GCAM Hydrogen Modeling Challenges

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Page Kyle
Pacific Northwest National Laboratory

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Topics to cover

- Brief overview of hydrogen in GCAM
- Question of a “unified” hydrogen market
- Scale-dependent distribution costs
- T&D energy requirements
- Estimating hydrogen leakage
- Estimating water demands
- Estimating characteristics of non-standard end-use technologies
- Timing of use / electric sector dynamics

Hydrogen in GCAM

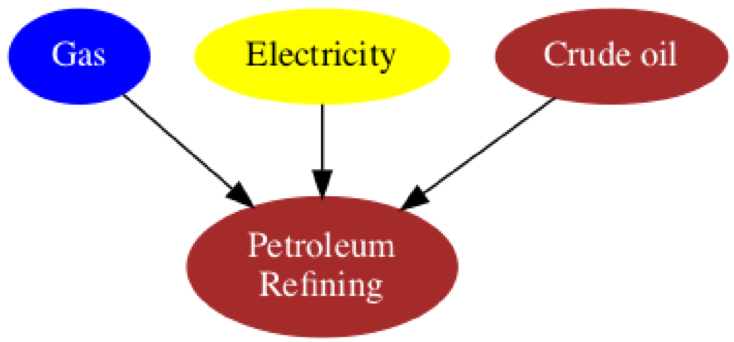
- Added to the model in about 2007
- End-use applications include light duty vehicle transport, and generic industrial energy use

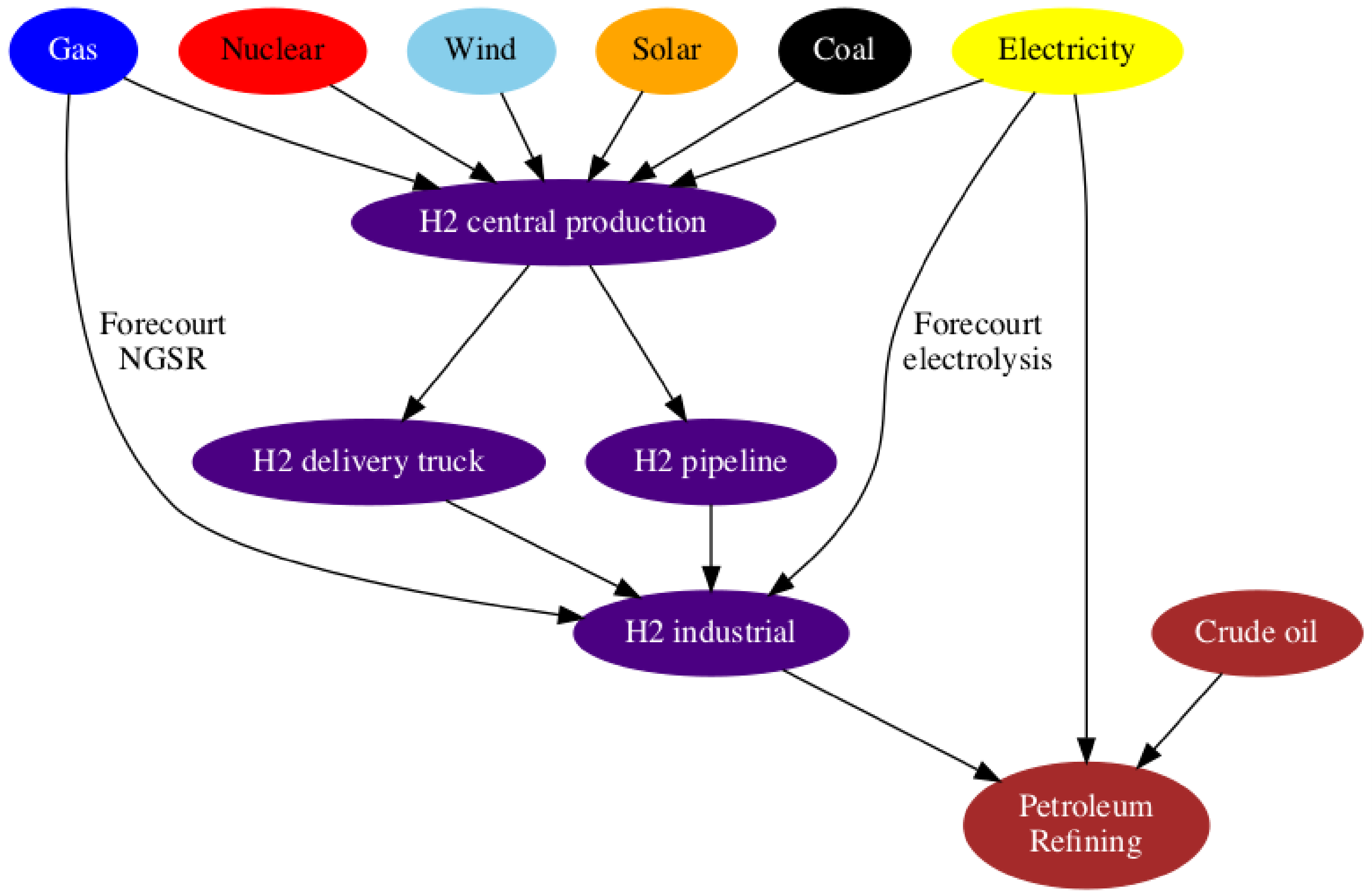
- Since June of 2021 we have been conducting a comprehensive update
  - Adding end-use technologies in a variety of sectors
  - Updating costs and performance levels of production technologies
  - Updating representation of T&D

Question of “unified” hydrogen market

- Do we want to be representing on-site production and use of hydrogen in petroleum refineries and ammonia factories as the modeled hydrogen commodity available to a variety of end users?
  - Would allow technology choice where currently there is none
  - Requires calibration
    - ✓ Hydrogen is not an energy commodity in energy statistics
  - Unclear connection between historically calibrated flows and future modeled behavior

Integrating the hydrogen market into oil refining



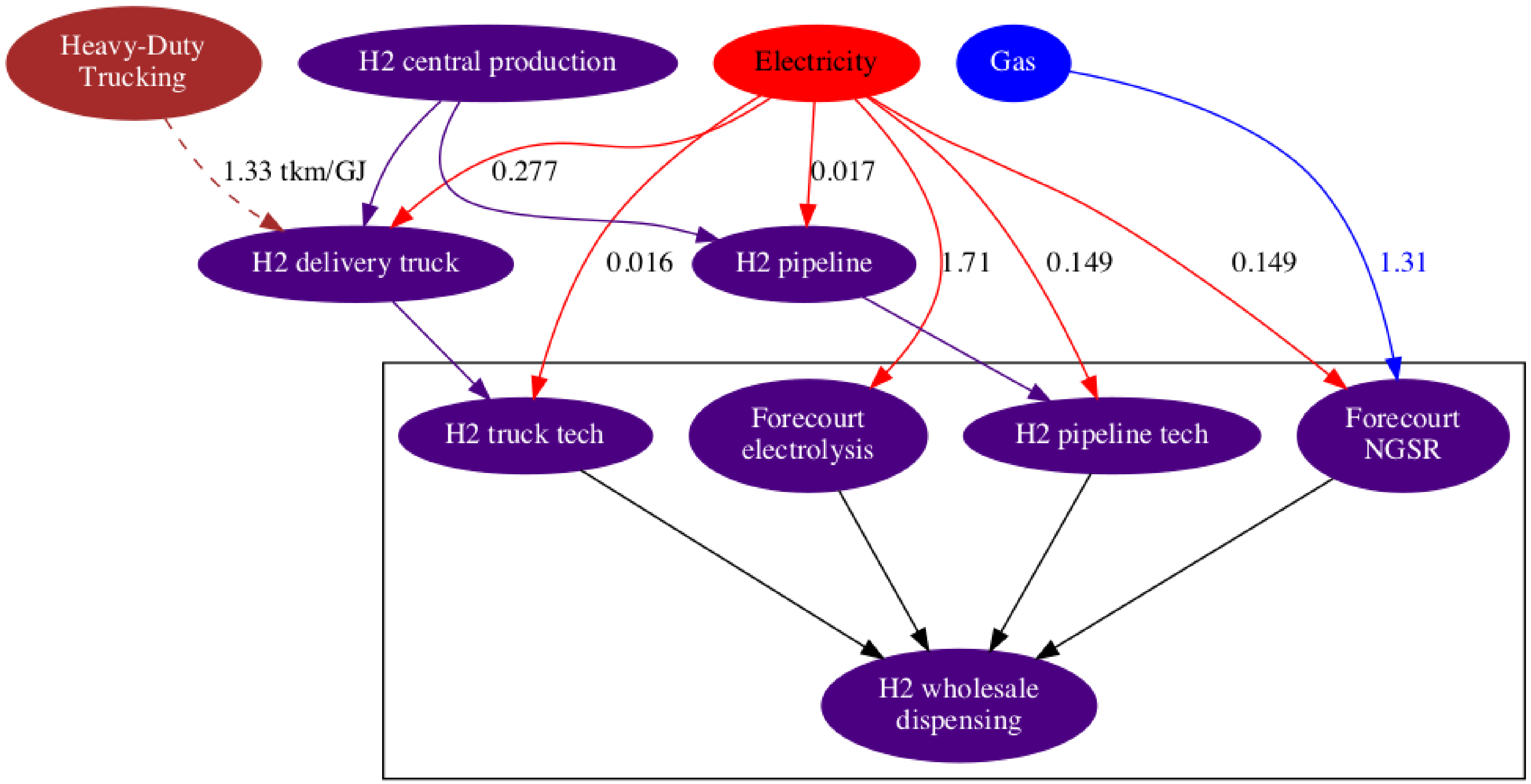


Scale-dependent distribution costs

- “First-of-a-kind” issue; expensive first years
- Scale issue: larger markets should expect to see lower levelized costs of pipeline distribution
  - We are planning to use HDSAM to construct generic pipeline cost curves, describing the average levelized cost of distribution as a function of the volume of hydrogen being delivered
- Implementing “upside down” supply curves may lead to solution instability for GCAM; we’ll see!
  - Normally, supply-price curves are upward sloping, and this is a key feature that market equilibrium models use as they adjust prices to match supply and demand

T&D energy requirements

- Pipeline pathway
  - Pipeline pressurization: 0.017 GJ-elec / GJ-H2
  - Dispensing: 0.149 GJ-elec / GJ-H2
- Truck pathway
  - Liquefaction: 0.277 GJ-elec / GJ-H2
  - Driving: 1.33 tonne-km / GJ-H2
  - On-site storage: 0.016 GJ-elec / GJ-H2



For a system where natural gas with CCS is used for producing both hydrogen and electricity, including these T&D energy demands increases the primary energy footprint of fuel cell vehicles by 20-40%

Estimating hydrogen leakage

- Interest in the climate modeling community on this topic
  - H_2 has a global warming potential of about 5, due to indirect impacts on lifetimes of other climate forcers such as methane
- The emissions factor is equal to the losses, which should be accounted for energy tracking as well
  - Each unit of hydrogen lost to leakage has an upstream energy footprint
- Not something we’ve researched in detail; plan to do so next year
  - HDSAM assumes 5% leakage in liquid truck loading/unloading

Estimating water demands

- Electrolysis requires a minimum of 9 kg of water per kg of hydrogen, equal to 0.075 cubic meters of water per GJ of hydrogen
  - For comparison, coal power plants take:
    - ✓ ~40 m3/GJ with once-through flow cooling
    - ✓ ~1 m3/GJ with recirculating cooling
    - ✓ ~0.1 m3/GJ with dry cooling
- Water demands are estimated in H2A; we use:
  - 0.13 m3/GJ for electrolysis
  - 0.15 m3/GJ for NGSR
  - 0.32 m3/GJ for coal and biomass
- Unclear whether hydrogen will drive water scarcity, or whether water constraints will influence technology choice in any basins

Estimating technology characteristics of non-standard hydrogen end uses

- We expect hydrogen to be cost-competitive in low-emissions scenarios and in applications requiring significant on-board energy storage
  - There isn’t literature on hydrogen technologies in most of these applications

- Agricultural machinery (e.g., tractors)
- Construction equipment (e.g., cranes)
- Mining equipment (e.g., bulldozers)
- Aircraft
- Ships
- Locomotives

Timing of use, electric sector dynamics

- GCAM has an annual timestep, so isn't set up to easily represent some of the interactions between the power sector and the hydrogen sector that are described in the literature
  - Using excess renewable electricity to produce hydrogen (in the models, this electricity is typically available for a fraction of the normal producer price of electricity)
  - Using hydrogen as a backup power source

- Unclear at this point how to best represent this cheap electricity "resource"
  - The quantity and the price
  - In the real world, what would prevent other flexible-time uses such as EV charging from bidding up the price?

Thank you