Session IV: Rethinking Hydrogen Infrastructure and Markets

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Participants

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- David McCarthy, Air Products and Chemicals
- Mark Paster, US Department of Energy
- Stefan Unnasch, TIAX

Hydrogen from Electrolysis – Chip Schroeder

- Practical sources of hydrogen today:
  - From hydrocarbons (reforming)
  - From water (electrolysis)

- Electrolysis dismissed as net energy loser
  - Nonsense to make fuel from electricity
  - Closer look gets more interesting
  - Electricity enables many “arbitrages”
  - Coal /gasoline
  - Nuclear /gasoline
  - Renewables/gasoline

Advantages of Electrolysis:

- **With current electrolysis technology, *and* current FCVs, we get *1 mile per kWh. Thus,* $.07/kWh electricity competes with gasoline at $1.50 per gal today when H2 is profitably produced via electrolysis**
- **Low cost infrastructure: existing wires and water, reasonable incremental cost (modularity, scalability, solid state technology promises cost reduction), direct extension of industrial products**
- **Interesting arbitrages**
  - **Time of day differentials (2:1 price difference required)**
  - **Quality differentials (grid power costs: $1,000 / kW, backup power value: $4,000 / kW)**
  - **Fuels “crossover” (low cost to high value BTU’s --e. g. coal to gasoline)**

Summary: Hydrogen from Electrolysis

- **Enables efficiency – enhancing “arbitrages”**
- **Supports both stationary and mobility markets**
- **Game changer for enabling renewables**

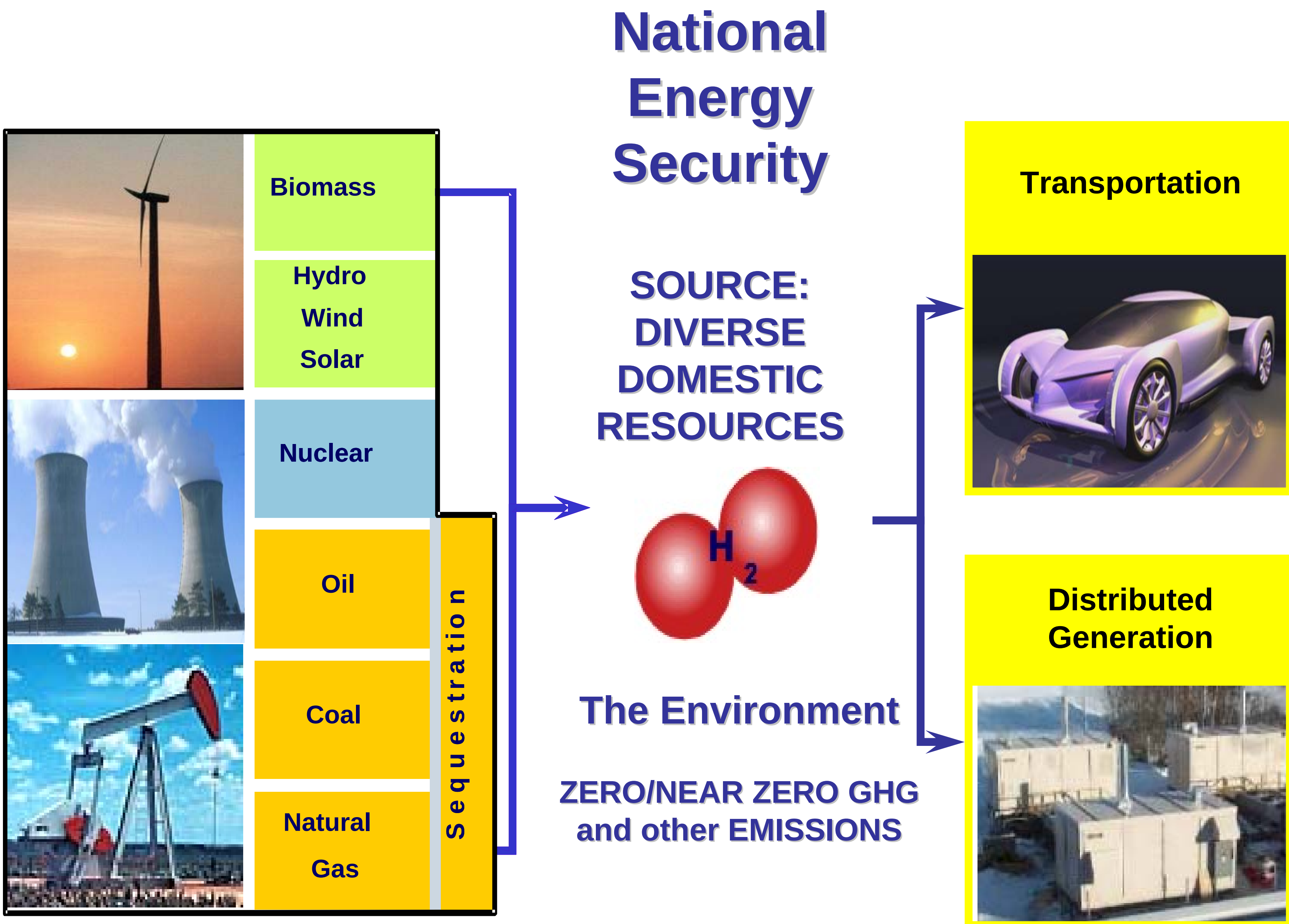
    Power on demand from unlimited renewables

    Fuel from renewably-generated power

Hydrogen Markets and Infrastructure – Dave McCarthy

- Hydrogen is available now to get the transition started
- There are will continue to be many production/distribution options (pathways)
- Pathways will be flexible and renewable
- Both large-scale and distributed pathways will be needed
- The final solution is still being developed
- The final storage technology on-board the vehicle will play the biggest role in defining hydrogen infrastructure

Hydrogen Infrastructure – Mark Paster



Hydrogen Can Be Produced from Multiple Resources

Coal

- **Supply: 5,780 Quads recoverable reserves**
- **Process options: central production from gasification**
- **Cost: Current: $0.90-1.80/kg**
  Projected: $0.50-1.10/kg
- **Requires sequestration and near-zero other emissions**

Hydrogen from Multiple Resources (Cont'd)

Natural Gas

- **Supply:**
  - **188 Quads proven reserves**
  - **Currently importing 15% of our needs**
- **Process Options**
  - **Central Reforming**
    - **Cost: Current: \$0.60-1.00/kg   Projected: \$0.40-\$0.90/kg**
    - **Requires sequestration**
    - **Lowest cost current route**
  - **Distributed Reforming**
    - **Cost: Current: \$4.00-\$6.00/kg   Projected: \$1.50-\$3.00/kg**
    - **Lowest cost current route for delivered hydrogen**
    - **Very sensitive to NG price**
    - **GHG emissions unavoidable**

Hydrogen from Multiple Resources (Cont'd)

Biomass

- Supply
  - 6-10 Quads/yr. currently possible
  - Could be much more with biotech advancements
- Feedstock Cost and Infrastructure are Key Issues
- Central Production Process Options
  - Gasification
    - Cost: Current \$2.00-\$4.00/kg   Projected: \$1.00-\$3.00/kg
  - Fermentation
    - Relatively unexplored
  - Anaerobic Fermentation (Methane to Hydrogen)
    - Agriculture, MSW or industrial sites →
    - Existing biomass "collection" infrastructure
    - Co-Gen power and hydrogen possible
    - Sensitive to scale of operations and required distribution infrastructure

Hydrogen from Multiple Resources (Cont'd)

Biomass

– **Central/Distributed Process Options**

- **Trades hydrogen delivery costs for liquid carrier costs plus reforming**
- **Fermentation → Ethanol → Hydrogen**
  - **Fungible transition from ethanol fuel**
  - **Cost ??**
- **Gasification → Syngas → Methanol (Ethanol) → Hydrogen**
- **Pyrolysis → Bio-Oil → Hydrogen**
- **Sugar Hydrogenation → Sugar Polyols (e.g., Sorbitol) Hydrogen**

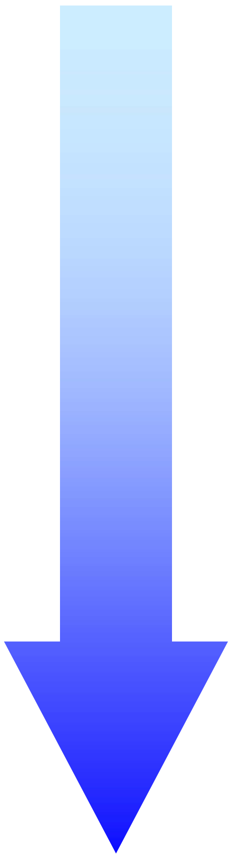
Hydrogen from Multiple Resources (Cont'd)

Water: Electrolysis

- **Distributed and central production**
- **Requires non-GHG emitting clean power: wind, solar, geothermal, hydroelectric, nuclear, fossil with sequestration**
- **Supply:**
  - **Essentially unlimited**
  - **Need purified water**

Both Near –Term and Long-Term Options Are Under Development

Short Term



Long Term

- Distributed: NG, Liquids (including biomass derivatives), Electrolysis
- Central NG, Coal and Biomass
- Renewable Power: Wind, Solar, Hydro, Geothermal
- Central Coal with Sequestration and Biomass
- Photolytic: Photoelectrochemical, Photosynthetic organisms
- Water Splitting Cycles: Nuclear and Solar

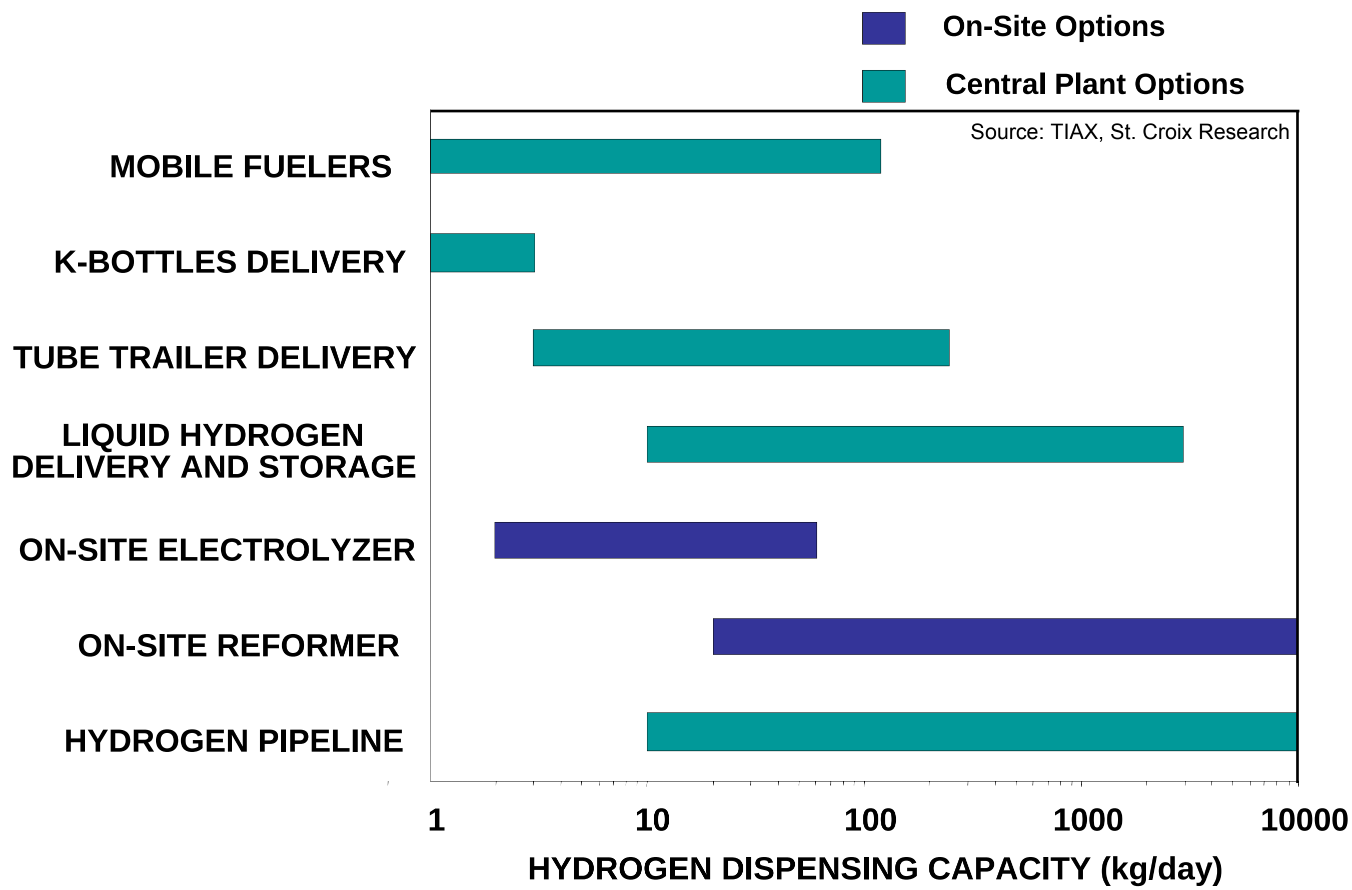
Summary

- Energy security and climate change are the two principal drivers for a hydrogen transition
- Hydrogen will be produced from multiple paths, necessitating a range of R&D
- Because of climate change issues, production from fossil fuels will require carbon sequestration
- Renewables are the preferred solution and thus a principal focus of the DOE program
- In the initial stages of a hydrogen transition, onsite (distributed) production is likely
- Ultimately, a combination of on-site production and centralized production are likely

Hydrogen Markets and Infrastructure – Stefan Unnasch

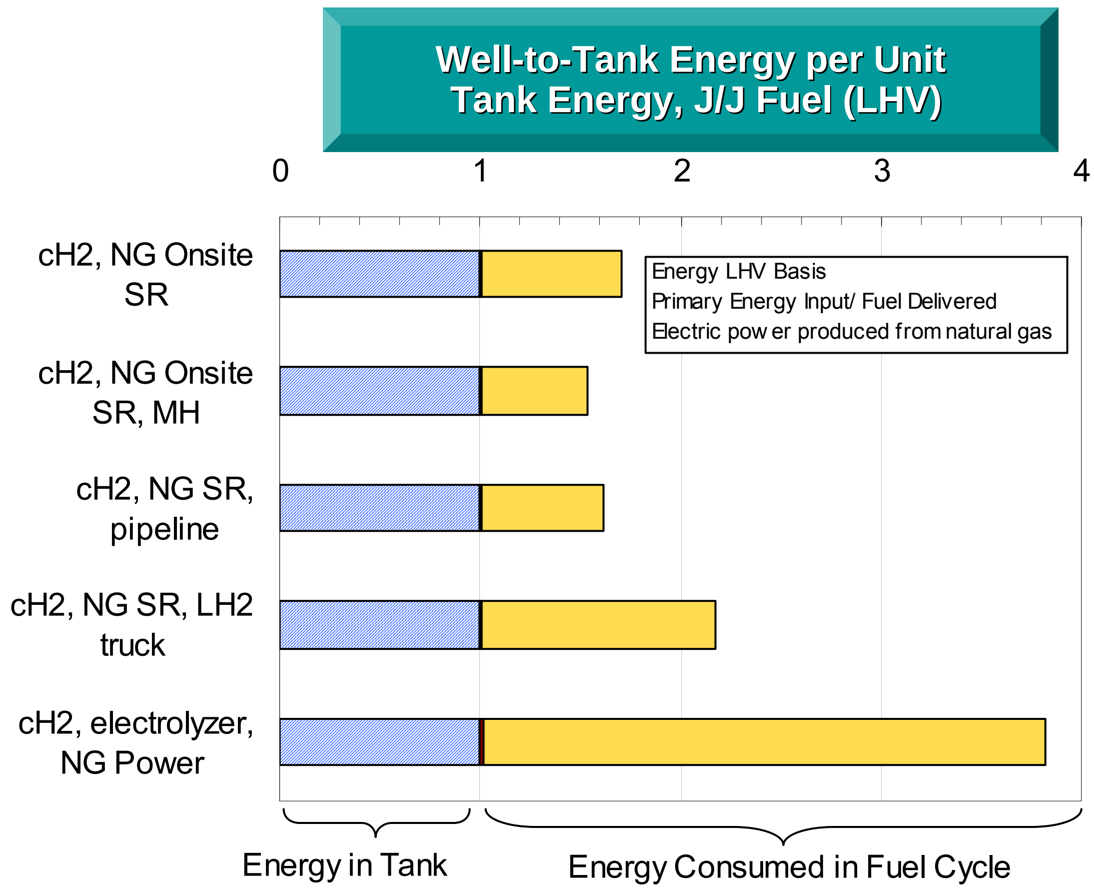
- Potential for criteria pollutant and greenhouse gas reductions provide motivation for H2 ICE and FCVs
- Hydrogen vehicles and fuel will not compete on cost with gasoline and diesel fueled ICEs for a very long time -- unless vehicles are designed and marketed differently, and fuel distribution systems are restructured
- Both vehicle and infrastructure cost reductions are needed before vehicles can achieve commercial success (>10,000 vehicles/yr)
- Hydrogen supply options and vehicle introduction pathways affect all aspects of vehicle operation

Distribution System Capacity Affects the Economics of Hydrogen Supply Systems

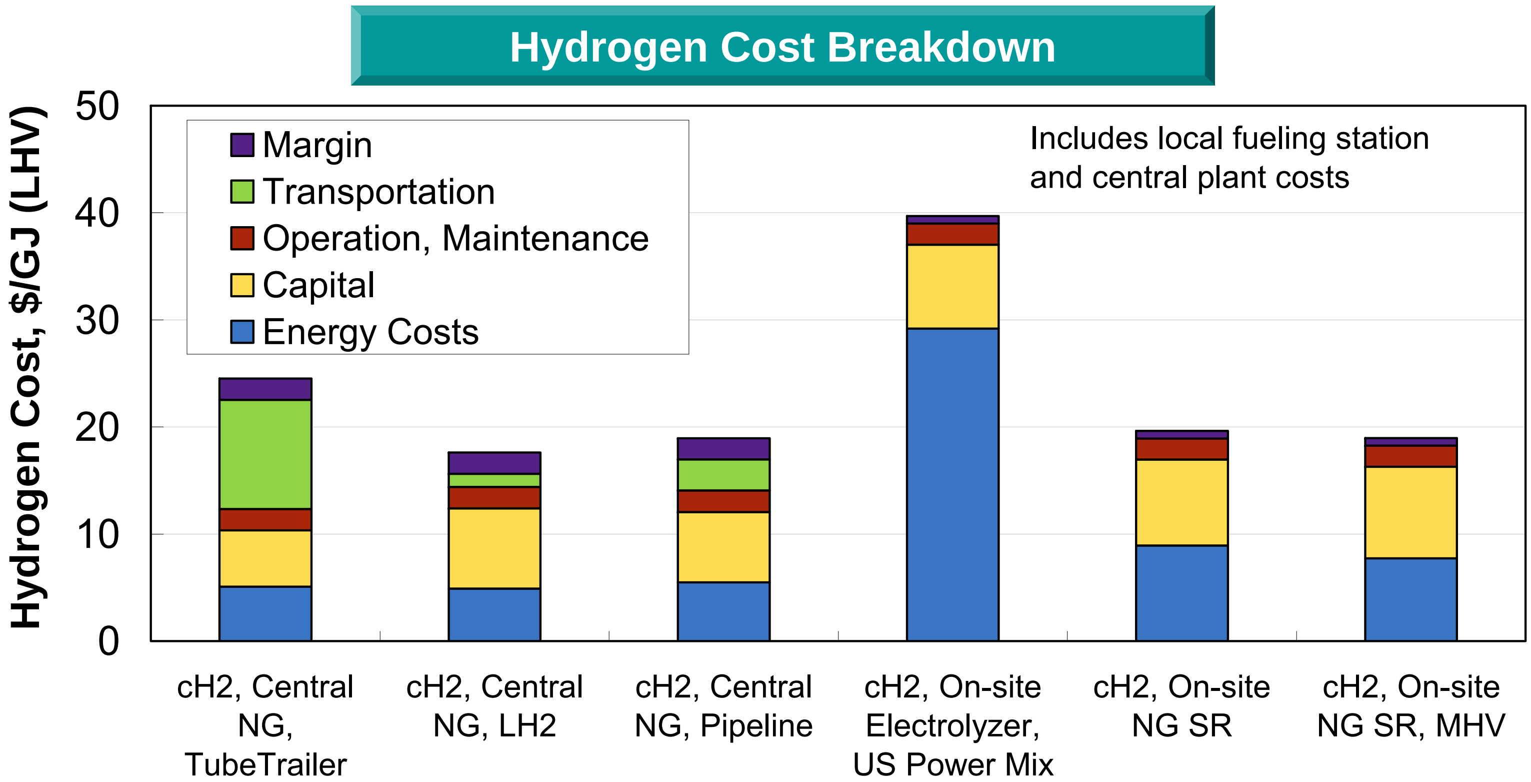


Options Also Differ in Their Energy Intensity (and Greenhouse Gas Emissions)

- WTT natural gas energy input for on-site SR is 1.7 J/J (59% η)
- Less energy use with central plant and MH vehicle fueling
- More energy use with LH2
- Over two times energy use from electrolysis
- Most near term production pathways involve natural gas

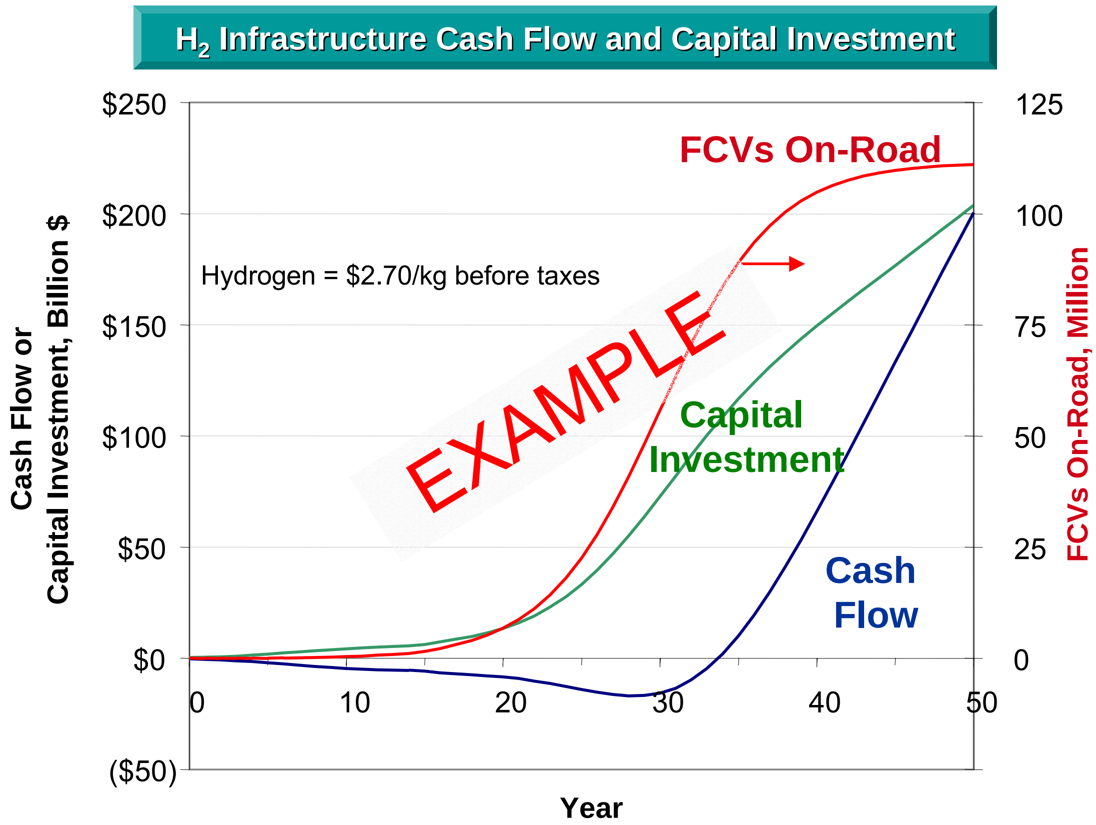


Most hydrogen production options range from about $1.80 to $3.00/kg (before taxes)



Local fueling station capital costs are significant, ranging from $300,000 to $2 million per station, far outstripping franchise owners' resources.

Using preliminary assumptions, if H_2 were priced to provide cost-parity with conventional vehicles, break-even would occur in ~ 30 years...



In the long-run, stakeholders can turn a profit if hydrogen is sold for $2.50-$3.00/kg

- Acceptable to FCV owners if fuel economy is 2-3 times better?
- Near-term pathways are needed to improve CF and reduce capital cost

…if an initial premium of 50-100% (1.5-2x gasoline ICEV cost/mi) is accepted, break-even may occur in ~ 20 years.

For an aggressive FCV program, H_2 production costs would ultimately reach $2/kg, but initial costs are high

- Initial capital cost and utilization (capacity factors) must be improved
- Innovative introduction could help bring the initial costs down:

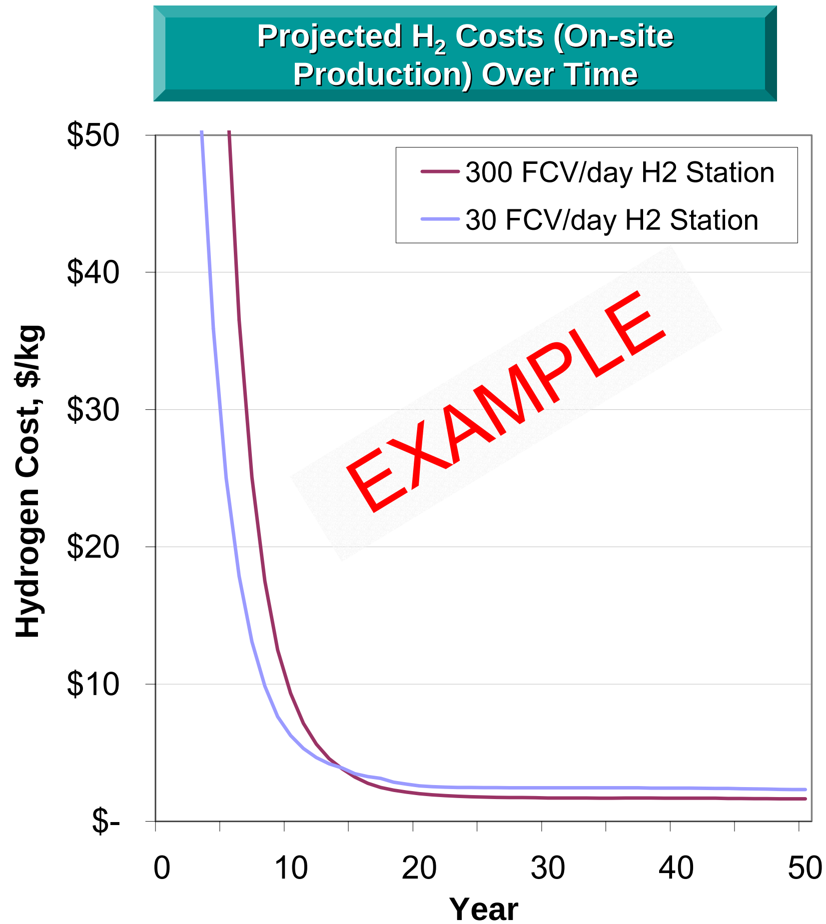
Utilize existing excess H_2 capacity (e.g. methanol and fertilizer plants)

FCV demonstrations and fleets (buses, government vehicles, etc)

Hydrogen ICEVs

Energy station (e.g. hydrogen for fueling and stationary power)

Alternative FCV and H_2 infrastructure introduction scenarios



50 buses would consume 10 percent of existingCalifornia merchant H2 capacity.