# HEC Hydrogen Sessions

# The Economics of Hydrogen Production

## April 8, 2022

**Brad Bradshaw**
**President, Velerity**
**President, Hydrogen Energy Center**
**brad@velerity.com**

# Hydrogen Energy Center

HEC is a nonprofit individual membership organization focused on accelerating the hydrogen as an enabling solution for a renewable energy future

HEC provides public forums, conducts research and implements projects focused on accelerating the clean energy future

Consider supporting this important effort by becoming a member

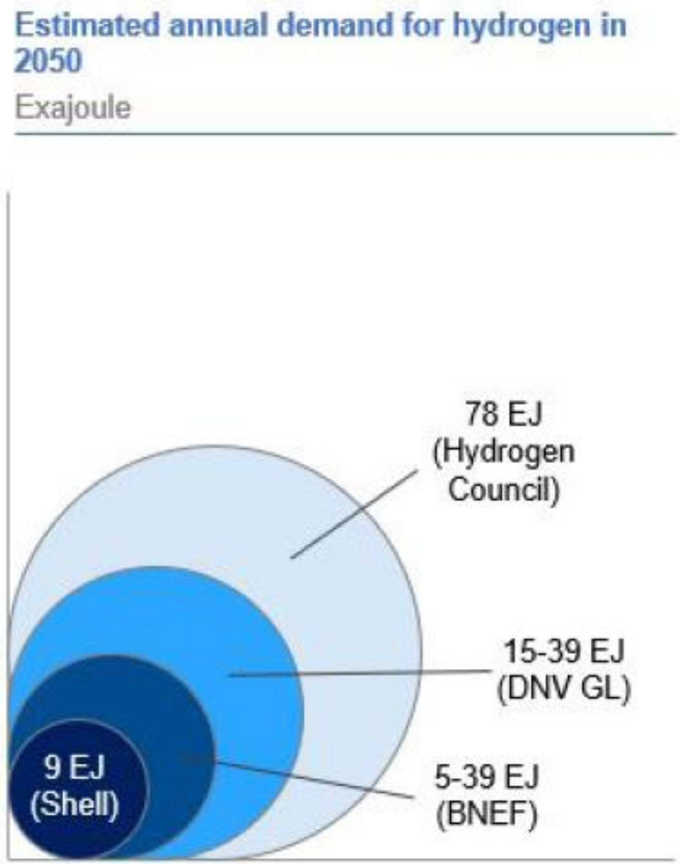
www.HydrogenEnergyCenter.org

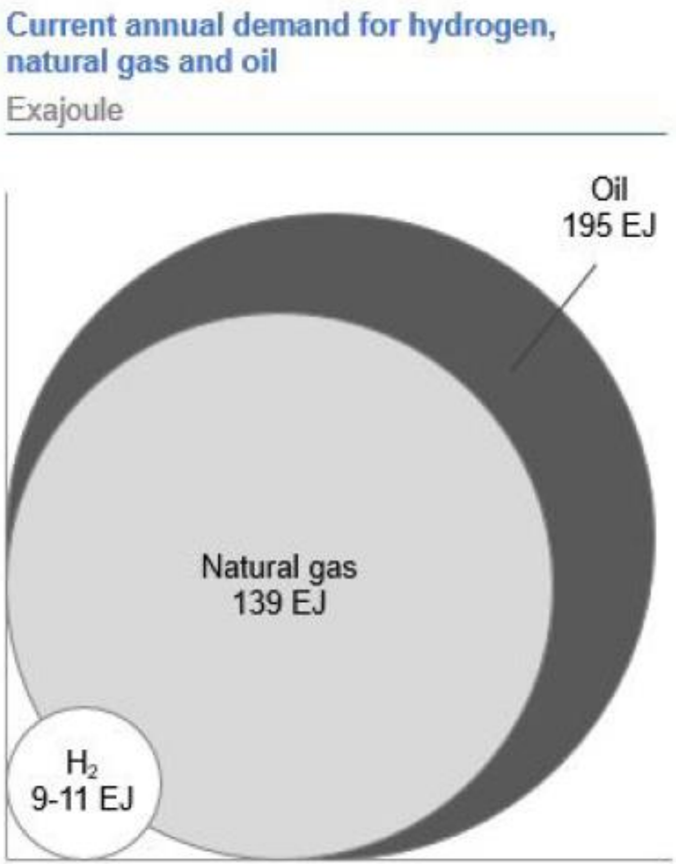
# Velerity provides consulting services to the energy industry

*Hydrogen projects in the past twelve months have included:*

- Conducted due diligence on a solid oxide fuel cell acquisition for a major mid-stream oil and gas company, covering markets, technology and operations
- Advised the CEO and senior leadership of a $7 billion multi-national company on their hydrogen business strategy
- Advised the senior leadership of a hydrogen generation company on their business strategy and capital raise, resulting in $5 million capital raise
- Prepared the market and competitive assessment and market entry strategy for a clean ammonia business for a hydrogen consortium
- Developed a detailed business and technology plan for carbon mitigation for a very large wastewater treatment plant, integrating green hydrogen for synthetic methane and methanol manufacturing

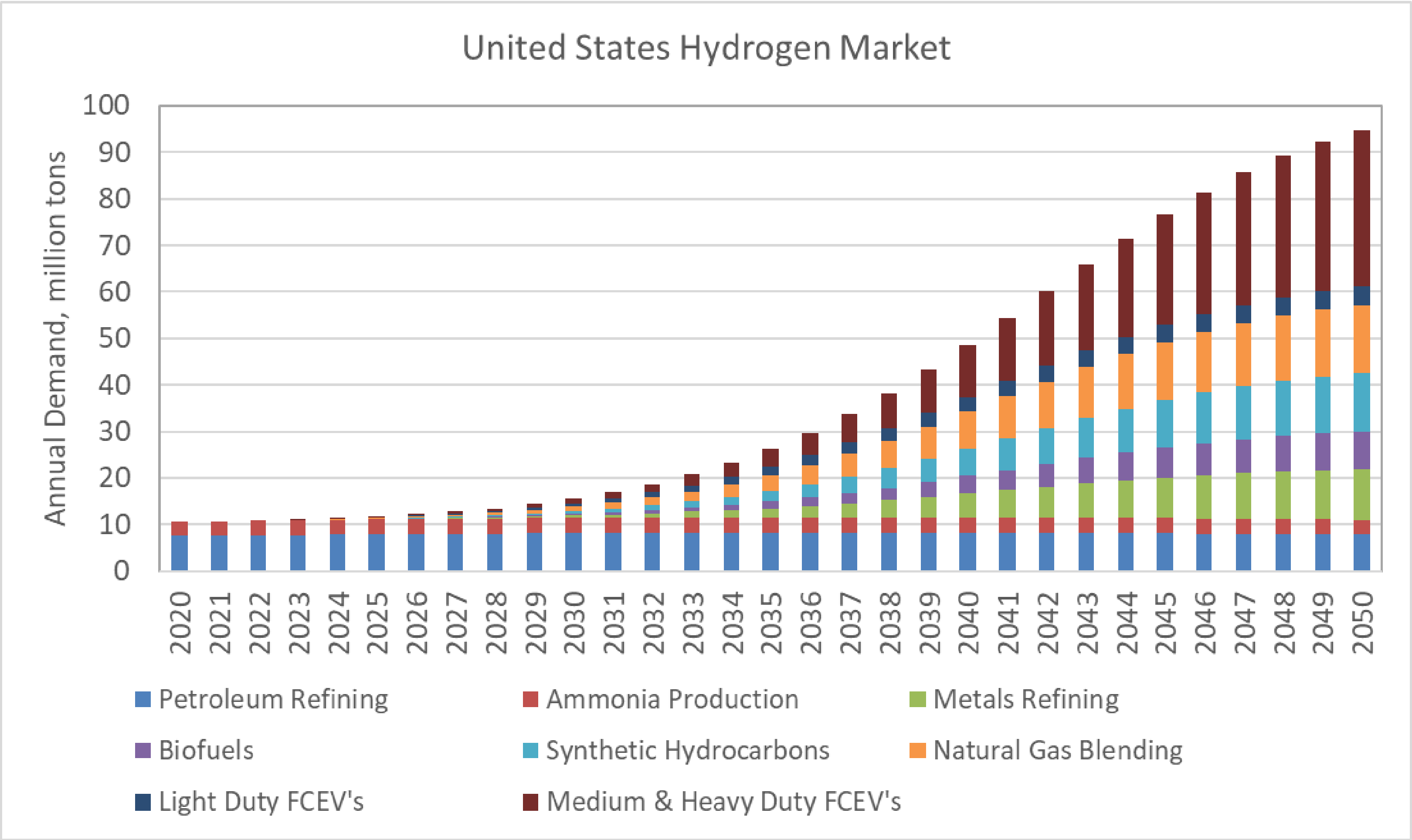
# The hydrogen market is expected to grow significantly over the next few decades




Harvard’s Belfor Center

# The United States is expected to see significant growth in a range of applications for hydrogen




Source: NREL and Velerity

# Current hydrogen production is dominated by steam methane reformation, with a significant cluster in Texas and Louisiana

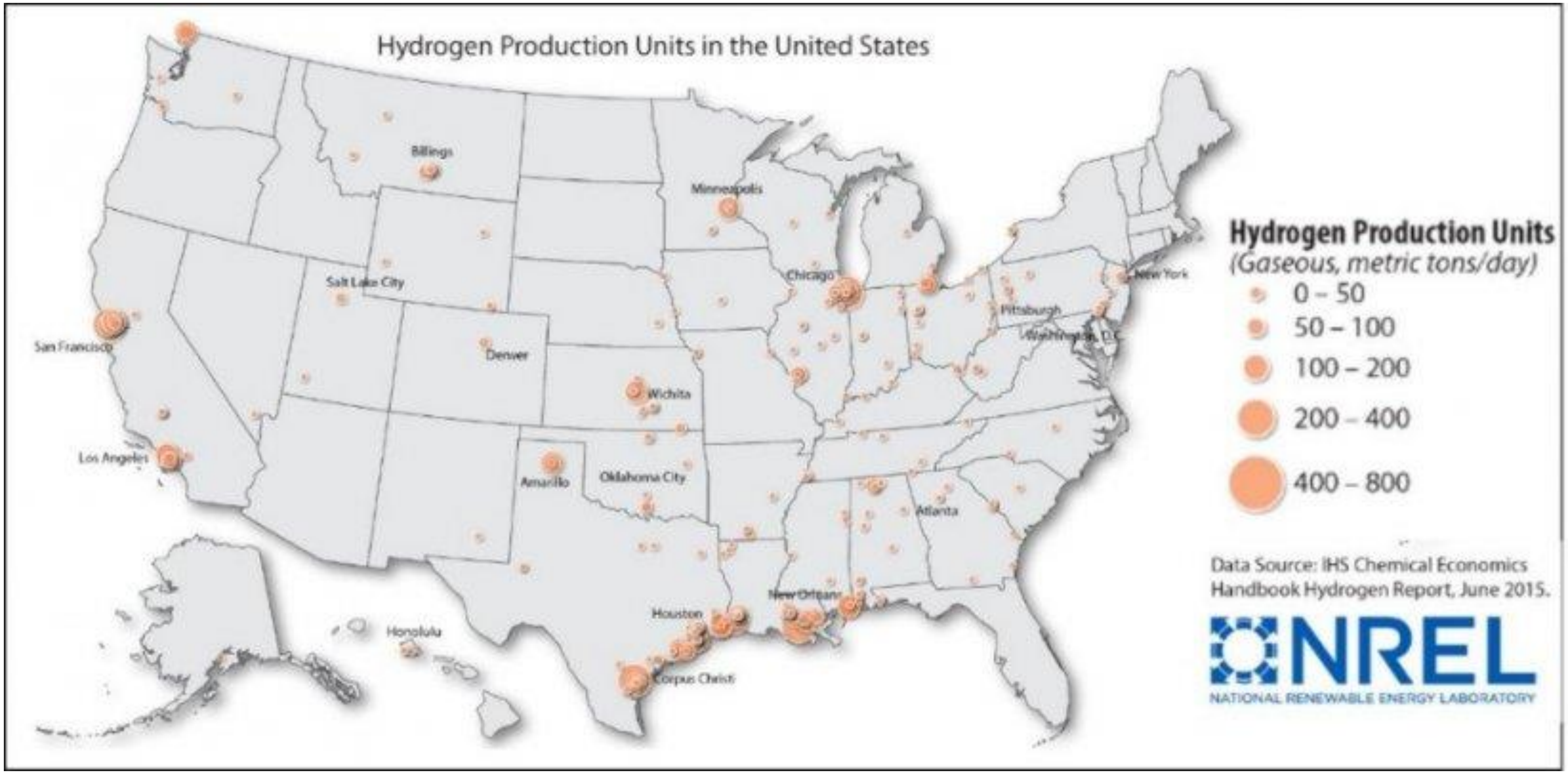
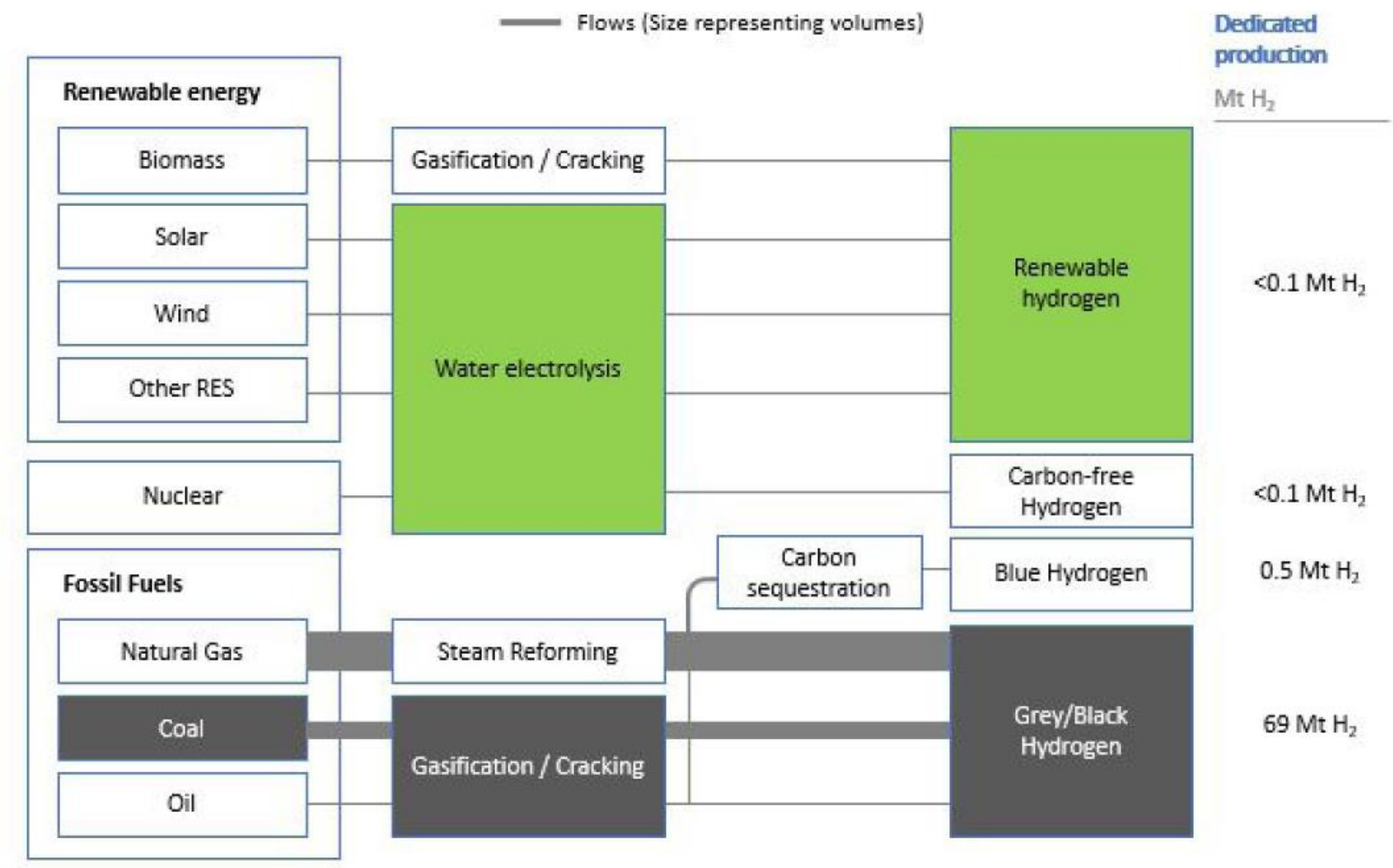



Figure from National Renewable Energy Laboratory. Data source: IHS Chemical Economics Handbook Hydrogen Report, June 2015.

# There is a large number of pathways for hydrogen production



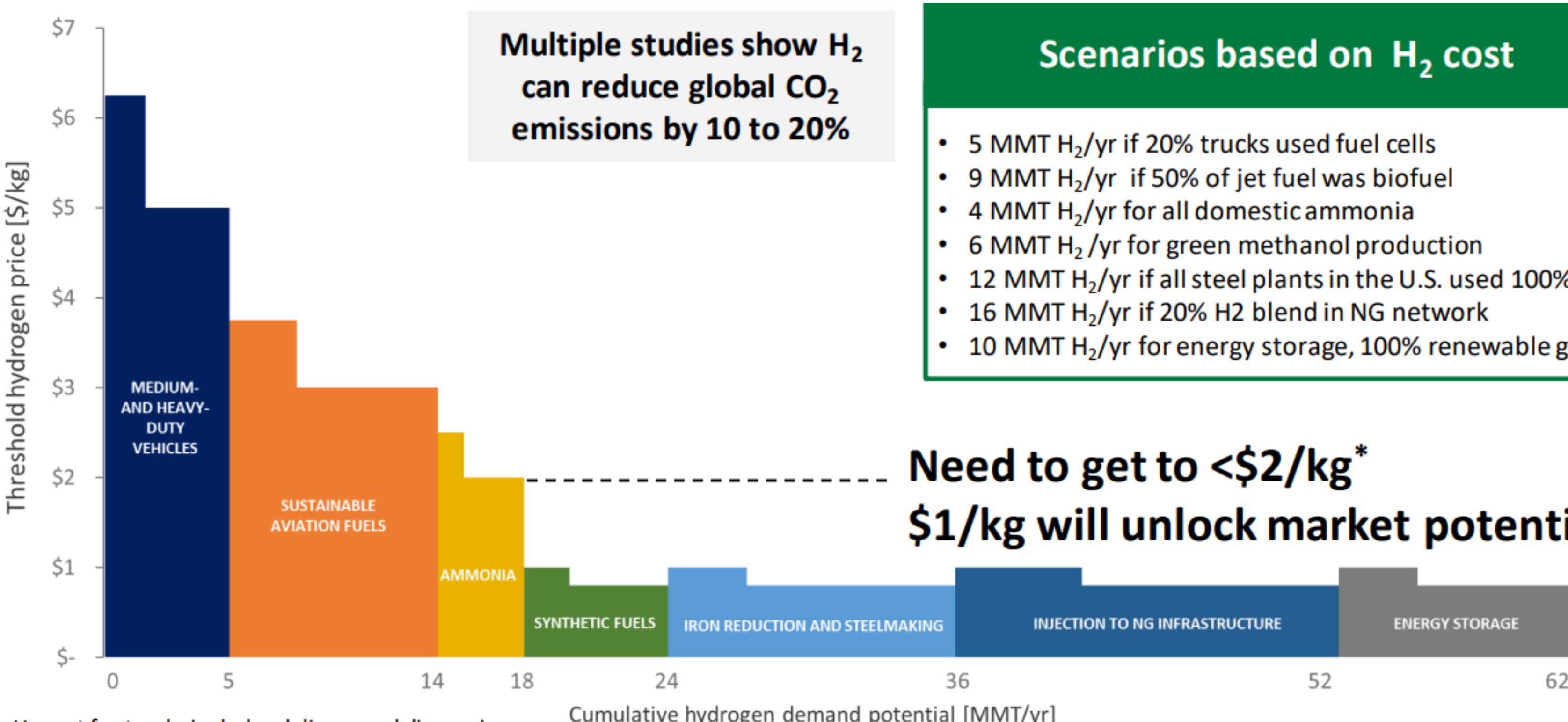

IEA 2019IEA (2019), "The Future of Hydrogen. Seizing today's opportunities. Report prepared by the IEA for the G20, Japan" Harvard's Belfor Center

# Market success will require offering a competitive hydrogen price in specific markets

**Multiple studies show $H_2$ can reduce global $CO_2$ emissions by 10 to 20%**

**Scenarios based on $H_2$ cost**

- 5 MMT $H_2$/yr if 20% trucks used fuel cells
- 9 MMT $H_2$/yr if 50% of jet fuel was biofuel
- 4 MMT $H_2$/yr for all domestic ammonia
- 6 MMT $H_2$ /yr for green methanol production
- 12 MMT $H_2$/yr if all steel plants in the U.S. used 100% $H_2$
- 16 MMT $H_2$/yr if 20% H2 blend in NG network
- 10 MMT $H_2$/yr for energy storage, 100% renewable grid




**Need to get to <$2/kg***
**$1/kg will unlock market potential**

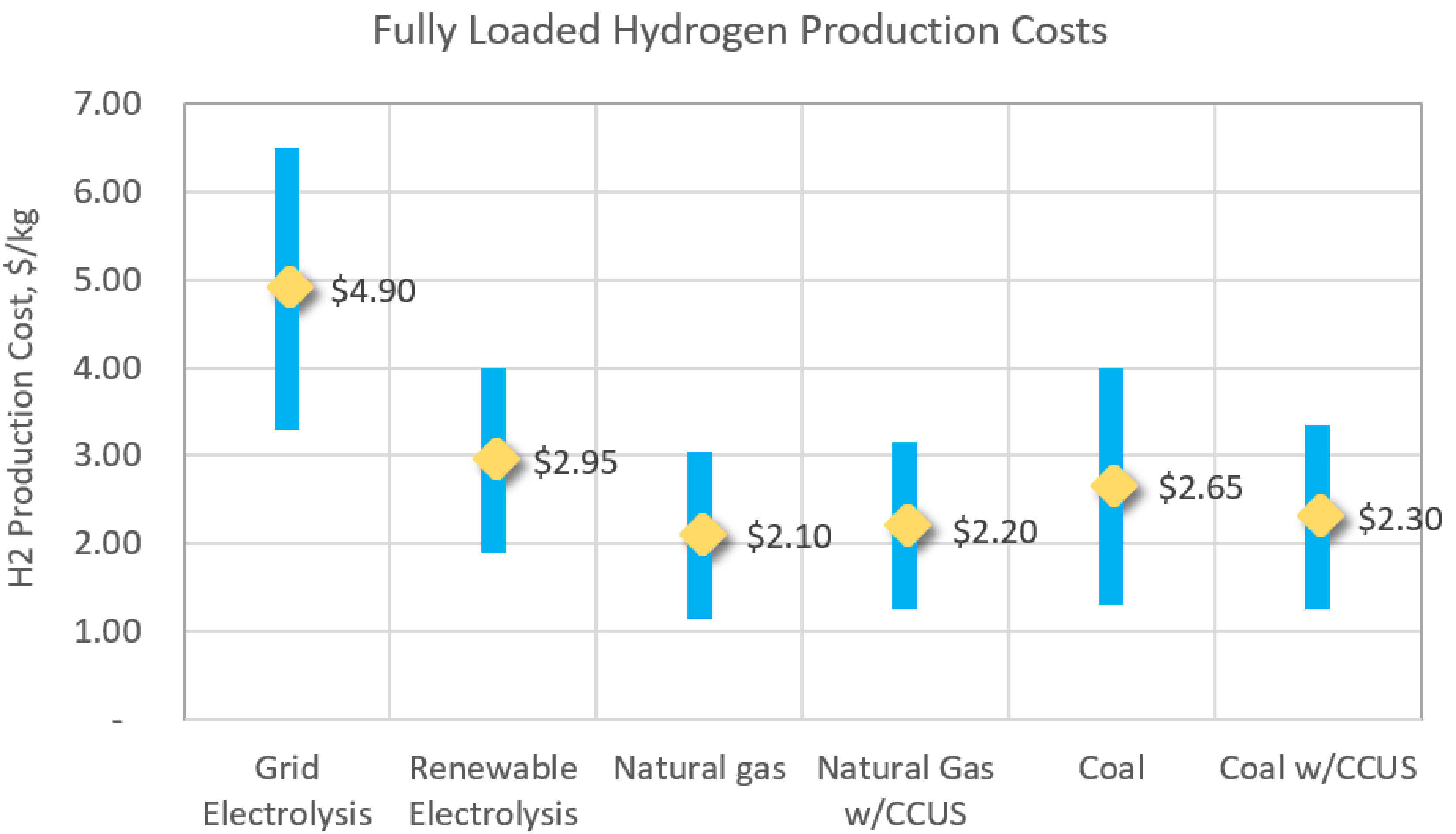
$H_2$ cost for trucks includes delivery and dispensing

* $H_2$ could compete at $1 to $2/kg higher cost with a carbon price

Results based on preliminary analysis

DOE H2 Overview for PA Dept of Environment CCAC 8-24-21

# The International Energy Agency has provided their own estimates of hydrogen costs depending on the source




Source: The Future of Hydrogen, IEA

# Today's analysis presents results associated with running a range of hydrogen production scenarios

- Purpose is to understand the sensitivity to price of various assumptions
- Selecting where and how to source hydrogen is a complex business challenge
- Most hydrogen produced today is produced in very large plants located near low-cost sources of natural gas, and co-located with the end-use application, such as petroleum refining, and ammonia and methanol production
- Future hydrogen markets are strongly aligned with carbon reduction goals, especially for so-called hard to abate sectors, such as:
    - Heavy transport
    - Aviation
    - Ammonia production
    - Methanol production
    - Steel manufacturing
- Each decarbonized end-use application requires carefully aligned hydrogen sourcing and distribution to ensure economics aligned with customer preferences and market adoption goals

# Today's presentation is focused on a core set of production approaches

- Approaches evaluated
  - SMR w/CCS
  - Solar to Hydrogen
  - Solar to Hydrogen w/Clipping
  - Solar plus Storage
  - Biogas to Hydrogen
  - Grid Hydrogen - California
  - Grid Hydrogen – Louisiana

- The analysis is a starting point to illustrate key sourcing choices and their implications
- The models utilize discounted cash flows to calculate a price of hydrogen that covers operating costs, returns capital and provides a profit

# Steam methane reforming with carbon capture and sequestration

| | |
|---|---|
| Hydrogen output | 300 tons/day |
| Natural gas for feedstock and steam generation | 294 million therms/yr |
| Electricity for compressor, boiler feedwater pump, amine system and CO2 compression for pipeline | 189,388 MWh/yr |
| Pipeline – length | 100 miles |
| Pipeline – diameter | 8 inches |
| CO2 capture | 85% from combustion flue and process CO2 |
| CO2 volume | 1.25 million tons/yr |

**Cost of hydrogen $2.86/kg**

# SMR with CCS – Capital Expenditures

| Capital Expenditures | |
|---|---|
| Reformer | 89,950,577 |
| Air Compressor | 765,972 |
| Steam Boiler | 250,000 |
| Water Gas Shift | 11,367,381 |
| Amine AGR Unit | 122,570,016 |
| Heat Recovery Steam Generator | 250,000 |
| Pressure Swing Absorption | 77,100,494 |
| CO2 Pipeline | 101,434,425 |
| CO2 Storage | 25,000,000 |
| Total | 428,688,865 |

# Important factors to consider for SMR with CCS

- The pipeline and sequestration capital and operating costs are significant
- Developing shared CO2 infrastructure is critical to advance CCS projects
- CCS project locations will be driven by pipeline availability and being within a reasonable distance of depleted wells
- Methane leaks throughout the natural gas value chain from production to transmission and distribution are not insignificant
- According to EPA, leaks from gas pipelines were responsible for 21 million metric tons of CO2-equivalent emissions of methane in 2020

# Solar to Hydrogen

| | |
|---|---|
| Hydrogen output | 300 tons/day |
| Solar system size | 3,000 MW |
| Electrolyzer size | 3,000 MW |
| Location | Blythe, California |
| Solar output | 5,485,207 MWh/yr |
| Water consumption for feedstock | 263 million gallons/yr |
| Electrolyzer capacity factor | 20% |
| Capital expenditures | |
| Solar | $1.82 billion |
| Electrolyzer | $2.55 billion |
| Total capital expenditures | $4.37 billion |

**Cost of hydrogen $5.42/kg**

# In-the-Fence Solar to Hydrogen with Clipping

- Electrolyzer size is reduced while the solar system size is increased
- Clipped electrons are not monetized

# In-the-Fence Solar to Hydrogen with Clipping

| | |
|---|---|
| Hydrogen output | 300 tons/day |
| Solar system size | 3,249 MW |
| Electrolyzer size | 1,917 MW |
| Location | Blythe, California |
| Solar output | 5,940,478 MWh/yr |
| Solar output consumed by the electrolyzer | 5,478,659 MWh/yr |
| Water consumption for feedstock | 263 million gallons/yr |
| Electrolyzer capacity factor | 33% |
| Capital expenditures | |
| Solar | $1.97 billion |
| Electrolyzer | $1.63 billion |
| Total capital expenditures | $3.67 billion |

**Cost of hydrogen $4.50/kg**

# Solar plus Storage

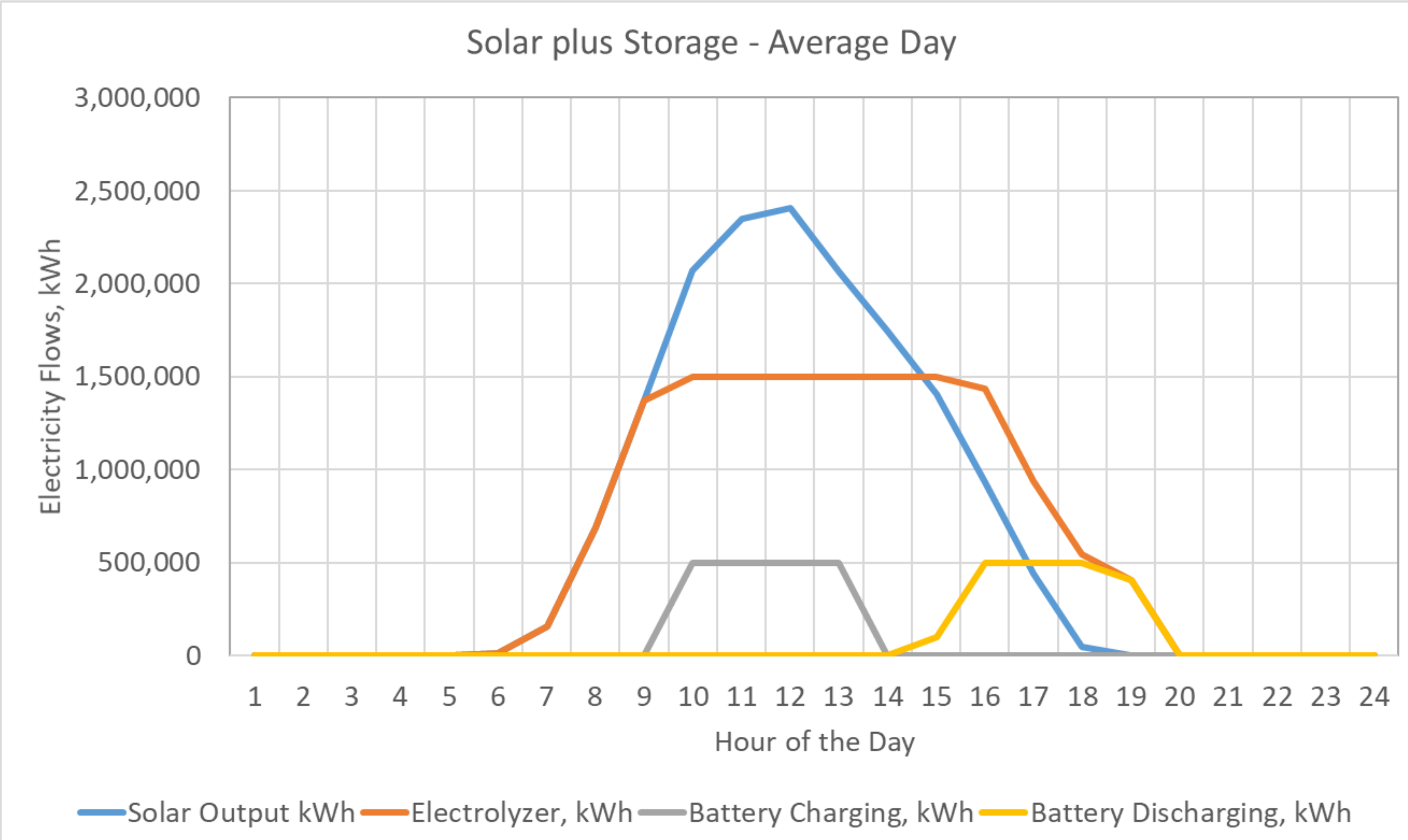
- Integrated storage to capture stranded electrons and reduce the size of the electrolyzer
- Impact on hydrogen cost was limited

# Solar plus storage

| | |
|---|---|
| Hydrogen output | 291 tons/day |
| Solar system size | 3,134 MW |
| Electrolyzer size | 1,500 MW |
| Battery size | 500 MW/2,000 MWh |
| Location | Blythe, California |
| Solar output | 5,729,910 MWh/yr |
| Solar output consumed by the electrolyzer | 5,313,289 MWh/yr |
| Water consumption for feedstock | 263 million gallons/yr |
| Electrolyzer capacity factor | 41.7% |
| Capital expenditures | |
| Solar | \$1.905 billion |
| Electrolyzer | \$1.275 billion |
| Battery | \$0.375 billion |
| Total capital expenditures | \$3.555 billion |

**Cost of hydrogen \$4.50/kg**

# Solar plus Storage



# Biogas to Hydrogen

- Examples of sources of hydrogen from biogas and bio-materials include, at a minimum:
  - Wood waste pyrolysis
  - Landfill gas
  - Agricultural waste with anaerobic digestors
  - Wastewater treatment facilities with anaerobic digestors
- To simplify modelling, used a standard SMR system while varying the cost of the methane inputs
- Individual systems and configurations will have a range of input and output costs
- According to a 2019 study prepared for the American Gas Foundation, about 44 percent of prospective RNG projects can be developed at a cost of \$7 to \$20 per MMBTU, with a median cost among those of approximately \$18/MMBtu

# Biogas to Hydrogen

| | |
|---|---|
| Hydrogen output | 300 tons/day |
| Renewable natural gas for feedstock and steam generation | 294 million therms/yr |
| Electricity for compressor and boiler feedwater pump | 163,874 MWh/yr |
| Renewable natural gas price | $15/MMBtu |
| Capital Expenditures | |
| Reformer | 89,950,577 |
| Air Compressor | 765,972 |
| Steam Boiler | 180,000 |
| Water Gas Shift | 11,367,381 |
| Heat Recovery Steam Generator | 150,000 |
| Pressure Swing Absorption | 77,100,494 |
| Total | 179,514,423 |

**Cost of hydrogen $4.58/kg**

# Grid Hydrogen

| | | |
|---|---|---|
| Hydrogen output | 300 tons/day | 300 tons/day |
| Electrolyzer Size | 658 MW | 658 MW |
| Electricity consumption | 5,475,876 MWh | 5,475,876 MWh |
| Water Consumption | 263 million gallons/yr | 263 million gallons/yr |
| Capital expenditure – Electrolyzer | $559 million | $559 million |
| Large Commercial Electric Rate | *LADWP* | *Proxy for Entergy Louisiana* |
| T&D Charges | $264 million | $166 million |
| Energy Cost | $405 million | $263 million |
| Total electricity costs | $669 million | $430 million |
| Effective Electricity Rate | $0.1222/kWh | $0.0785/kWh |
| Hydrogen Cost | $6.90/kg | $4.65/kg |

# Summary Results