Current Hydrogen Cost

DOE Hydrogen and Fuel Cell Technical Advisory Committee

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30 October 2013

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Who is Air Products?

- Global $10B atmospheric, process and specialty gases, performance materials, equipment and services provider
- Serving industrial, energy, and technology markets worldwide
- Fortune 300 company
- Operations in over 40 countries
- 18,900 employees worldwide
- Known for our innovative and diverse culture , operational excellence and reliable supply
- Leader in sustainability
- Recognized industry leader in safety

50+ Years of Hydrogen Experience

- World's largest producer of merchant hydrogen
- >5.0 million kg per day H_2 production
- Bulk, liquid, and pipeline distribution
- Onsite generation
  - SMR, POX, CPOX, ATR, EHTR, electrolysis
  - Waste gas clean-up technologies
- Extensive experience from 40 plus worldwide central plants, ~50 small onsite generators and 500 plus customers
- H_2 energy projects since 1993
  > 160 hydrogen station projects
  > 850,000 fuelings/year
- Provide the lowest cost molecule

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Infrastructure Vision

- End game is clear, transition to date has been murky
- Lessons Learned
  - Improve delivery technologies
  - Reduced maintenance costs
  - Simple, modular, expandable
  - Piggyback on existing assets
  - Drive to high variable , low fixed cost option
- Consider three components of supply chain:
  - Infrastructure requirement at point of use
  - Means of hydrogen production
  - Delivery from point of production to point of use

Duplicate the proven gasoline forecourt

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Supply Options

- Onsite
  - SMR
  - Electrolysis

- Delivered
  - BHY (gas)
  - LHY (liquid)

Cost Elements

- Feedstock
- Production
- Distribution
- Station Equipment
- Operations

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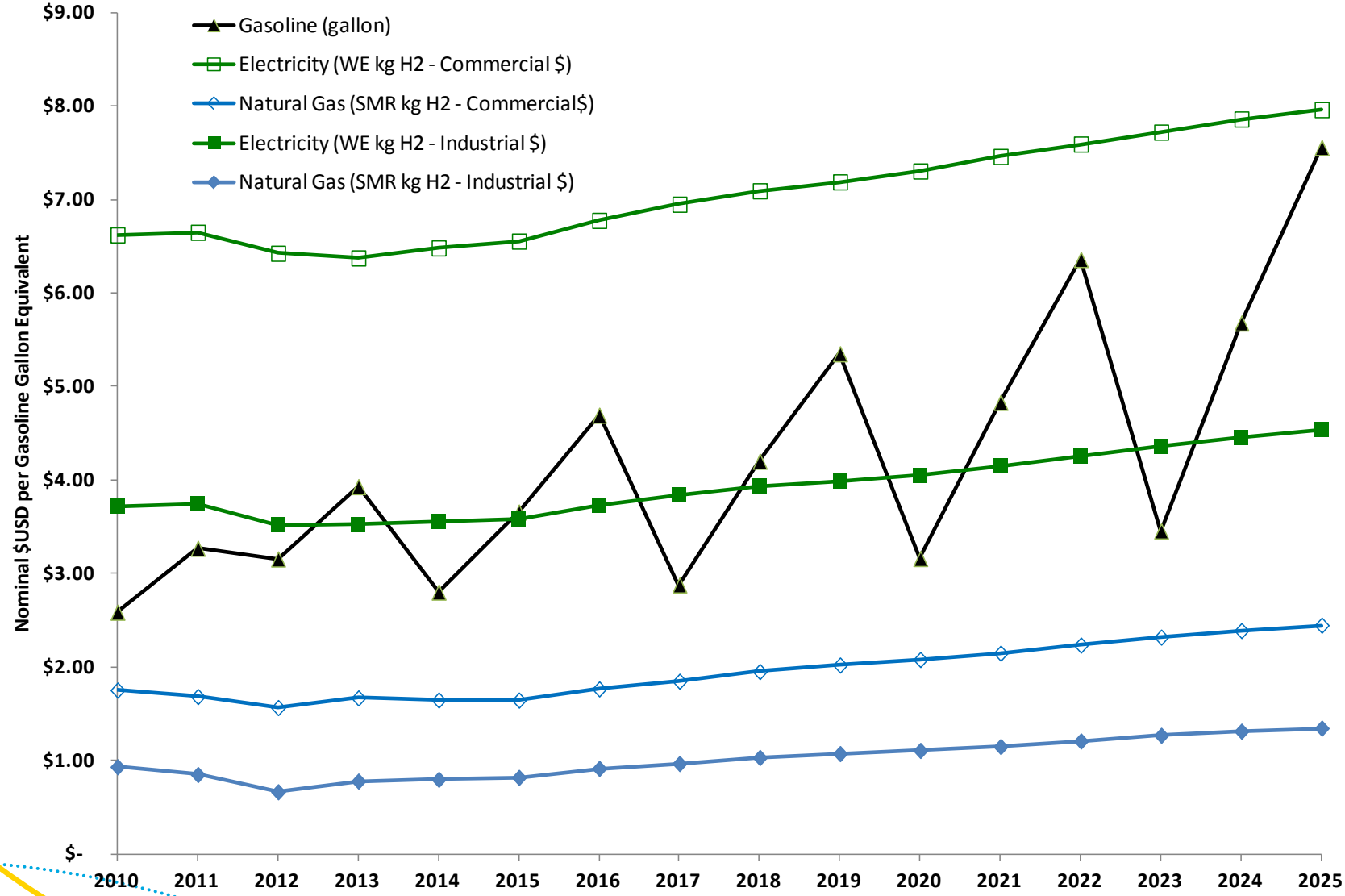
Hydrogen Energy Feedstock Cost to Gasoline Cost
EIA 2013 Energy Outlook - Reference Case



1kg hydrogen = 1 gasoline gallon; LHV basis

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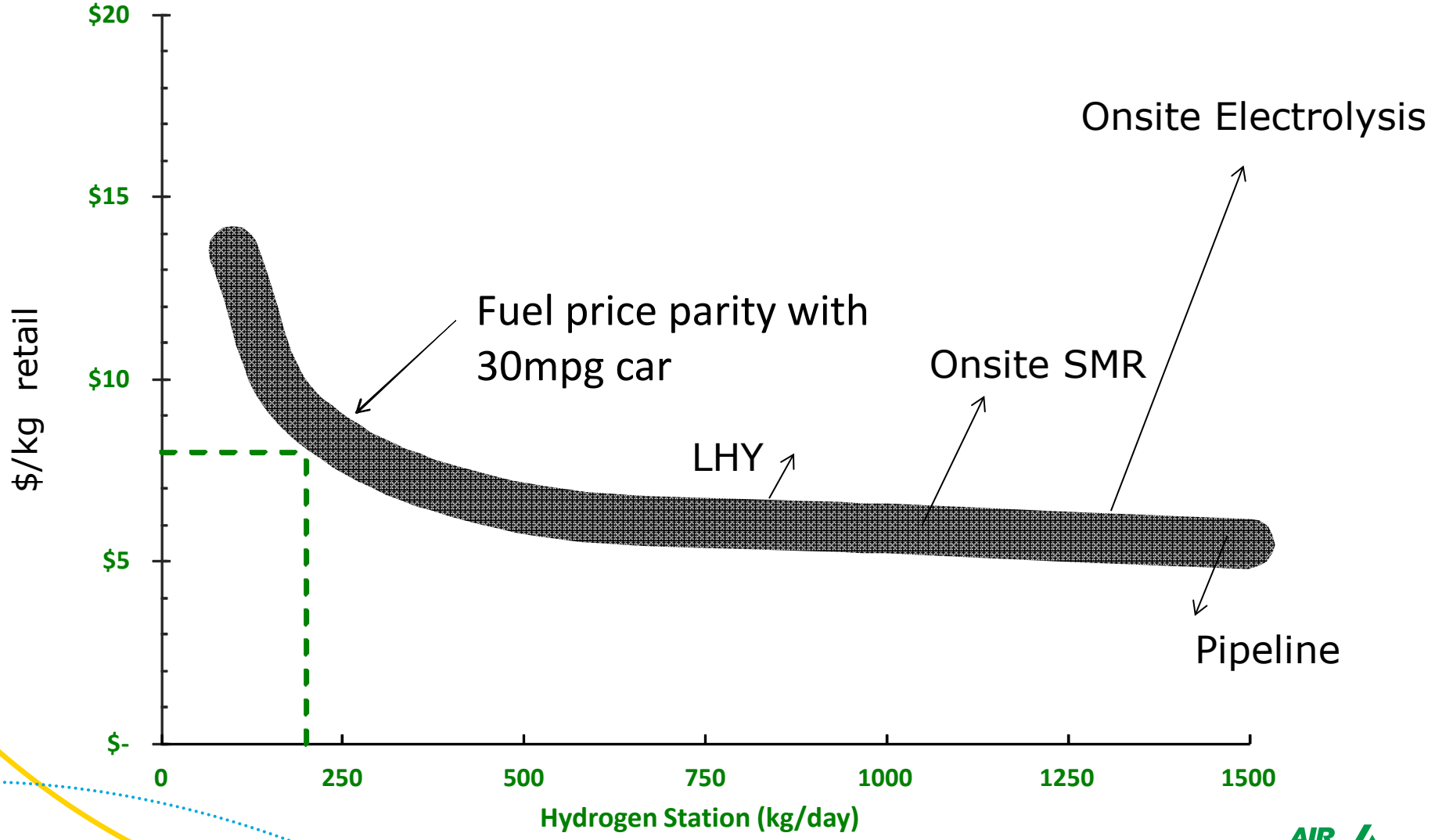
Hydrogen competes with gasoline using latest BHY technology advancements



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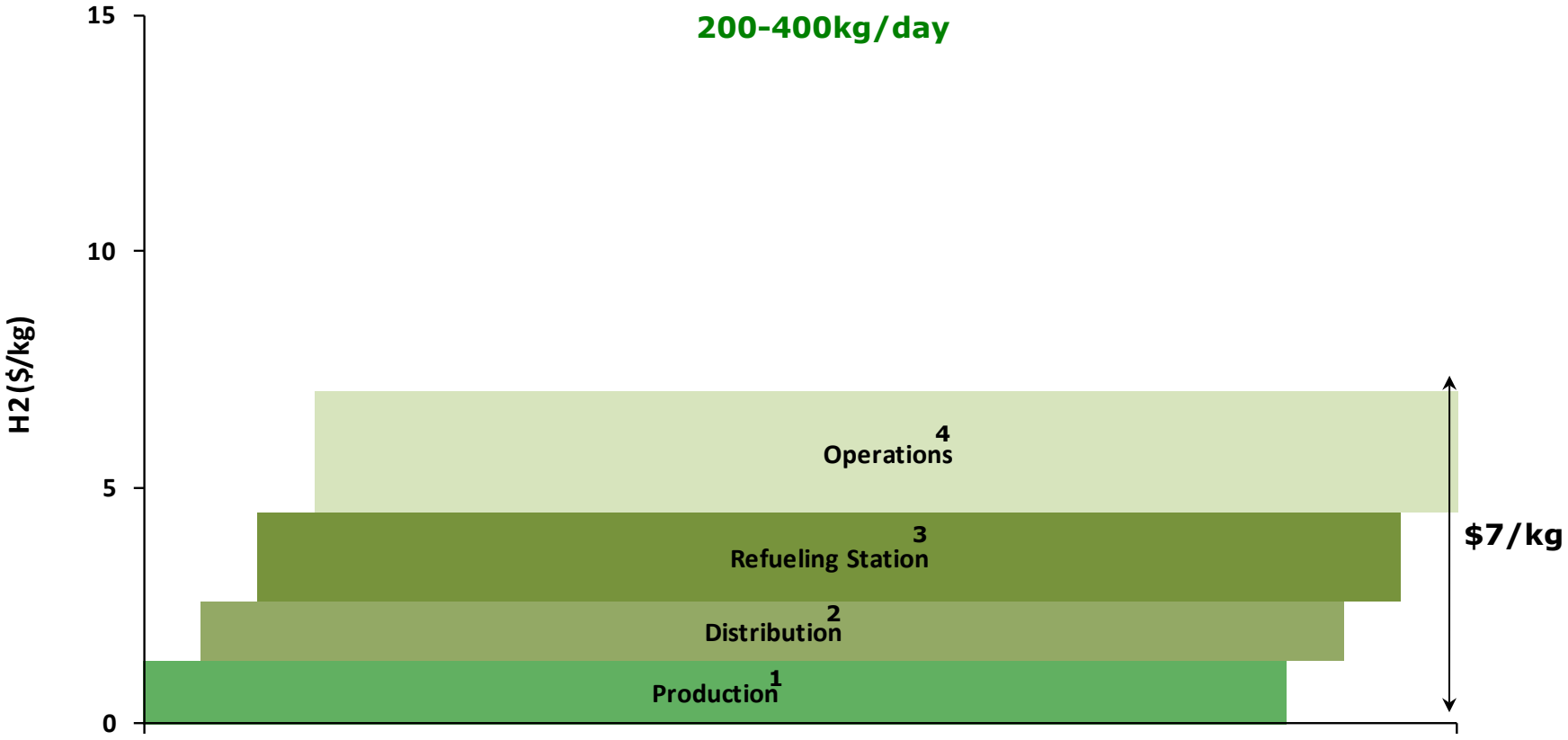
Commercial Delivered Hydrogen Cost



1- NREL, Ruth et al 2009. Central SMR production
2- US DOE 10/2010. Infrastructure (Station with Tube Trailer Delivery)
3- APCI 2011 ($1.5 million hydrogen refueling station at 250 kg/day)
4- UCD 2011 ($250k/year.; Land rent, Operations & Maintenance, Insurance, Excise Tax)

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Comparative Economics

(200-400kg/day)

	BHY[1]	LHY[2]	WE Cent.	WE Dist.	SMR Dist.	Pipeline
Feedstock	$ 0.82	~2X	~4X	~8X	~2X	1X
Production	$ 0.68	~2X	~1.5X	~4X	~4X	1X
Distribution	$ 1.50	~1/2X	Same	-	-	~0.5X
Station Equipment	$ 2.50	~1.25X	Same	~1.5X	~1.5X	<1X
Operations	$ 1.80	~1.5X	Same	~1.5X	~1.5X	<1X
Dispensed Price	$ 7.30	$ 10.00	$ 10.50	$ 16.00	$ 10.50	$ 6.00
Feed, Prod., Dist.	$ 3.00	$ 4.50	$ 6.00	$ 10.00	$ 4.25	$ 2.25

1- BHY (gaseous H2)
2 –LHY (liquid H2)

- Plot space, standoff distances , utilization issues aside

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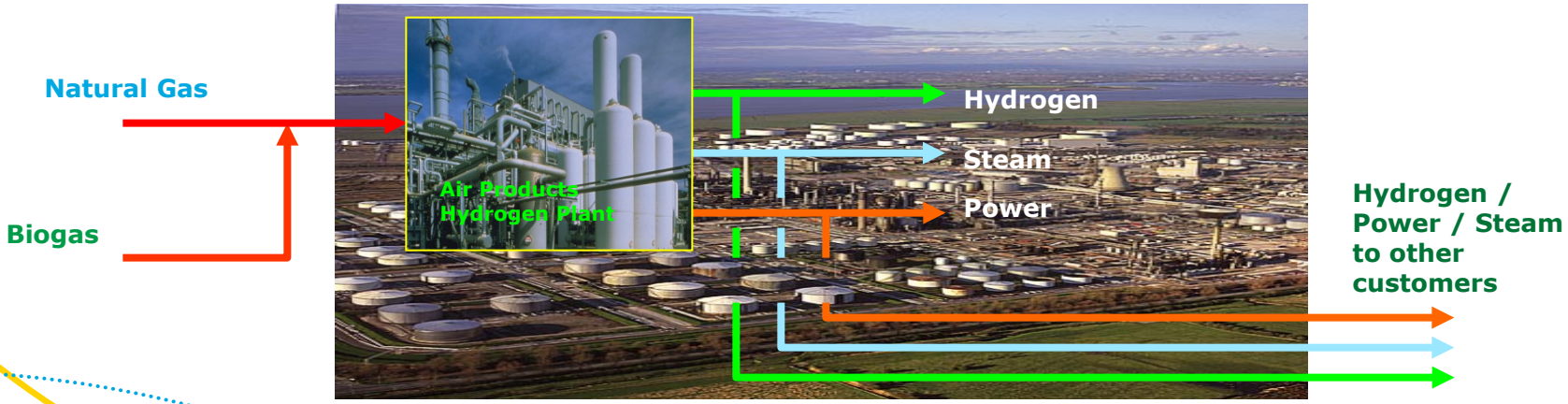
City Gate Hydrogen Is Low Cost

- World-scale, highest efficiency hydrogen network located on a host refinery sites supplying products to multiple customers via pipeline – hydrogen, power and steam
- Efficiency significantly improved by scale and technology development to allow maximum recovery of excess process heat to produce steam and/or power
- Infrastructure offers a safe, reliable, and cost-effective platform for development of the hydrogen economy

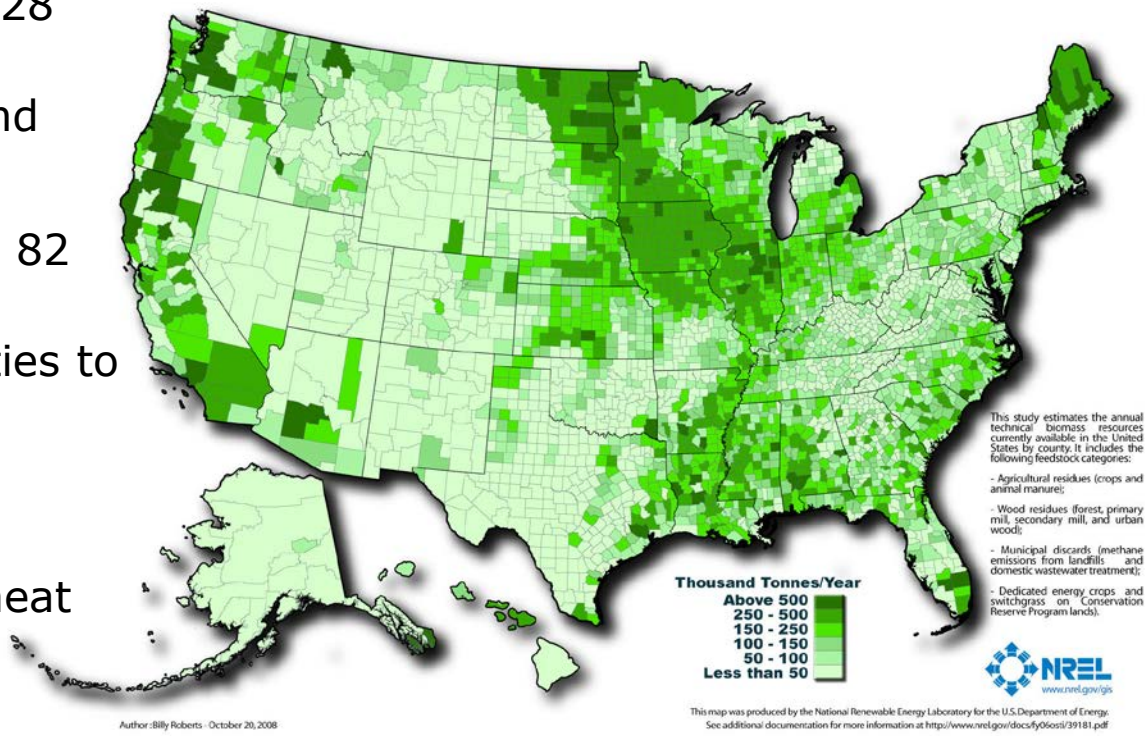


Hydrogen can be made efficiently with renewable biogas in significant quantities and is sustainable

Biogas can fuel ~ 210 Million cars

- 40,000 anaerobic digester facilities: 10.8 TCF of H2 (128 Million cars)
  - Operating at OCSD today and dispensing
- Landfill gas facilities: 7 TCF (82 Million cars)
  - Used today in AP's CA facilities to meet SB1505 renewable requirements to serve H2 stations
- 150 waste streams used for heat value vs. hydrogen
- Biogas adds ~$1/kg to the dispensed price.

US Biogas Resources



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Summary

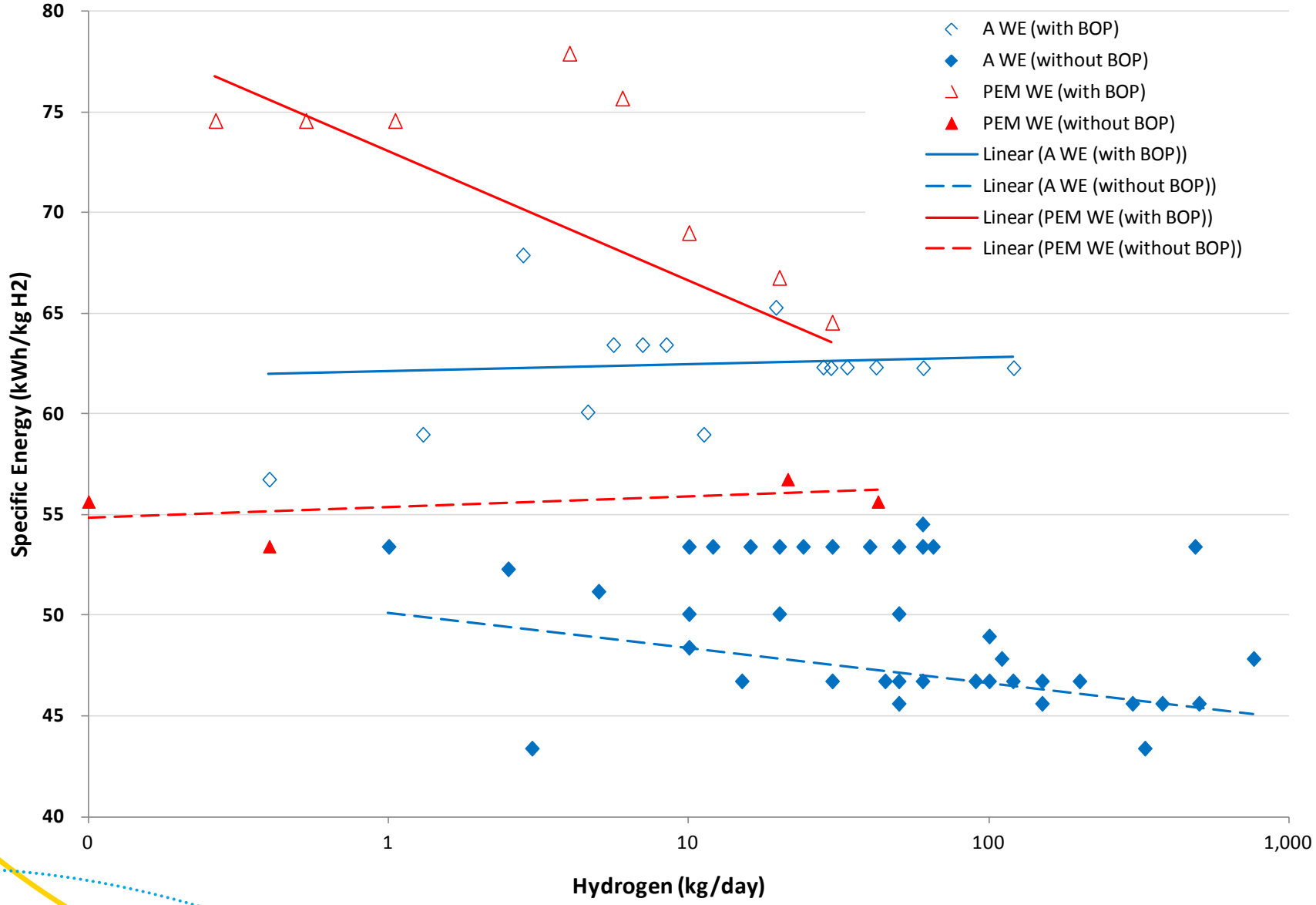
- End markets Total Cost of Ownership of vehicle and fuel will influence market acceptance and market scale of hydrogen as an alternative fuel. Gaseous delivered hydrogen will seed the early market.
- Other options come into play as mega stations and full deployment occur.
- Biogas conversion is the lowest cost renewable hydrogen and eliminates an existing GHG issue.

Thank you…
tell me more

www.airproducts.com/h2energy

Supporting Information

Specificy Energy (kWh/kg) Consumption of Electrolyzers



Sources: WE manufacturer's listed data; NREL: Danish electrolyzer study NEI-DK-5057

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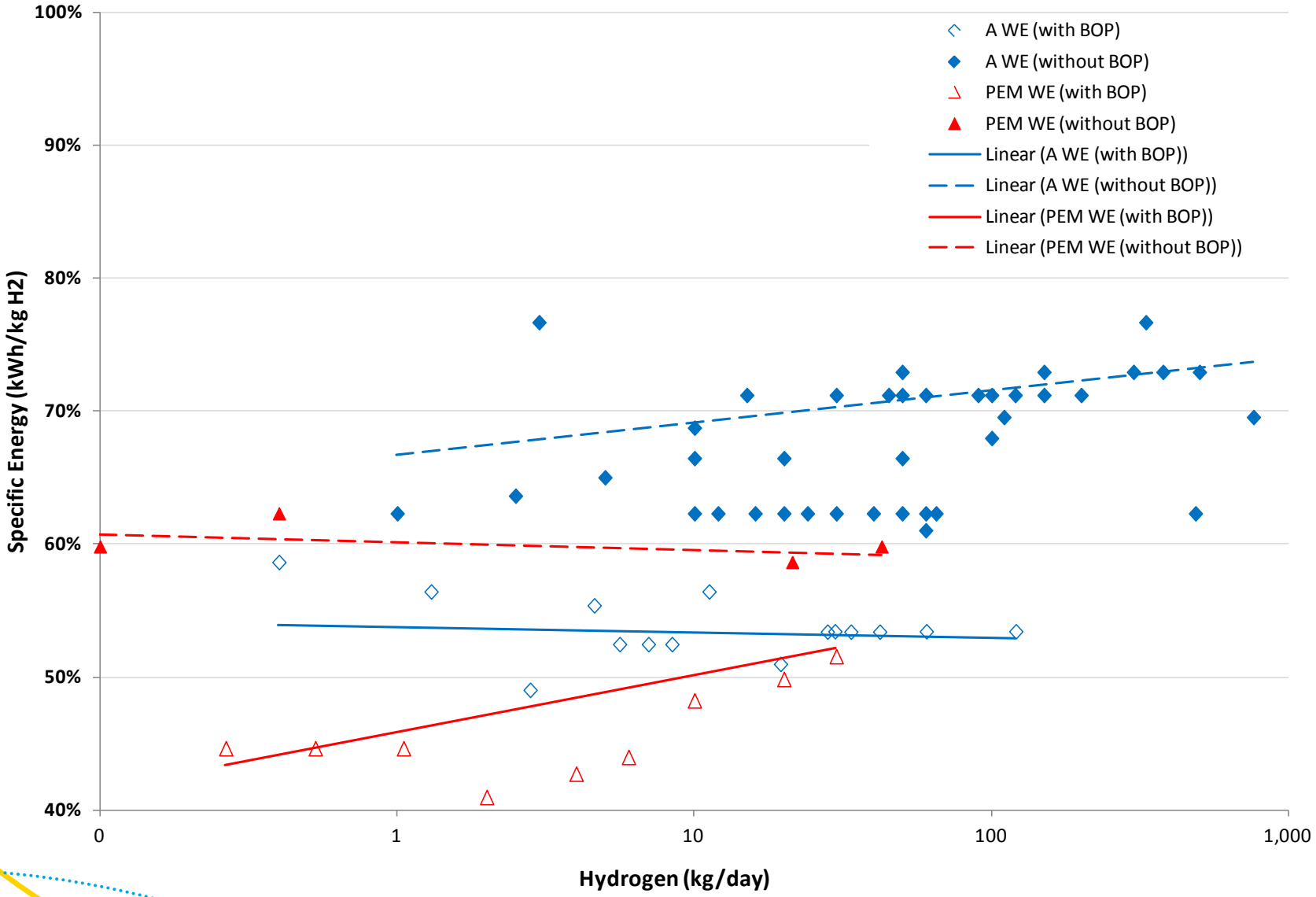
Efficiency of Electrolyzers - LHV H2 Basis (33.3 kWh/kg H2)



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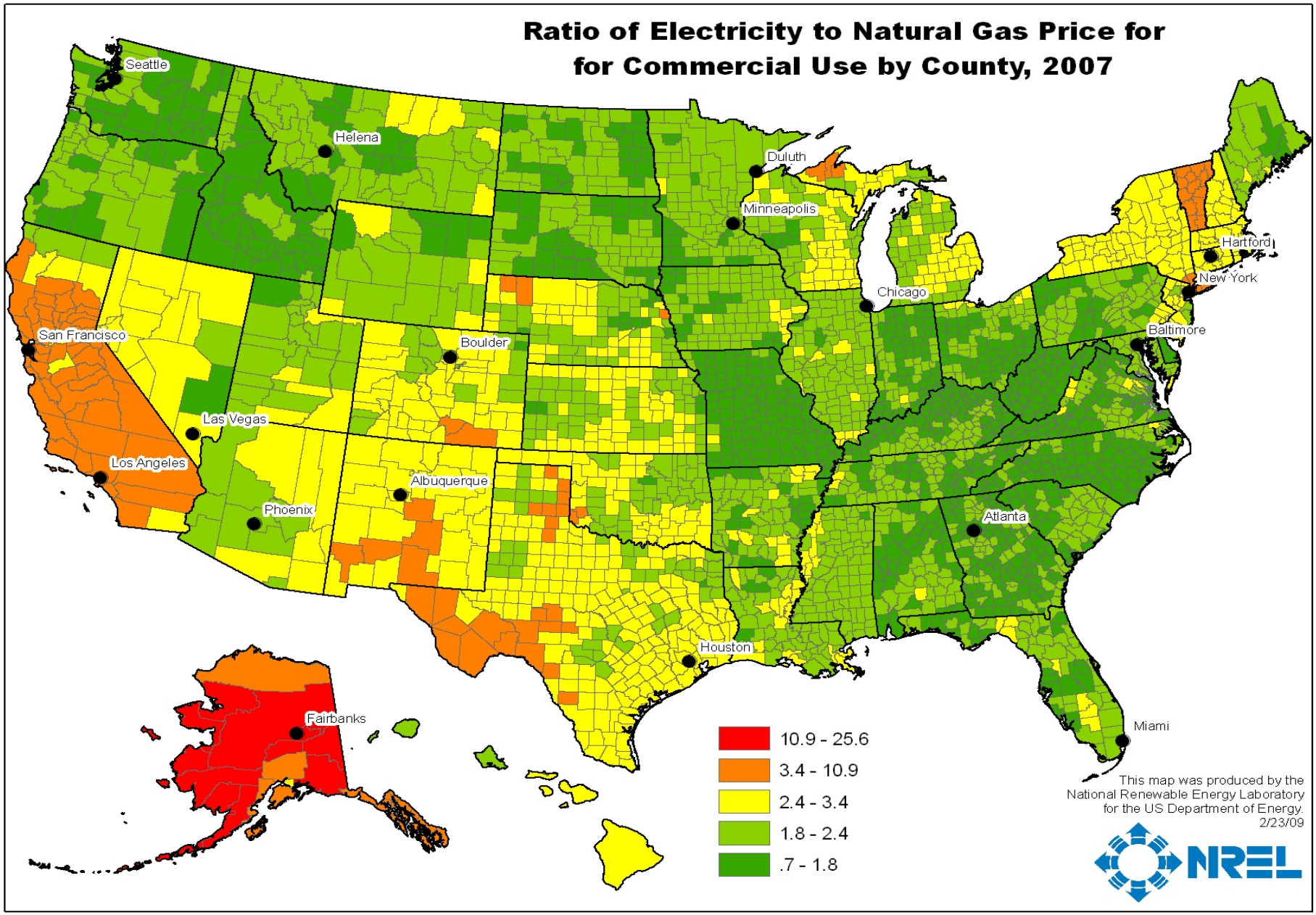

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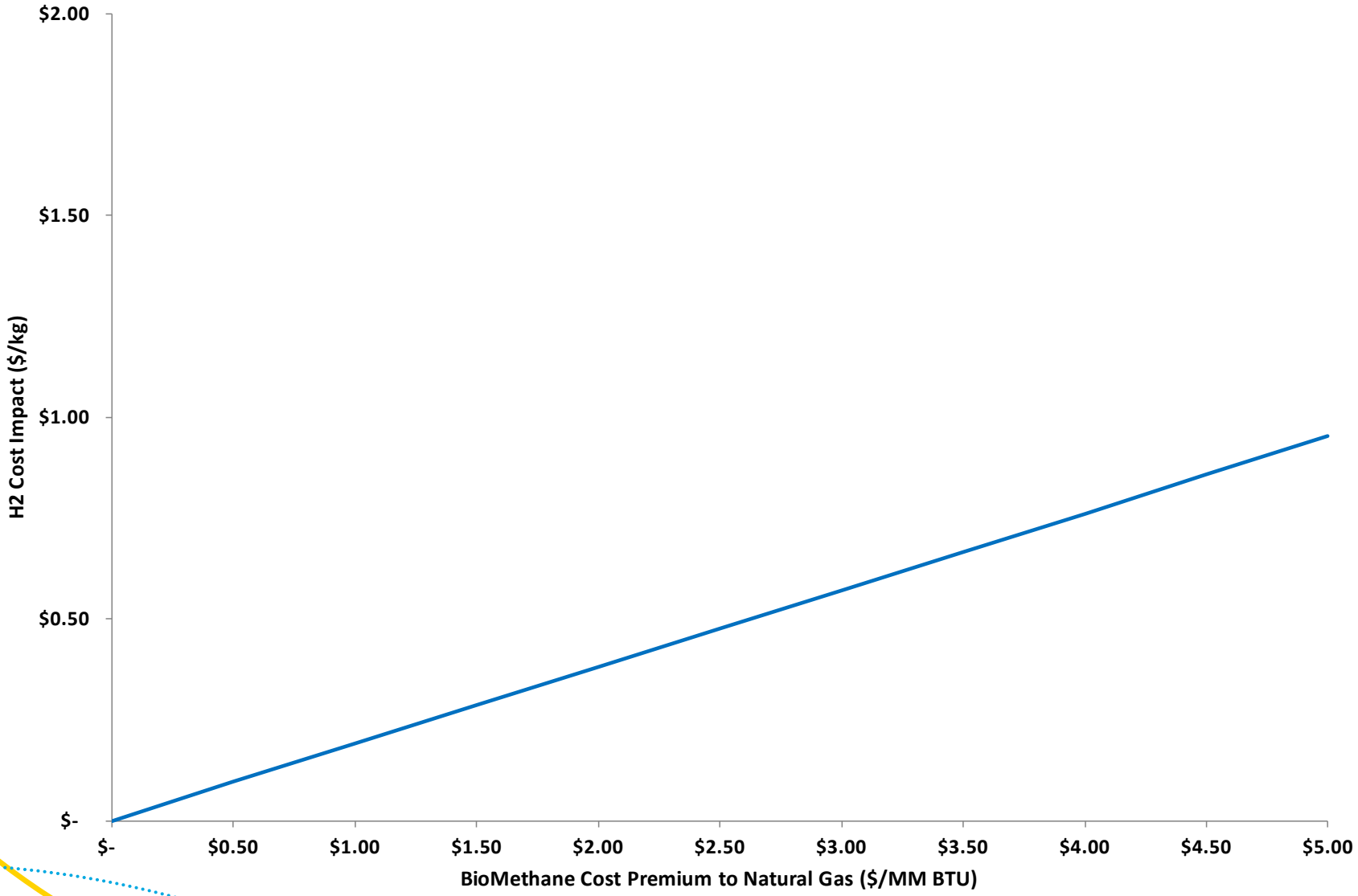
SMR H2 Cost Premium for Biogas (Biomethane)
(60% SMR efficiency; LHV H2)



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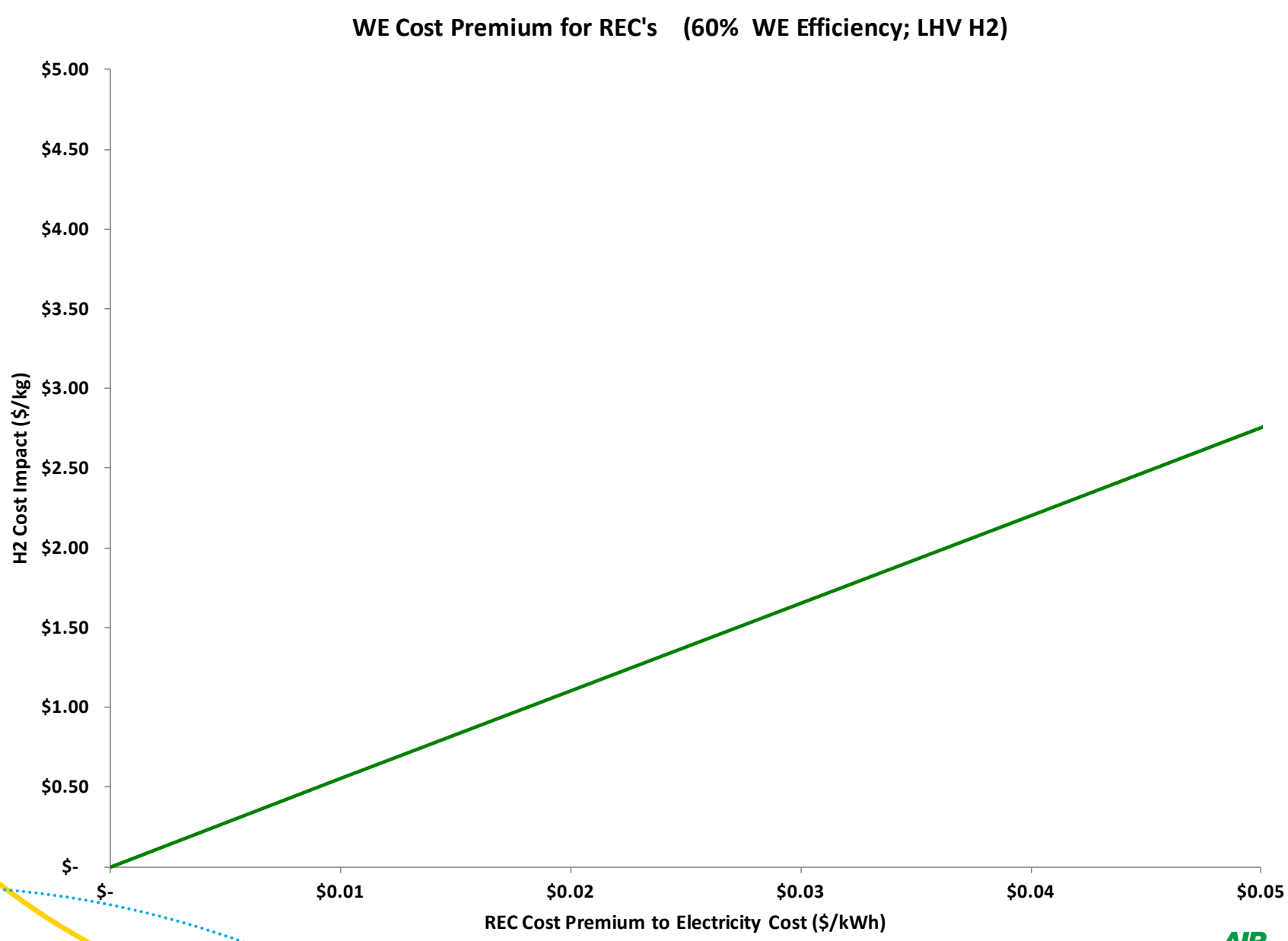
WE Cost Premium for REC's (60% WE Efficiency; LHV H2)
$5.00
$4.50
$4.00
$3.50
$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$-
H2 Cost Impact ($/kg)
$-
$0.01
$0.02
$0.03
$0.04
$0.05
REC Cost Premium to Electricity Cost ($/kWh)

Hydrogen can make a significant contribution to energy independence

- Hydrogen can be made from multiple Hydrocarbon feedstocks. Any feedstock that can generate electricity can generate hydrogen. US natural gas reserves are:
  - Natural gas 238 TCF
  - Unconventional gas streams 400 TCF Shale formations expected 1,200 TCF
- If all U.S. transportation 300MM vehicles where to convert to hydrogen it would require ~10 TCF natural gas.
  - Current NG consumption is 25 TCF.