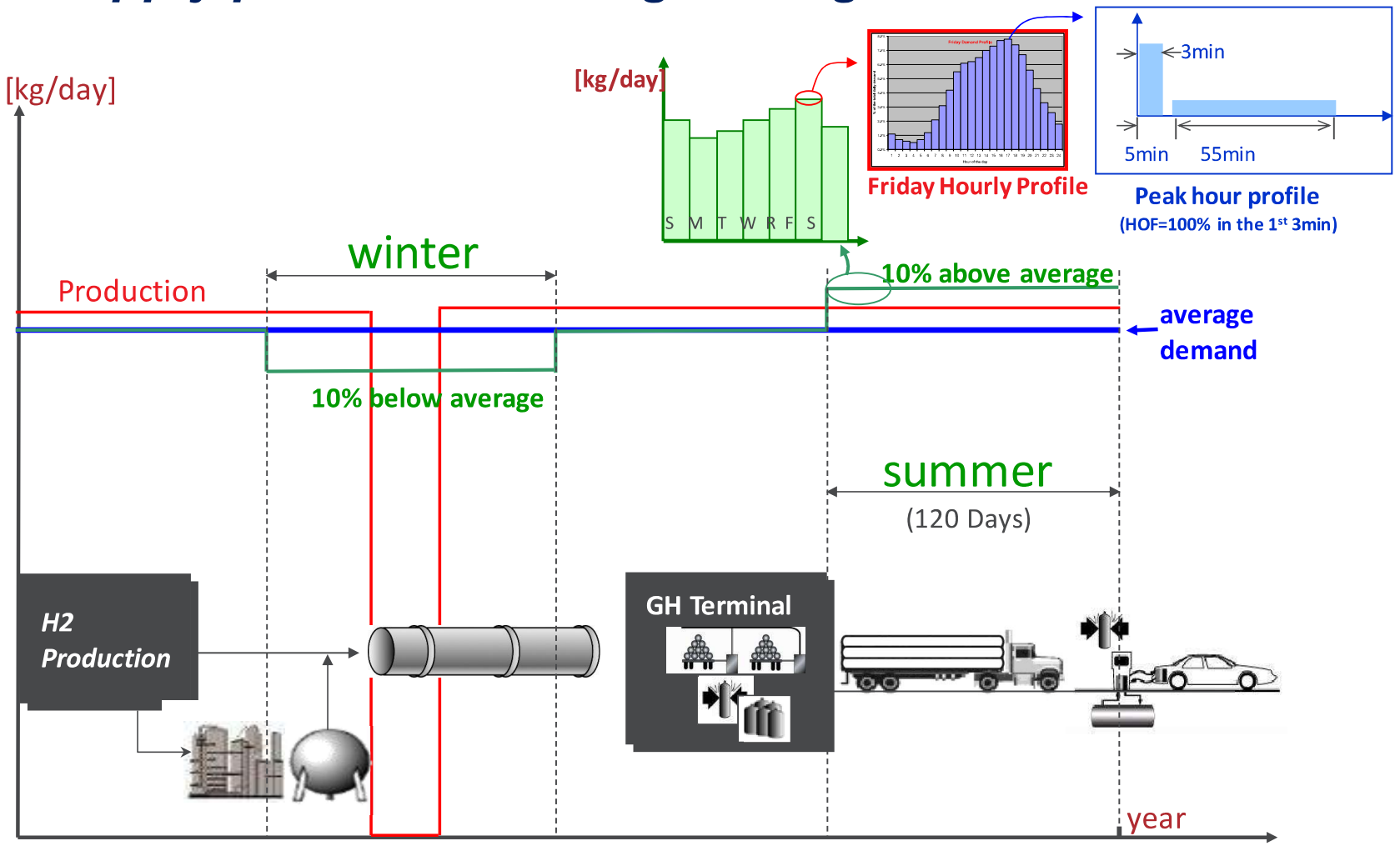
HDSAM infrastructure modeling approach

- Suite of tools complete bottom-up engineering designs and cost analyses of hydrogen infrastructure (pipelines, liquefiers, liquid tankers, tube trailers, geologic storage, gaseous fueling stations, and liquid fueling stations) based on user-defined scenarios.
- Models have been informed and extensively vetted by industry.
- Models are used by government agencies, academia, and industry to estimate investments necessary for growth of hydrogen infrastructure, and to inform technology-specific targets that guide R&D.
- All models are publicly available at: https://hdsam.es.anl.gov/

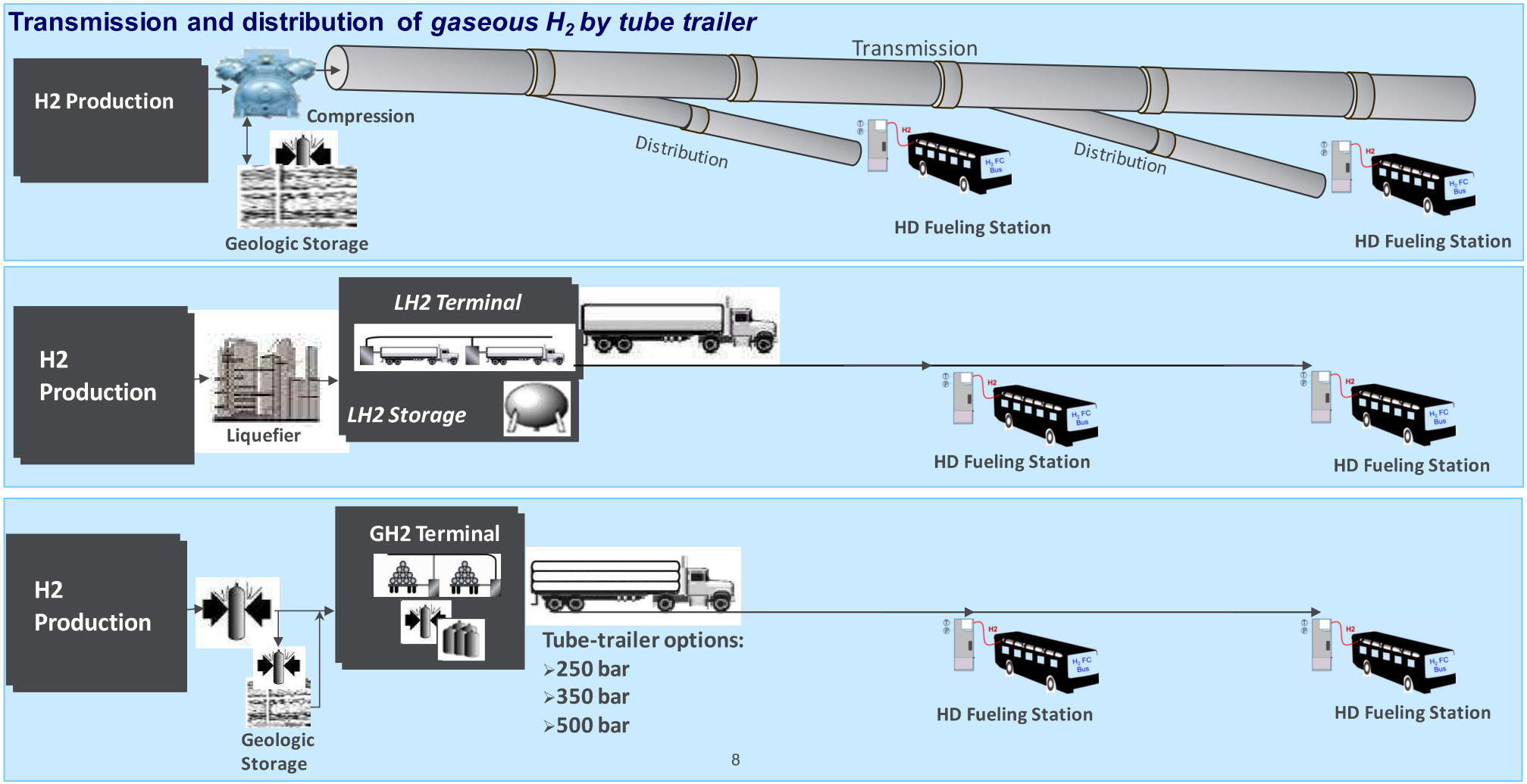
HDSAM simulates transmission, storage and distribution delivery pathways



Demand/supply profiles for storage sizing

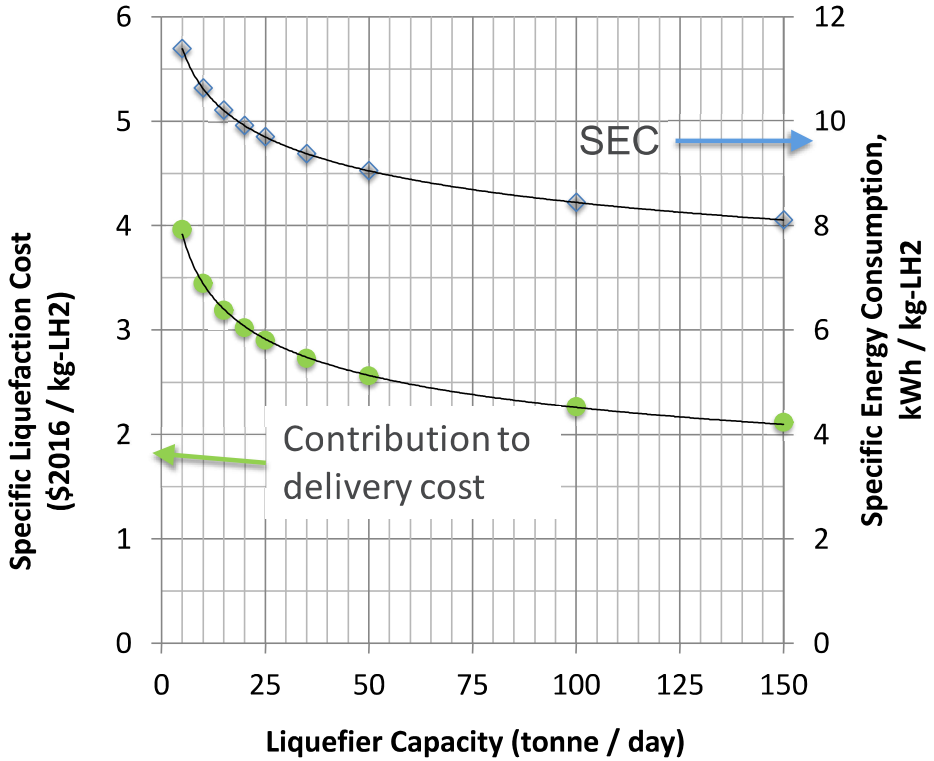


HDSAM HEAVY-DUTY MARKET DELIVERY PATHWAYS - SCHEMATIC



HDSAM liquefaction model

- Scaling laws based on aggregation of industry input
  - Liquefier CAPEX
  - Specific energy consumption (*SEC*)
- Modeling and analysis in the literature suggest SEC can potentially be as low as 6 kWh/kg
- *SLC* – Specific liquefaction cost



Delivered	Liquefier	SLC	SEC	GHG Emissions 2021 (US mix)
	5 tpd	$4.0 / kg-LH2	11 kWh / kg	4.8 $kgCO_{2e}$ / kgH_2
30 tpd	33 tpd	**$2.8 / kg-LH2**	**9.4 kWh / kg**	**4.1 $kgCO_{2e}$ / kgH_2**
120 tpd	130 tpd	**$2.1 / kg-LH2**	**8.2 kWh / kg**	**3.6 $kgCO_{2e}$ / kgH_2**

https://doi.org/10.1016/j.ijhydene.2021.04.078.

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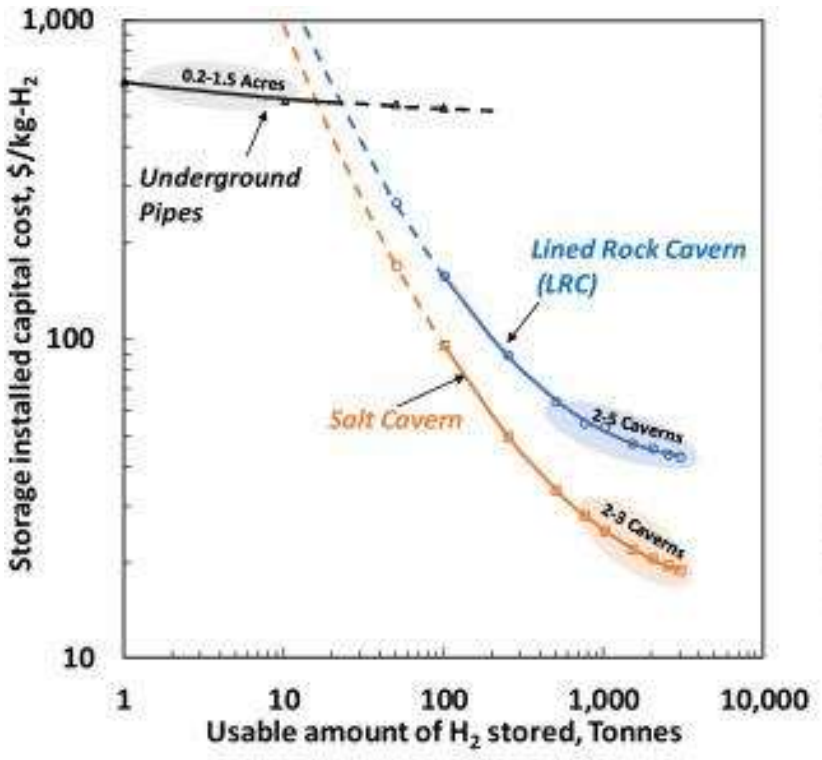
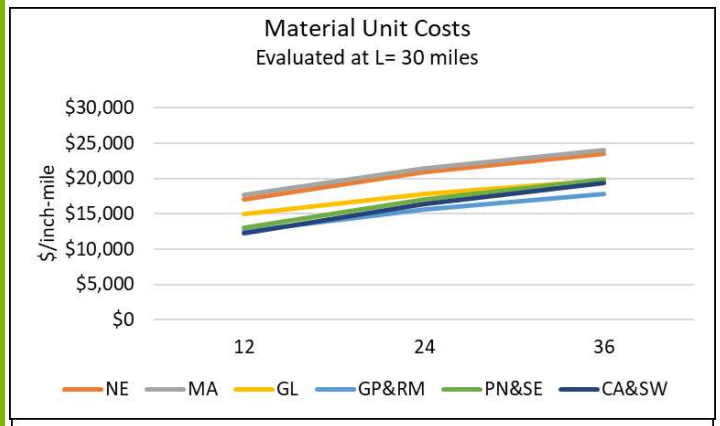
Cavern storage cost

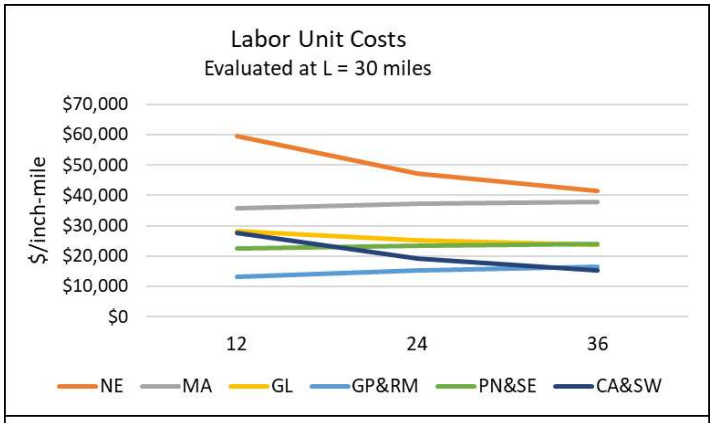


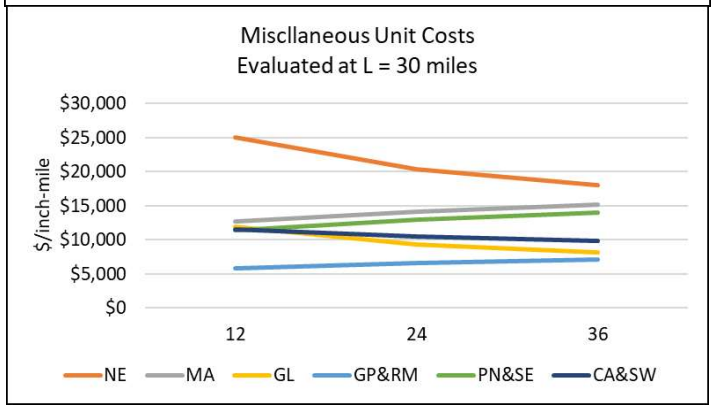
https://doi.org/10.1016/j.ijhydene.2021.08.028

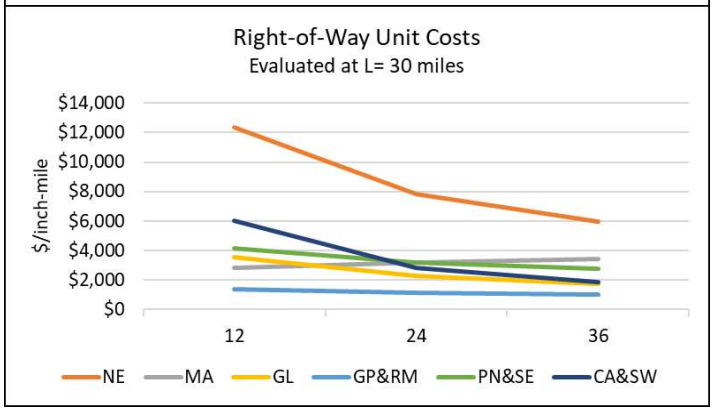
https://www.osti.gov/servlets/purl/1029761

HDSAM incorporates pipeline cost by region, by class location, and by material, labor, misc. and ROW

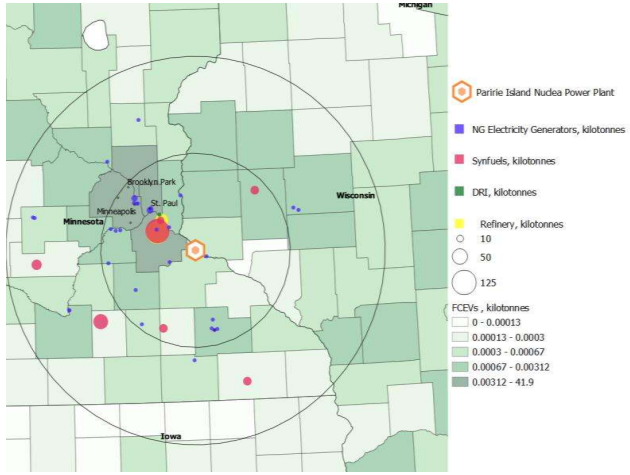








Regions	States Included
New England	ME, NH, VT, MA, CT, RI
Mid-Atlantic	PA, NY, NJ, WV, MD, DE, VA
Southeast	KY, TN, NC, SC, GA, FL, AL, MS, LA, AS
Great Lakes	MI, OH, IN, IL, WI
Great Plains	ND, SD, NE, KS, OK, MN, IA, MO
Rocky Mountain	ID, MT, WY, UT, CO, NM, NV
Pacific Northwest	OR, WA
Southwest	AZ, TX
California	CA



Hydrogen Delivery Pipeline Network Model

- Python-based technoeconomic analysis (TEA) tool that provides minimum cost of hydrogen delivery pipeline network ($/kg H_2). The model optimizes pipeline route and pipe size and compressor size for minimal total project cost.

Key Inputs to Model:

- H_2 demand and supply with locations and required pressures
- Economic & financial assumptions

Key Outputs:

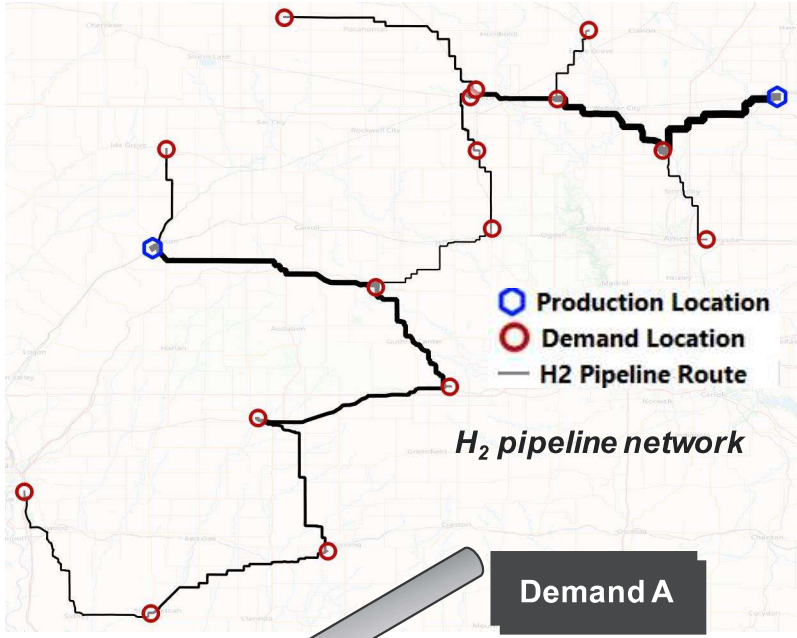
Optimized H_2 pipeline network route

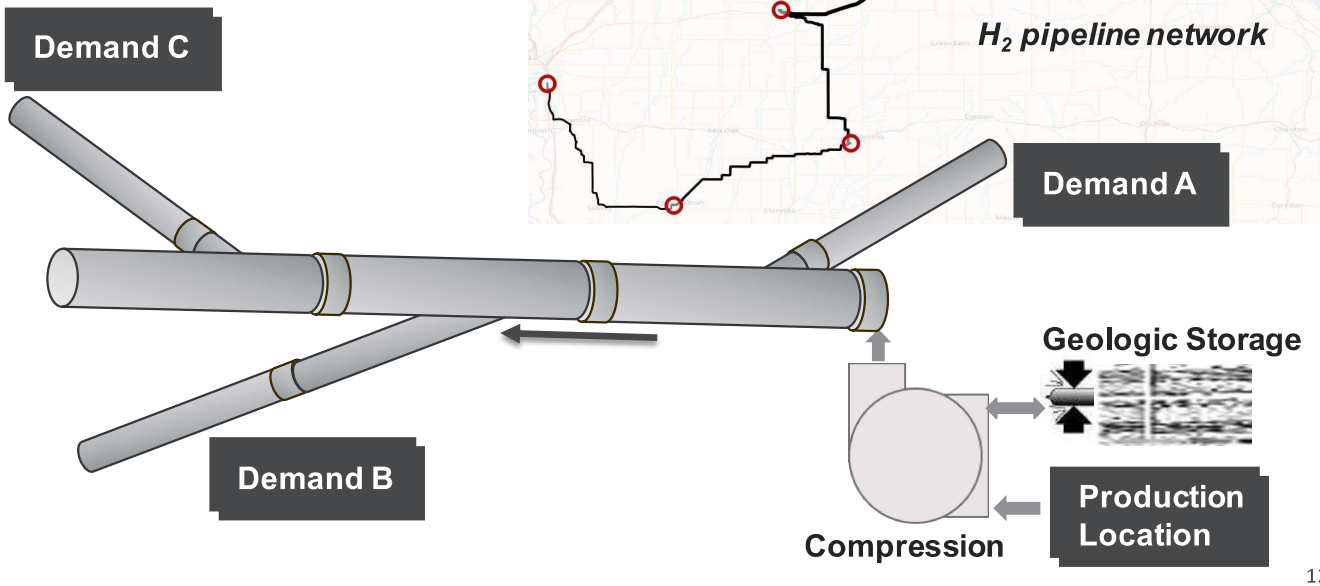
H_2 levelized price (pipe): [$/kg H_2]

- Total installed capital investment: [$]
- Right-of-way cost: [$]
- Operation and maintenance cost: [$]

H_2 levelized price (compressor): [$/kg H_2]

- Total capital investment: [$]
- Operation and maintenance cost: [$]
- Yearly electricity consumption: [MW]





Hydrogen Carrier Scenario Analysis Model (HCSAM)

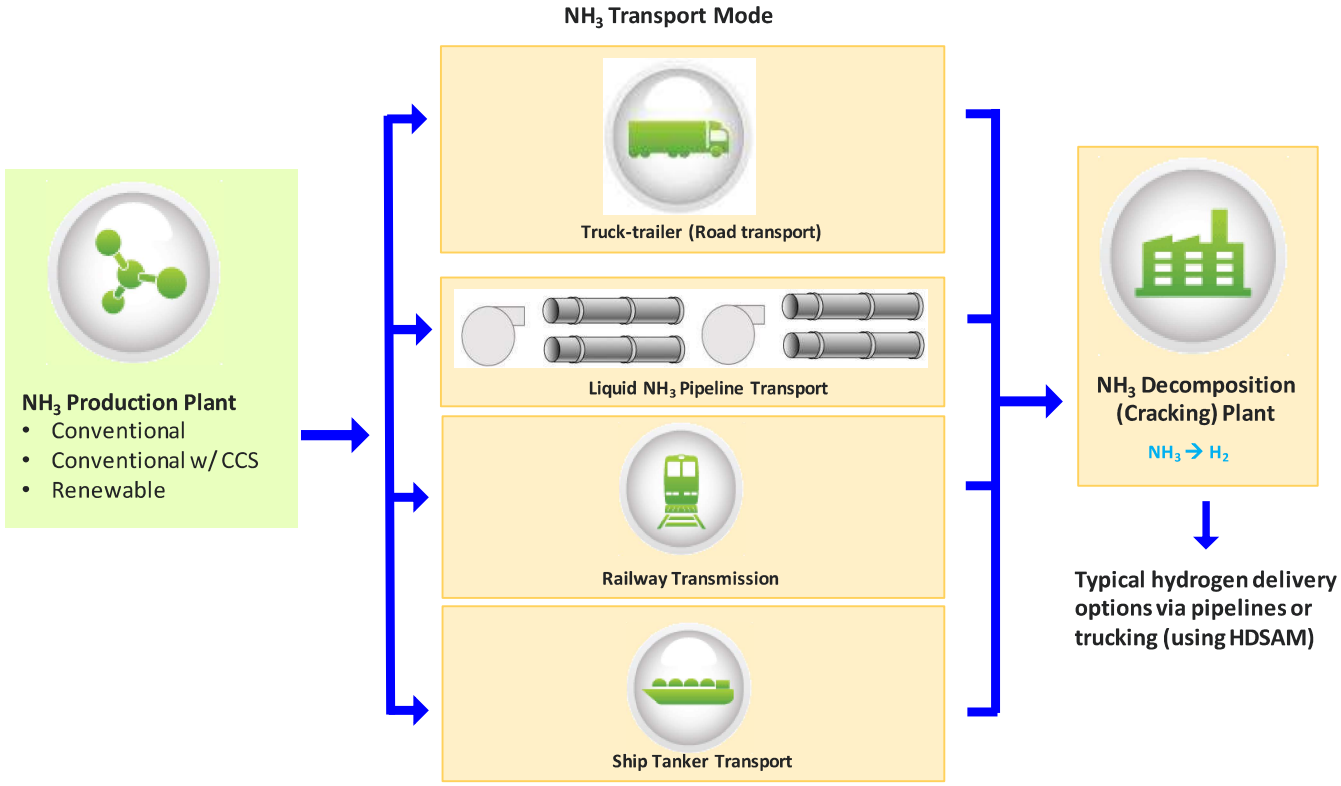
- Excel-based technoeconomic analysis (TEA) tool that covers entire supply chain pathways of hydrogen carrier (NH_3) starting with NH_3 production and ending with NH_3 cracking

Key Inputs to Model:

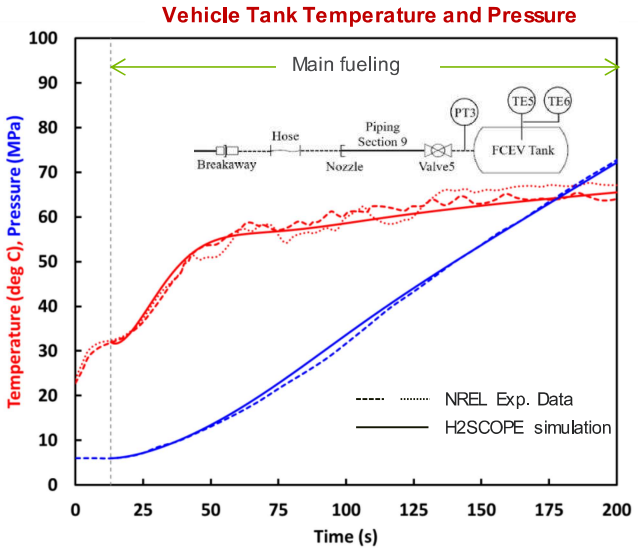
- NH_3 or equivalent H_2 demand
- NH_3 production, transport & cracking pathways definitions.
- Economic & financial assumptions

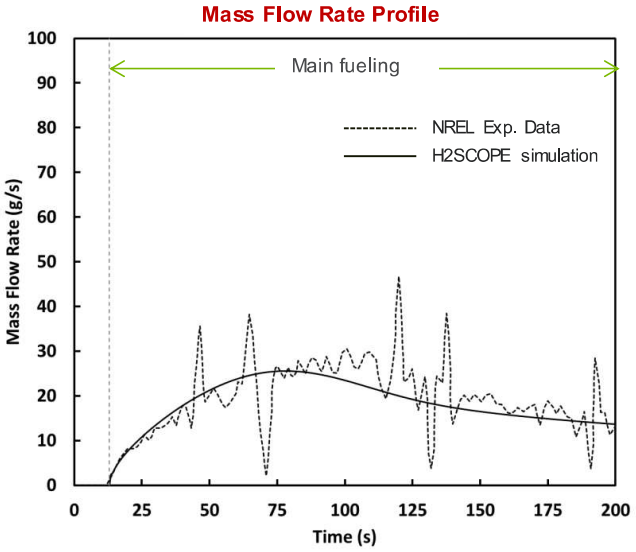
Key Outputs:

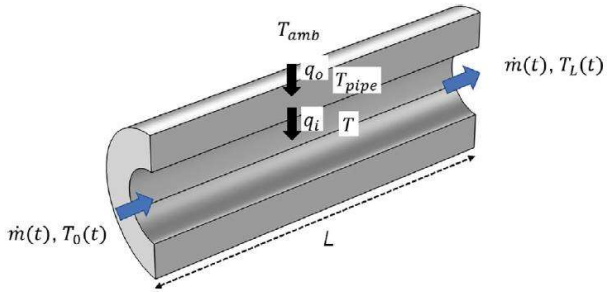
- Levelized cost ($/kg) NH_3 or equivalent H_2 at destination
- Cost contribution of production, transmission, cracking, storage components
- Total capital cost of investment and operating & maintenance cost
- Annual cash flows



Argonne H2SCOPE CFD model informs FCEV fueling protocol and station design



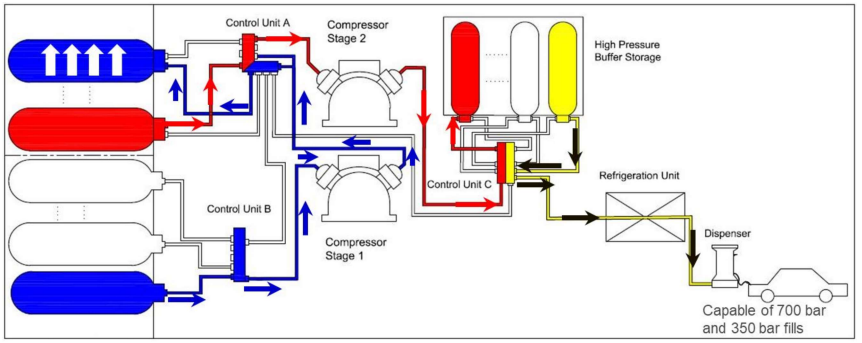




- ❑ Continuity equations
- ❑ Energy balance equations
- ❑ Heat transfer equations
- ❑ Equation of state
- ❑ Flow equations
- ❑ Finite volume method

Argonne developed several H_2 fueling technologies

U.S. Patent No. 9,739,418
U.S. Patent No. 10,267,45
U.S. Patent No. 11,105,469
U.S. Patent No. 11,506,342



Acknowledgment

HDSAM suite of models for techno-economic analysis has been supported by DOE's Office of Energy Efficiency and Renewable Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) since 2004

Thank You!

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Our models and publications are available at:

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