ARGONNE NATIONAL LABORATORY
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Benefits and Costs of Hydrogen Fuels

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Overview of the Presentation

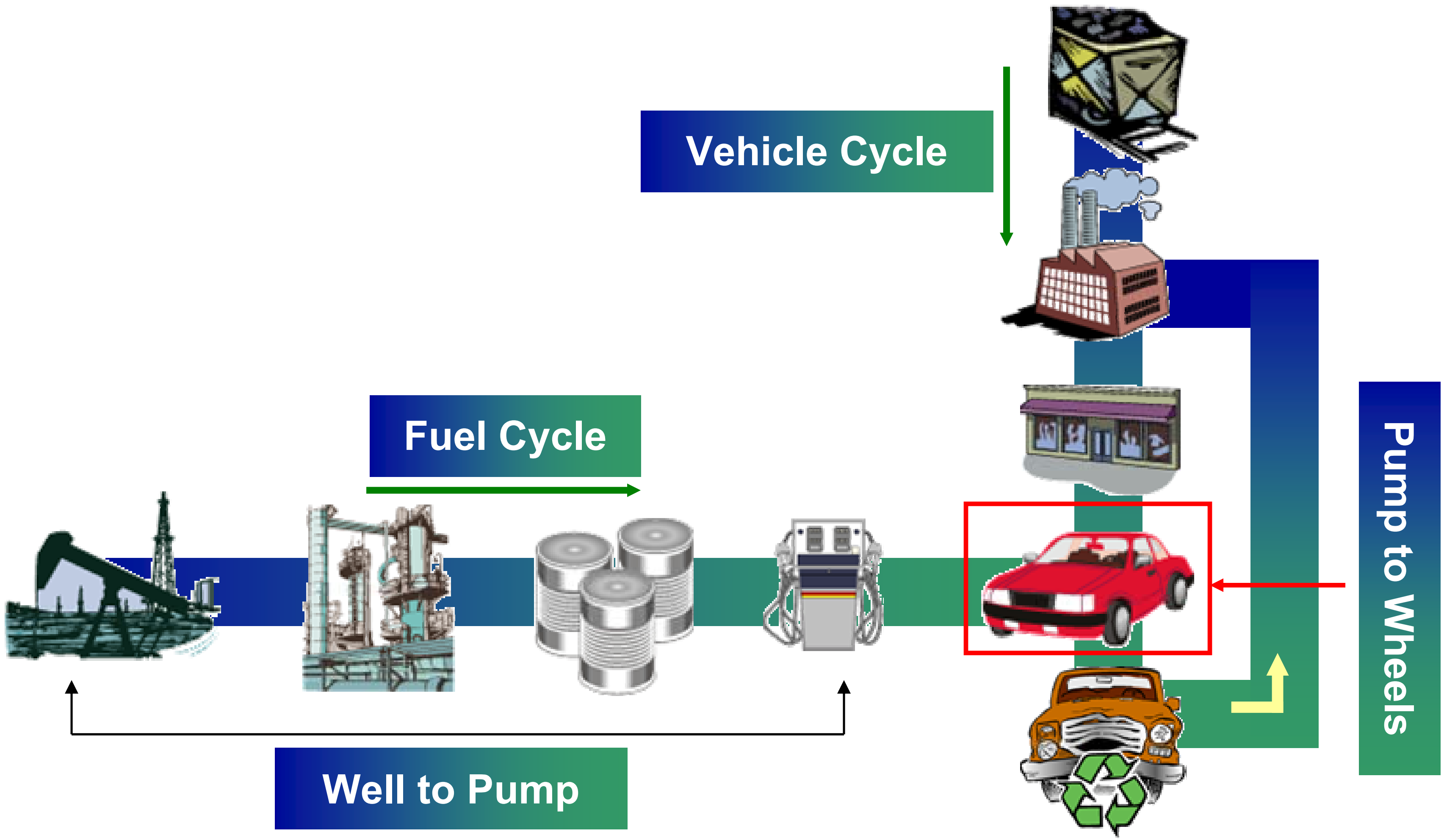
❑ Lifecycle Energy and Emission Benefits

- Full fuel cycle analysis needed to give an accurate picture of:
  - Energy benefits
  - Emissions benefits
- GREET model used for the analysis

❑ Fuel Infrastructure Costs

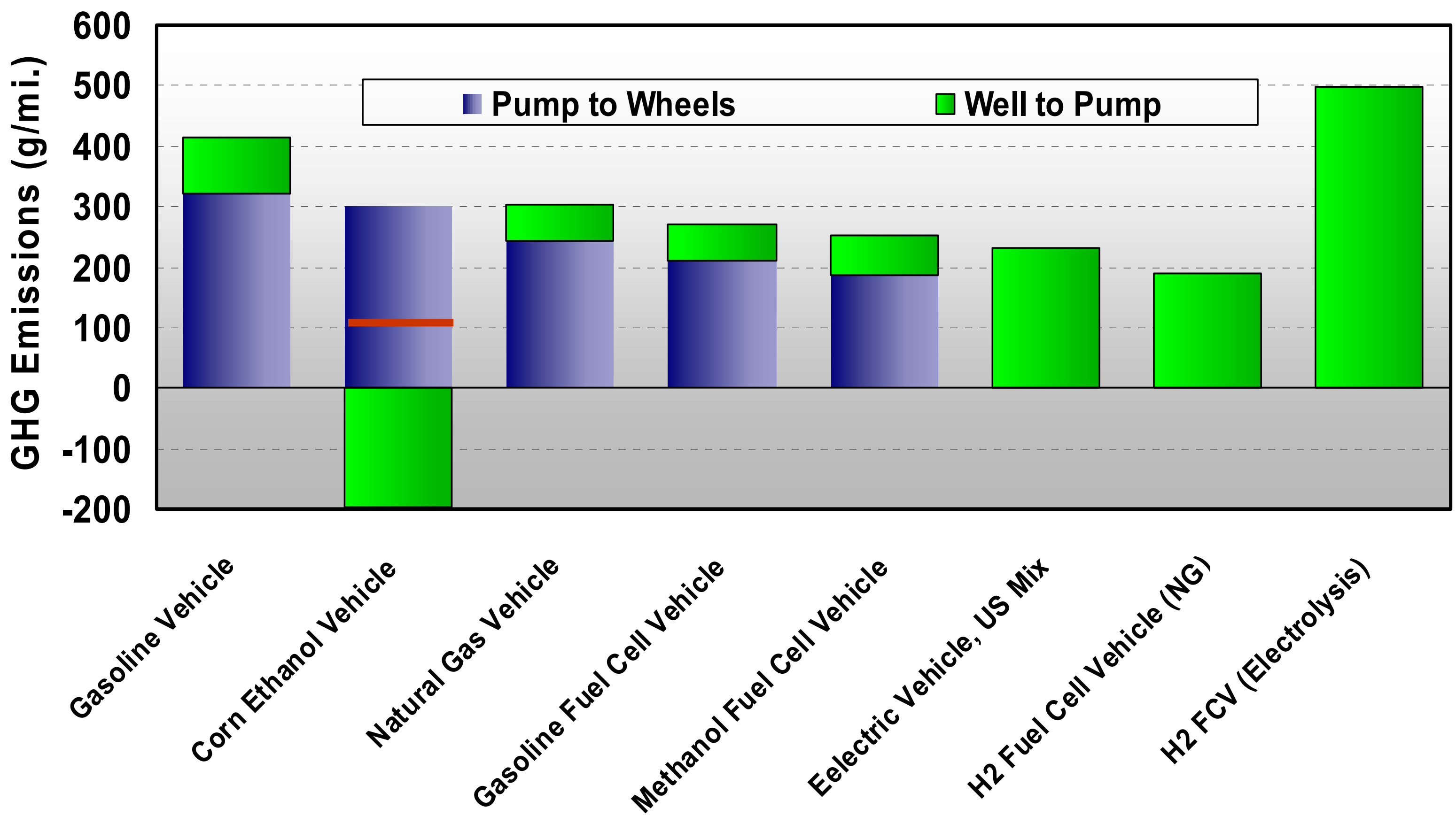
- Many hydrogen pathways; which is the the most cost effective?
  - Feedstocks: natural gas, coal, water (+energy)
  - Distribution: centralized or decentralized
- CHAIN model used for the analysis
- Transition issues are extremely important

Well to Wheels (WTW) Analysis Examines Fuels and Vehicles Together

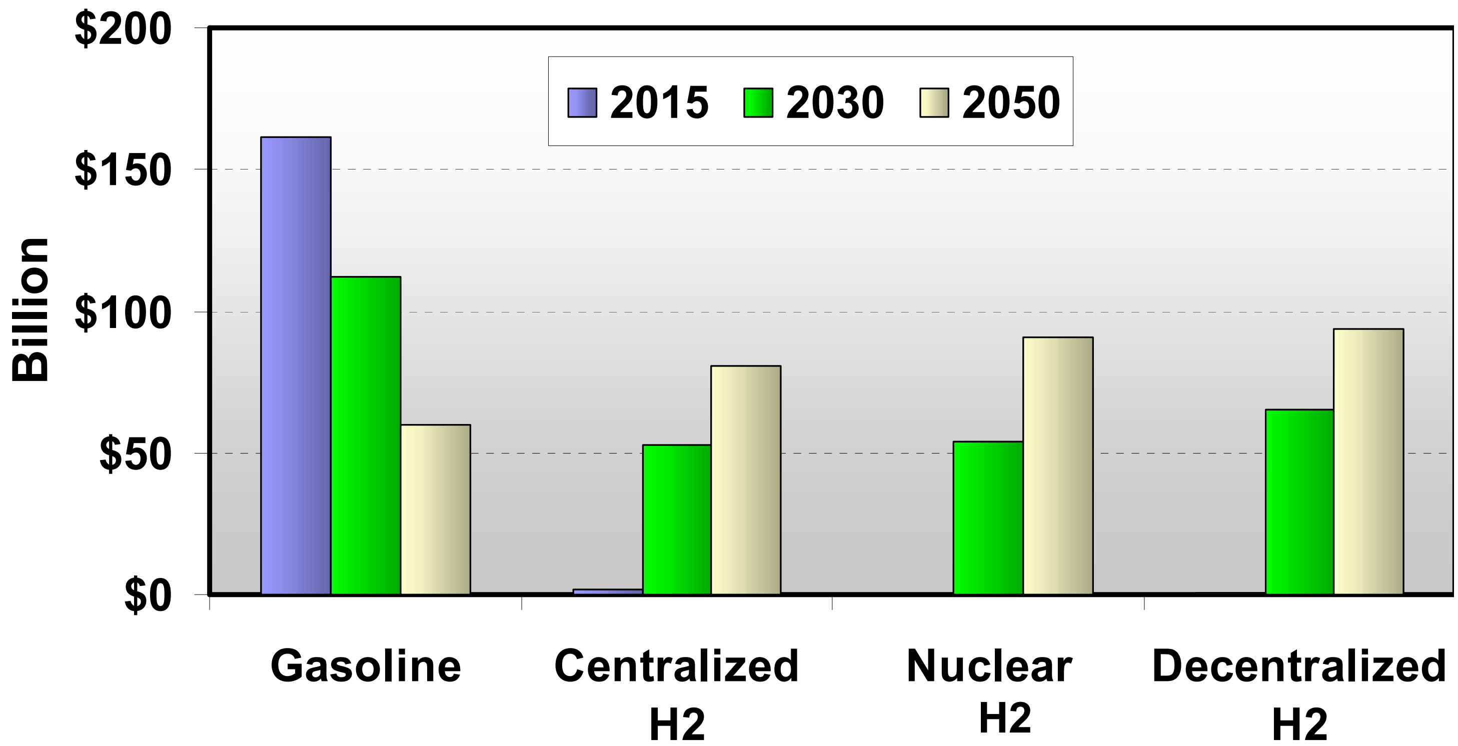


WTW Analysis Is a Complete Energy/Emissions Comparison

As an example, greenhouse gases are illustrated here



Annualized Fuel Costs (WTP) Are a Major Issue for a Hydrogen Vehicle Economy



In 2050 hydrogen costs could surpass gasoline cost, although accounting for only 30% of highway fuel use.

The GREET (*G*reenhouse gases, *R*egulated *E*missions, and *E*nergy use in *T*ransportation) Model

- **GREET includes emissions of greenhouse gases**
  - CO_2, CH_4, and N_2O
  - VOC, CO, and NOx as optional GHGs
- **GREET estimates emissions of five criteria pollutants**
  - Total and urban separately
  - VOC, CO, NO_x, PM_{10}, and SO_x
- **GREET separates energy use into**
  - All energy sources
  - Fossil fuels
  - Petroleum
- **Argonne's GREET model and Its documents are available at http://greet.anl.gov; there are 640 registered GREET users**

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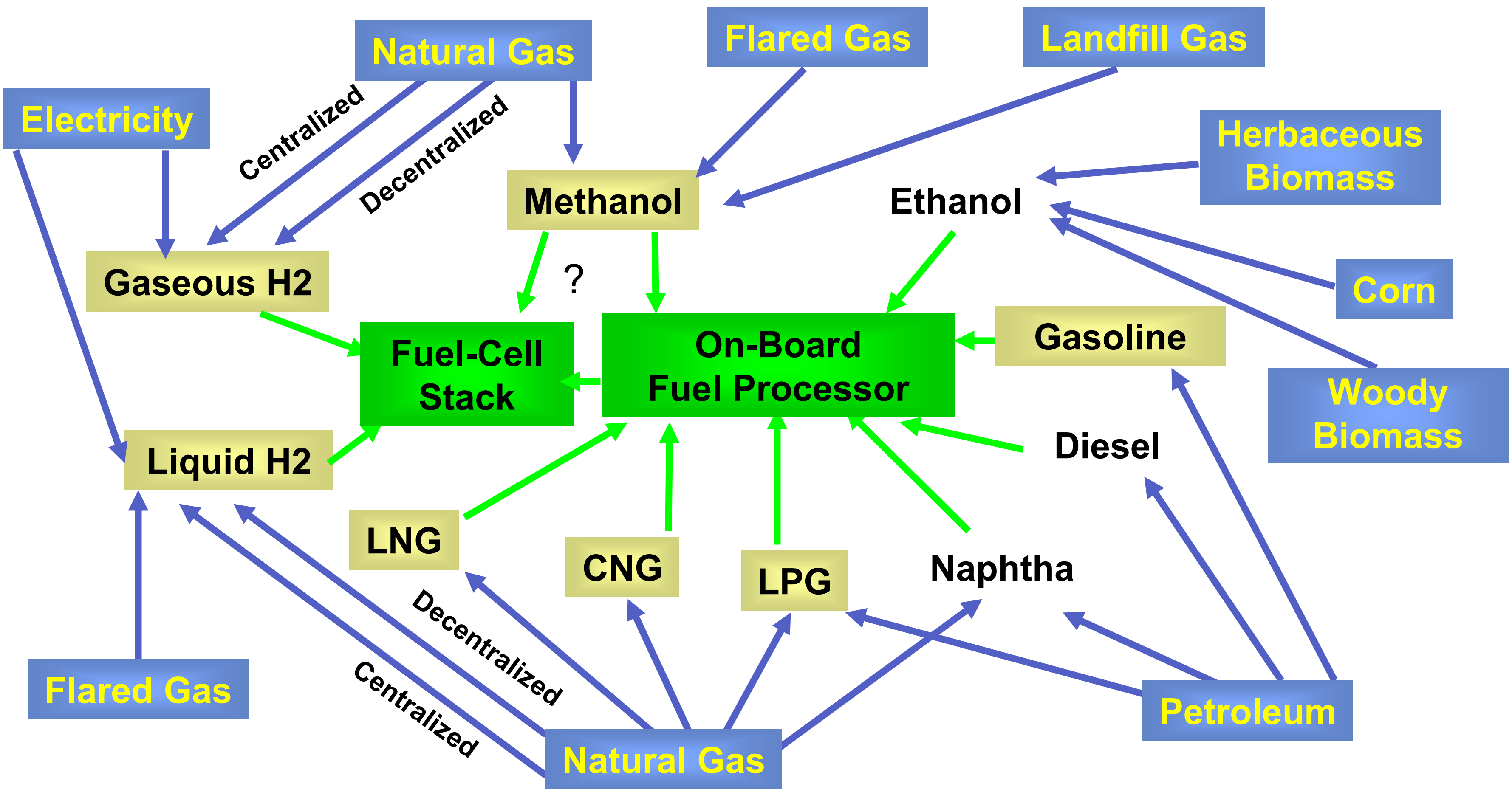
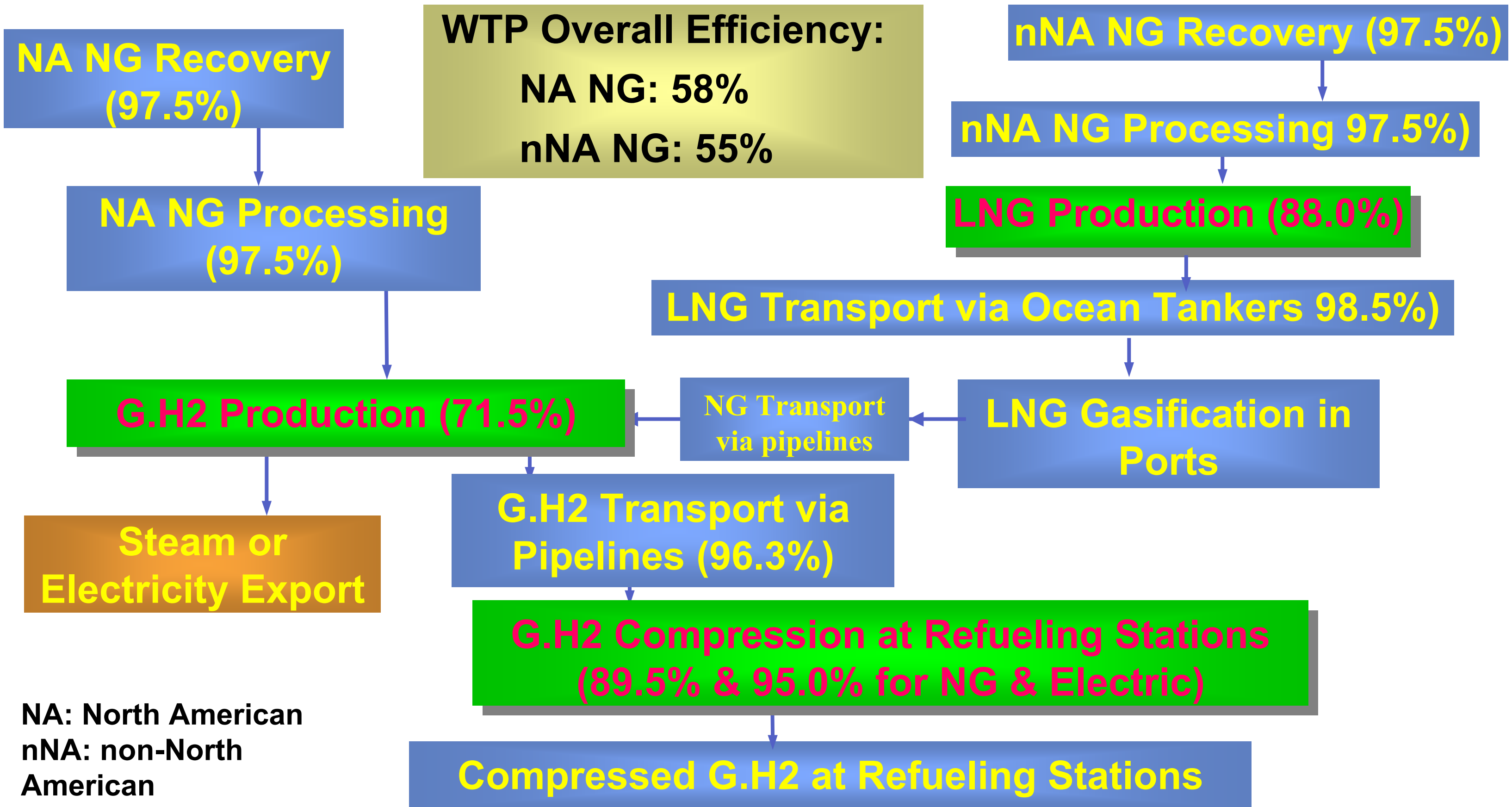
GREET Examines Many Fuels and Fuel Pathways

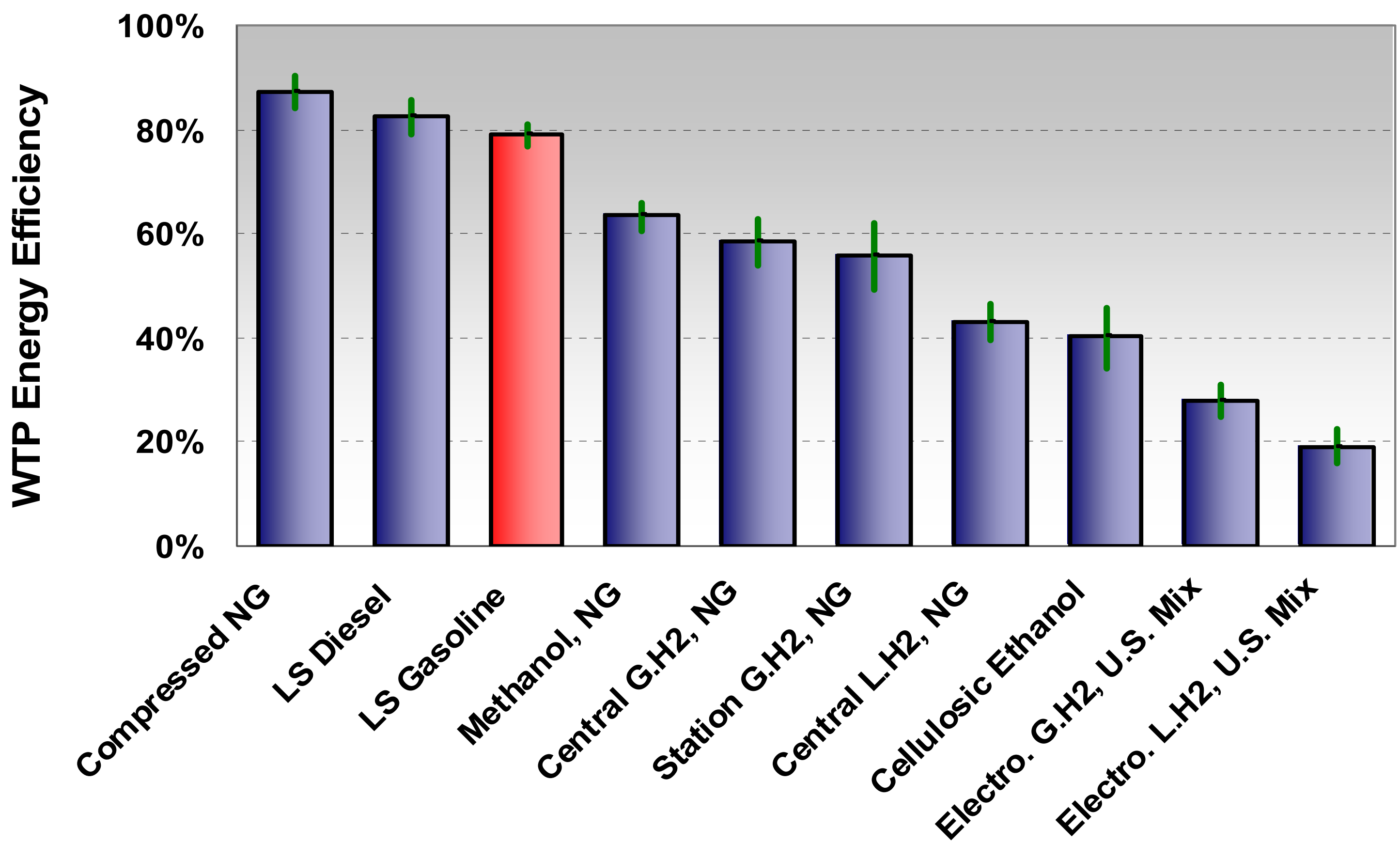


Production/Compression Are Key Steps for Gaseous H_2

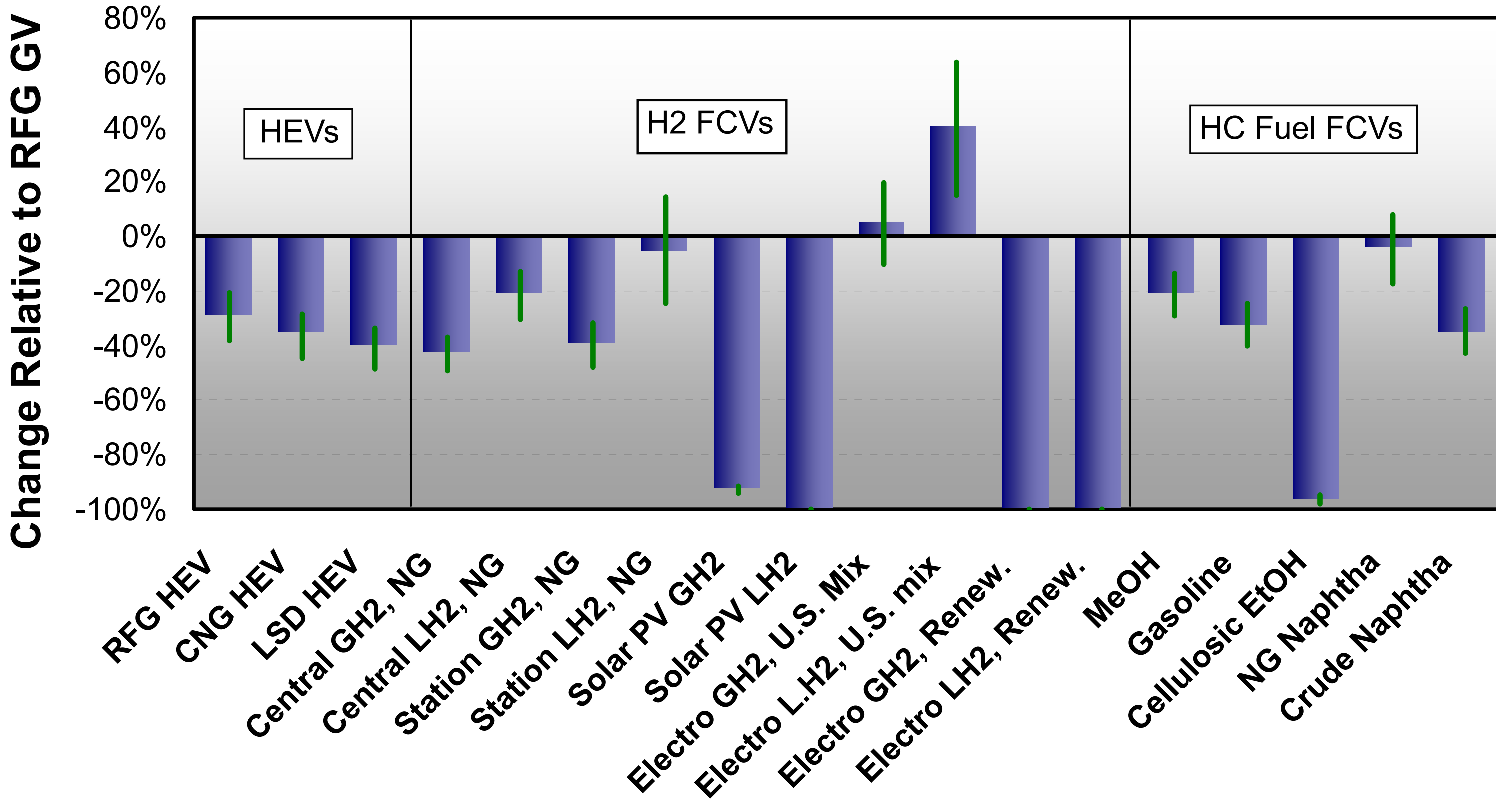


NA: North American
nNA: non-North American
NG: natural gas

WTP Energy Losses Can Penalize Overall FCV Efficiency

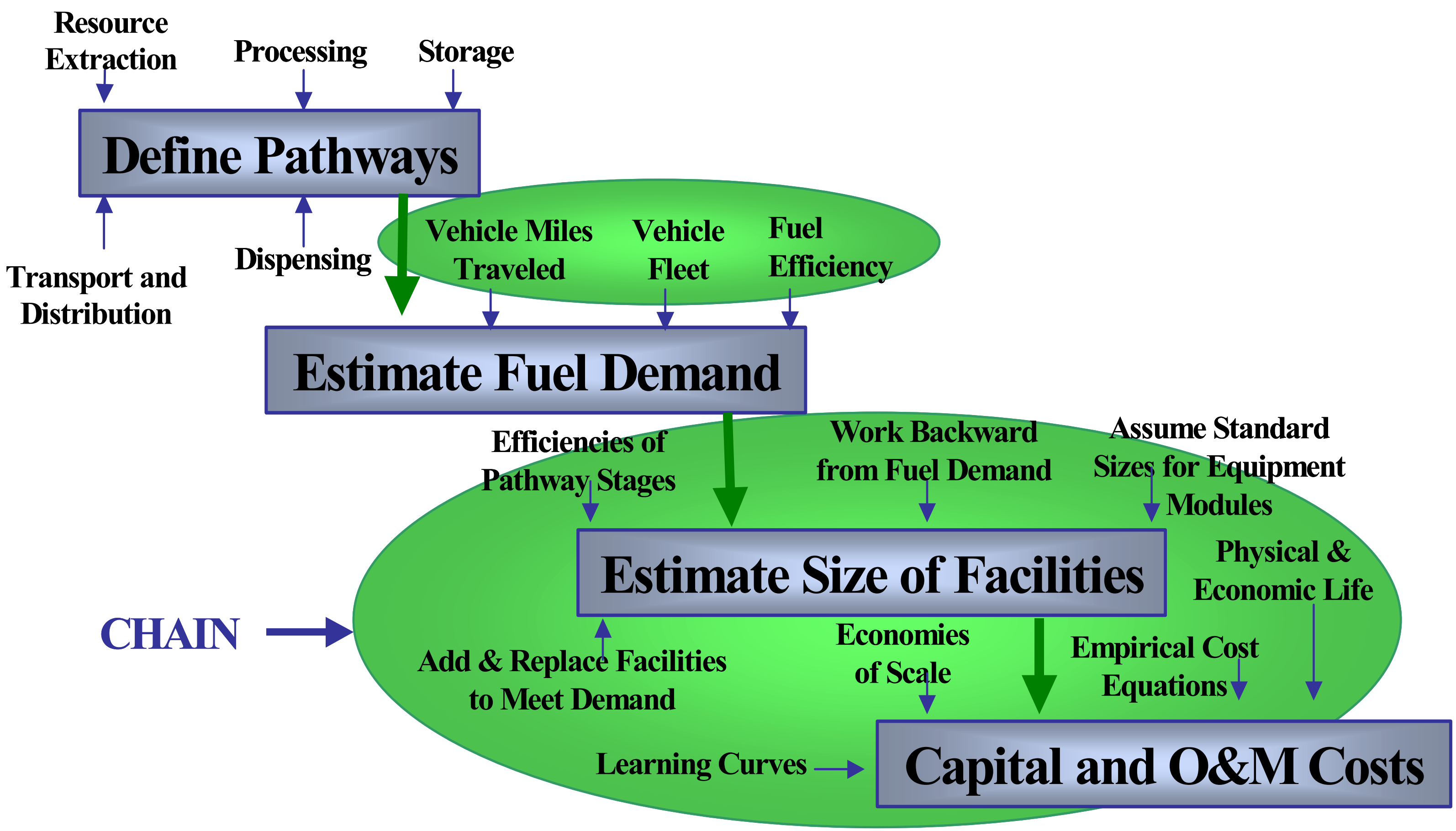


WTW H2 Pathways Are Critical for FCV Fossil Fuel Use

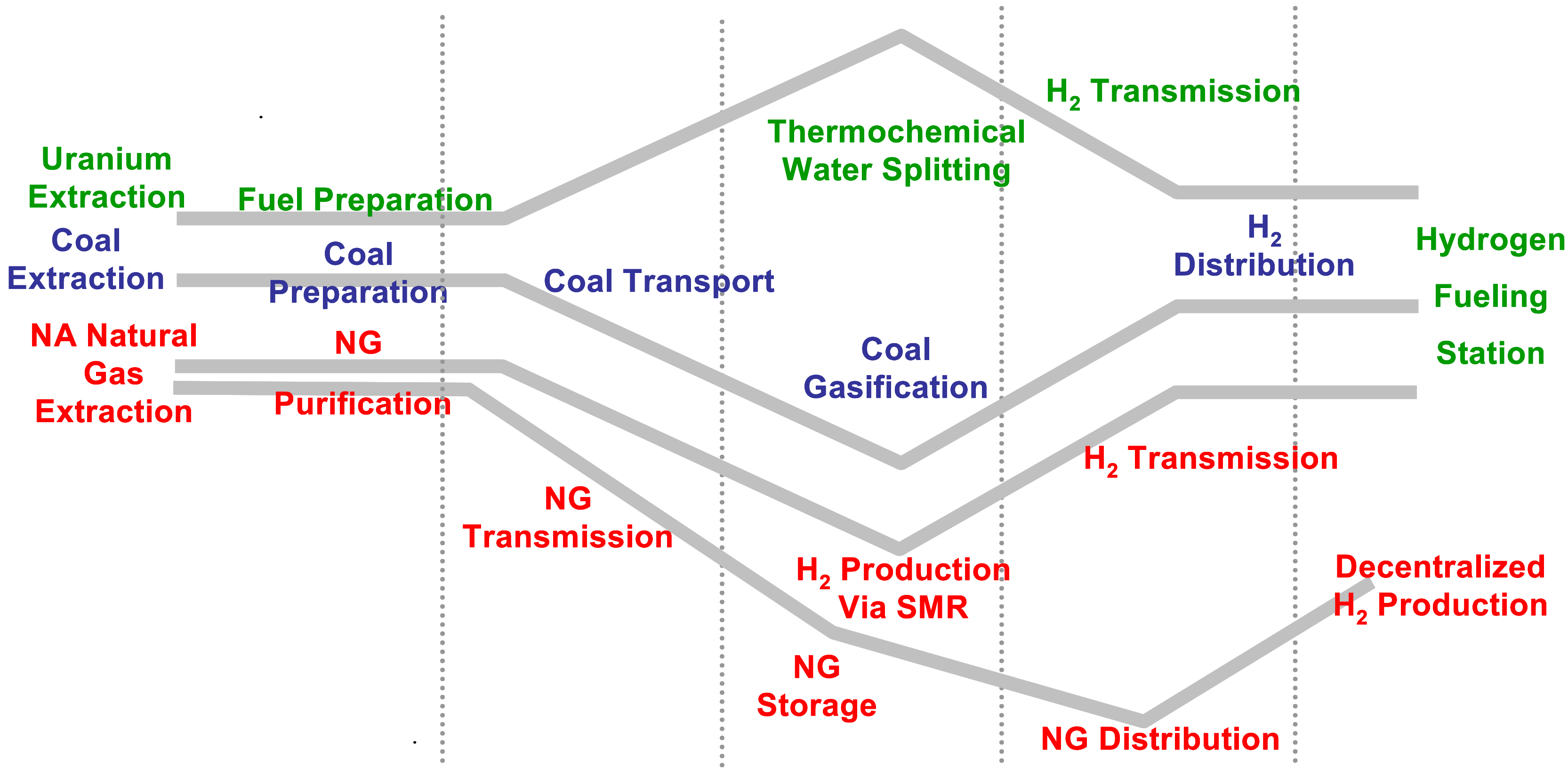


GHG results are similar to the fossil energy results

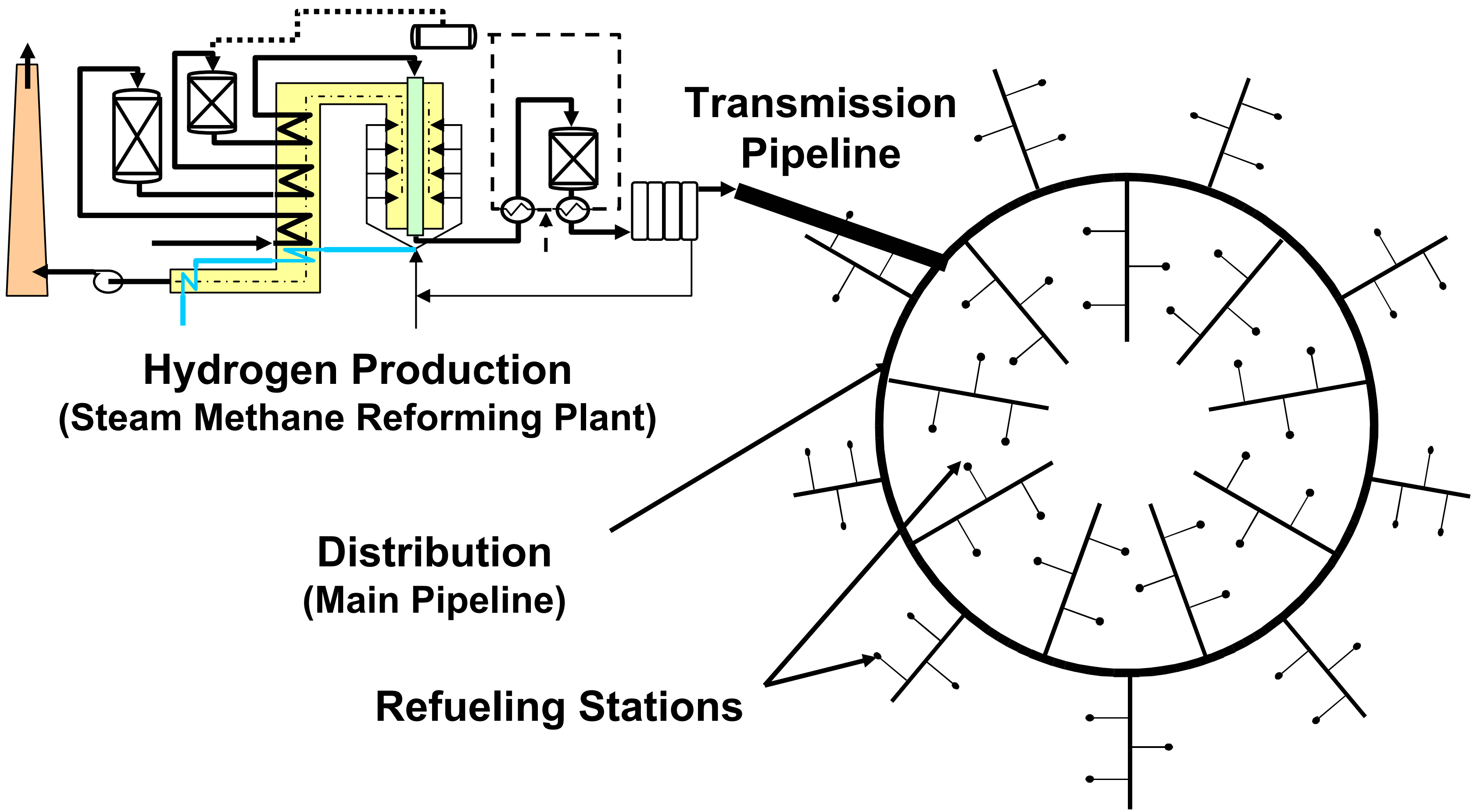
H2 Pathway Analysis Is Also Critical for Evaluating Costs



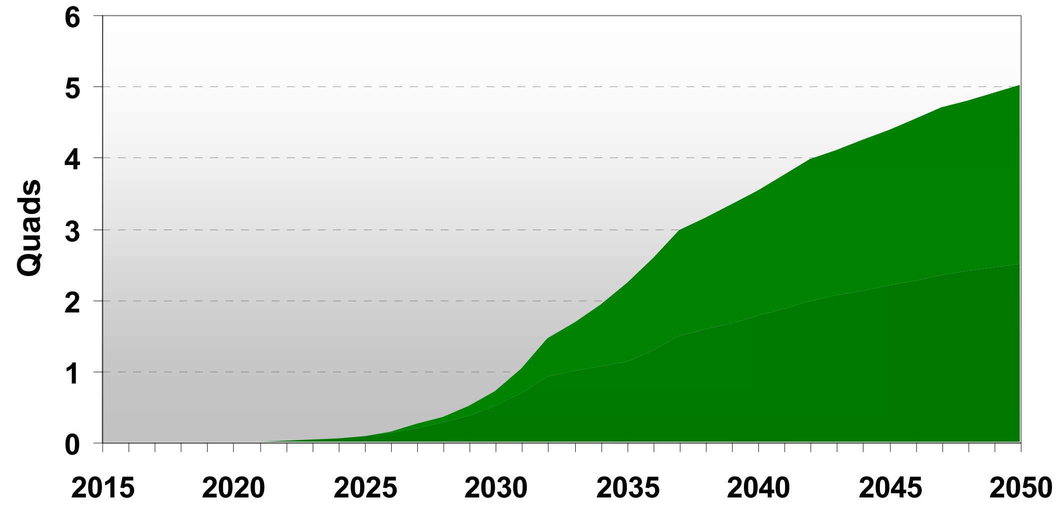
Four Hydrogen Pathways Were Defined and Modeled

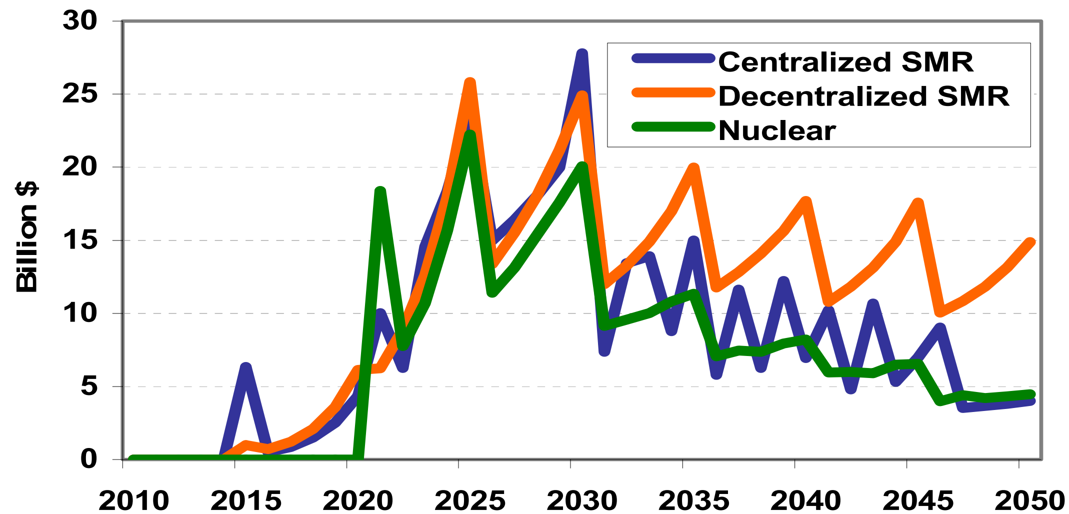


Gaseous H2 Production and Distribution System Is Modeled



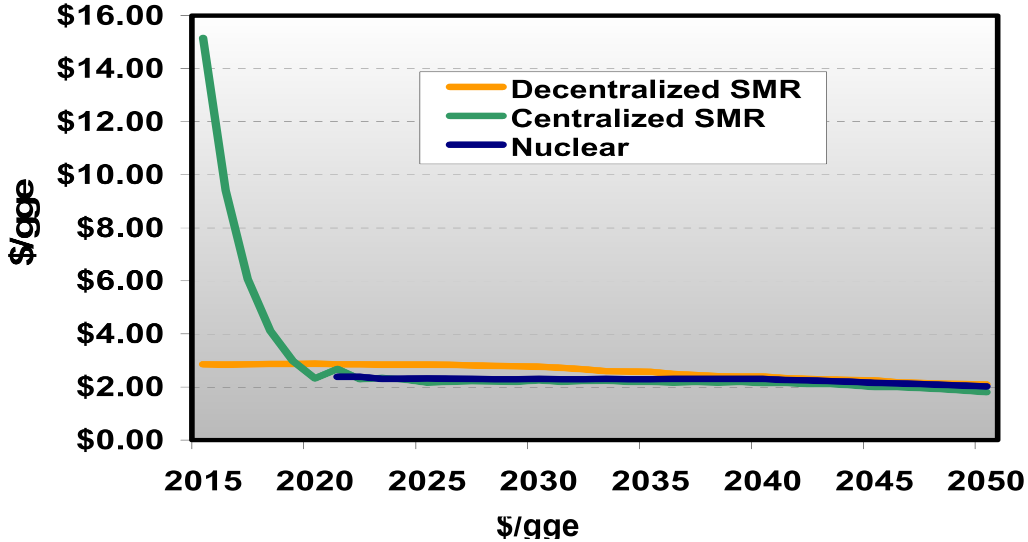
Annual Expenditures for H_2 Infrastructure Peak in First 15 Years and Then Decline

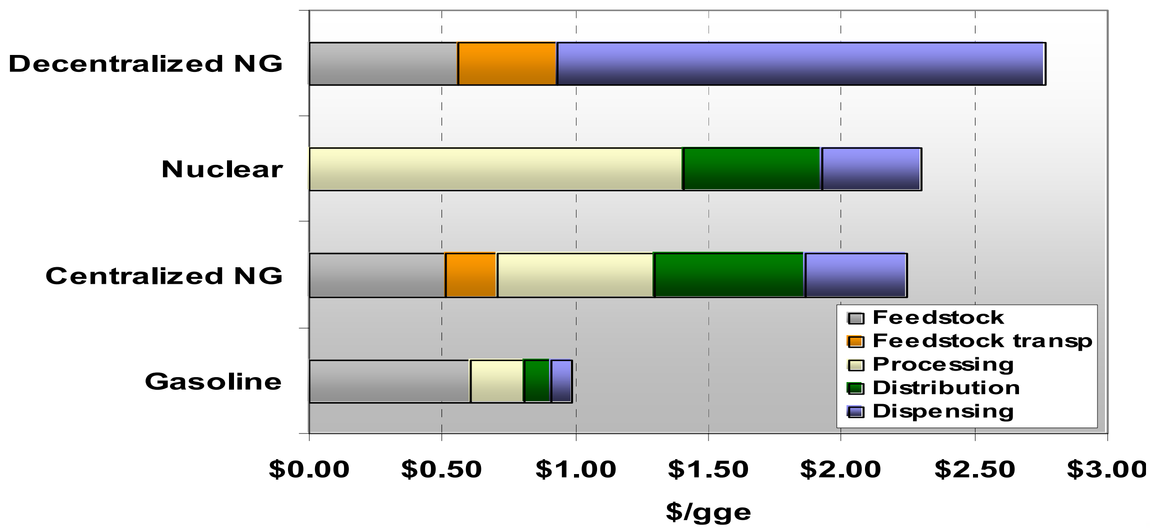




- With rapid demand growth, output quickly reaches capacity
- Capacity increases “in chunks”; annual expenditures fluctuate
- For first 15-20 years, annual expenditures (all paths) approximately 5 times historical rate for NG transmission
- Expenditures trend downward after 20 years especially for centralized paths

H_2 "WTP" Cost Declines with Volume; Production and Distribution Are Largest Components





- Unit costs drop over time as H_2 infrastructure is "built out" and amortized
- Production = 21% of gasoline cost ($28/bbl crude) vs. 25-75% for H_2 (2030)
- Distribution = 10% of gasoline cost vs. 25% for centrally produced H_2
- Crude oil = 61% of gasoline cost; NG = 25% of H_2 cost

Note: Cost distribution by stage is for 2030

Some Conclusions

Well-to-Wheels Fuel Analysis

- Direct hydrogen pathways have the lowest energy use and greenhouse emissions
- Fuel cell vehicles operating on hydrocarbon fuels have comparable benefits to hybrid vehicles – can help transition to hydrogen FCVs
- Some hydrogen pathways could be worse than conventional vehicles

Infrastructure Costs

- With current technologies, on a well-to-pump basis, unit cost of hydrogen is likely to be 2-3 times that of gasoline in 2030
- Hydrogen transport and production are the largest components of all paths examined, hence appropriate focus for cost reduction
- Bi-fuel engines and distribution networks offer potential cost reductions, especially in the transition