

Sustainable Transportation Energy Pathways (STEPS)

Natural Gas as a Transition to Zero Emission Fuels: H2 and NG in Transportation Applications

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Could natural gas fueling infrastructure to serve as a bridge to

- Which transportation markets are most promising for natural gas and hydrogen?
- What components of the natural gas refueling supply system could be used or adapted for hydrogen?
- What is the expected timing and scale for developing natural gas and hydrogen as transport fuels over next 2 decades?
  - How much will H2 and NG infrastructure coincide? Geographically? over time?
- What is the potential role of H2 blending w/ pipeline NG in H2 transition? ("Green" gas grid, "power to gas")

TRANSPORTATION APPLICATIONS for NG and H2

Application	NG		H2		NG -> Liquids	NG-> ELEC
	CNG	*LNG*	*CH2*	*LH2*		
LIGHT DUTY VEHICLES	X		X		X	X
BUSES	X		X		X	X
MED DUTY TRUCKS	X		X		X	
HEAVY DUTY TRUCKS	X	X	X	X	X	
RAIL		X		X	X	X
MARINE		X		X	X	
AVIATION		X		X	X	

Source: J. Ogden, presented at Transitioning the Transportation Sector: Exploring the Intersection of Hydrogen Fuel Cell and Natural Gas Vehicles, September 9, 2014.

Will Markets for H2 & NG Vehicles segment?

- "Vehicle choice for **commercial applications**, (e.g. freight trucks & delivery vans) is driven by economics and business needs. These businesses are already on a path towards broad use of NG for trucks & vans.
- "In contrast, automakers expect that H2 fuel cell electric vehicles (FCEVs) will be adopted more broadly for **personal transportation**.
- "While there may be overlap in selected niches, such as buses or light duty fleet vehicles, current market and manufacturer

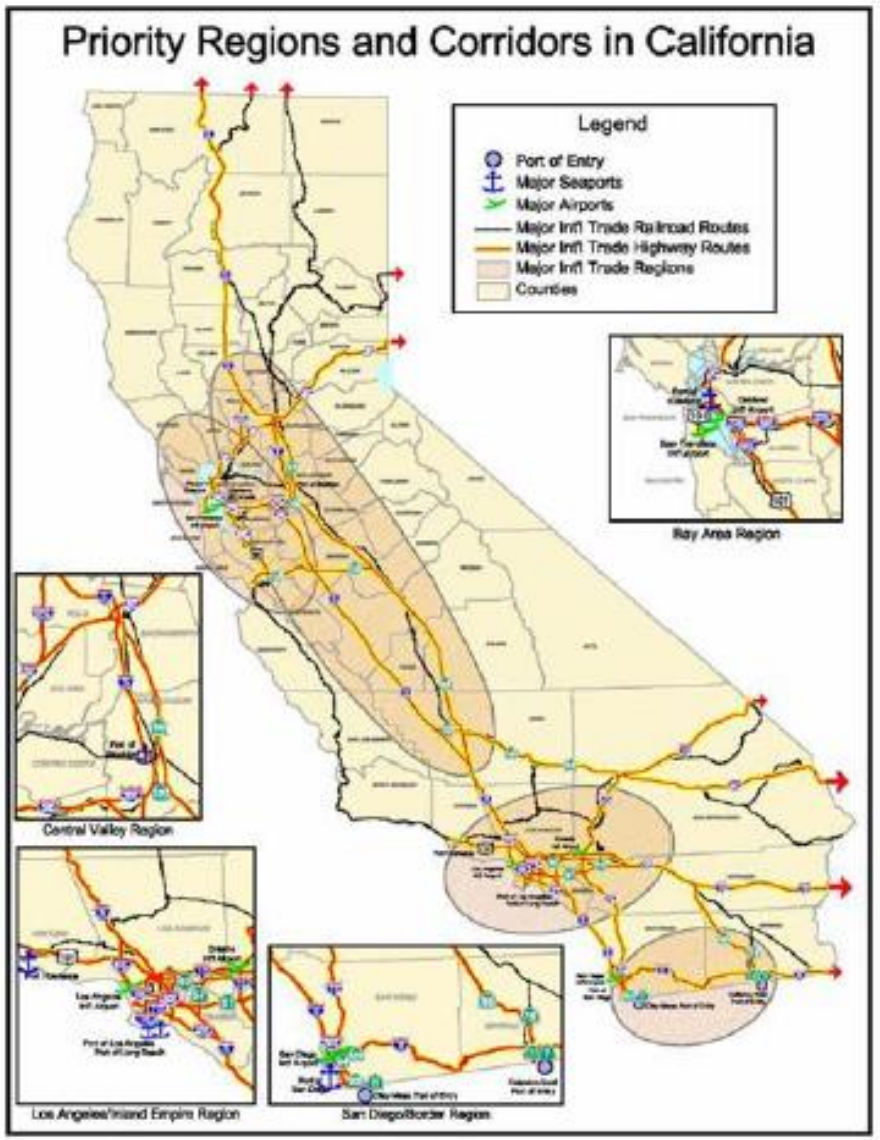
Source: Final Report Transitioning the Transportation Sector: Exploring the Intersection of Hydrogen Fuel Cell and Natural Gas Vehicles, September 9, 2014. American Gas Association, 400 N. Capitol St., NW, Washington, DC 20001. Organized in partnership by Sandia National Laboratories, AGA and Toyota, in support of the U.S. Department of Energy. http://energy.gov/sites/prod/files/2015/02/f19/2015-01_H2NG-Report-FINAL.pdf

Recent interest: H2 FC Medium &Heavy Dutv trucks in CA

Focus on

- Medium-Duty FCET platform: Class 4-6 last-mile package delivery trucks
- Heavy-Duty FCET platform: Class 7-8 short haul/drayage trucks (ports)

California Fuel Cell Partnership, *Medium- & Heavy-duty Fuel Cell Electric Truck Action Plan For California*
http://cafcp.org/sites/default/files/MD-HD_FCET-AP-Webinar-Nov-8-2016.pdf



How much of the natural gas refueling system could be used or adapted for hydrogen?

- Which hardware components of natural gas pathways (e.g. storage, pipelines, delivery trucks, compressors) might be compatible with H2 use?
- Would it make sense to “overbuild” natural gas infrastructure components (e,g, storage tanks or pipelines) to enable future compatibility with hydrogen?

FUEL SUPPLY PATHWAYS FOR NG & H2 (FROM NG)

NG PATHWAYS

- **CNG (NG pipeline delivery)**
- **LNG (LNG truck delivery)**
- **onsite LNG (NG pipeline delivery)**

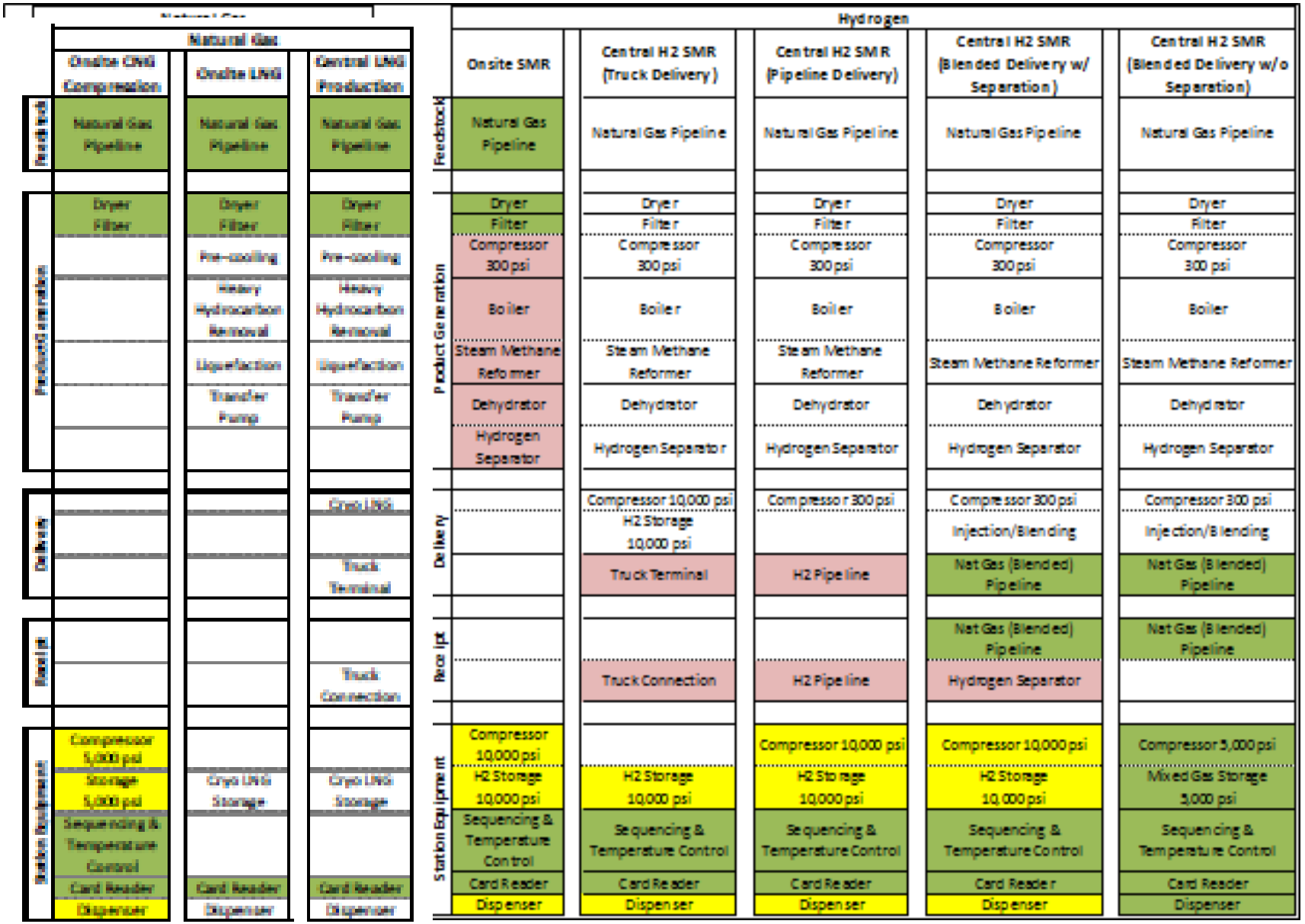
H2 PATHWAYS (H2 from NG)

- **On-site H2 via SMR (NG pipeline delivery to H2 station)**
- **central H2 via SMR (H2 Truck delivery)**
- **central H2 via SMR (H2 Pipeline delivery)**

NG/H2 BLEND

- **central H2 via SMR (NG pipeline, w/H2**

Supply chain overlap for NG & H2



Analyze NG & H2 Supply Pathways w/Potential Overlap

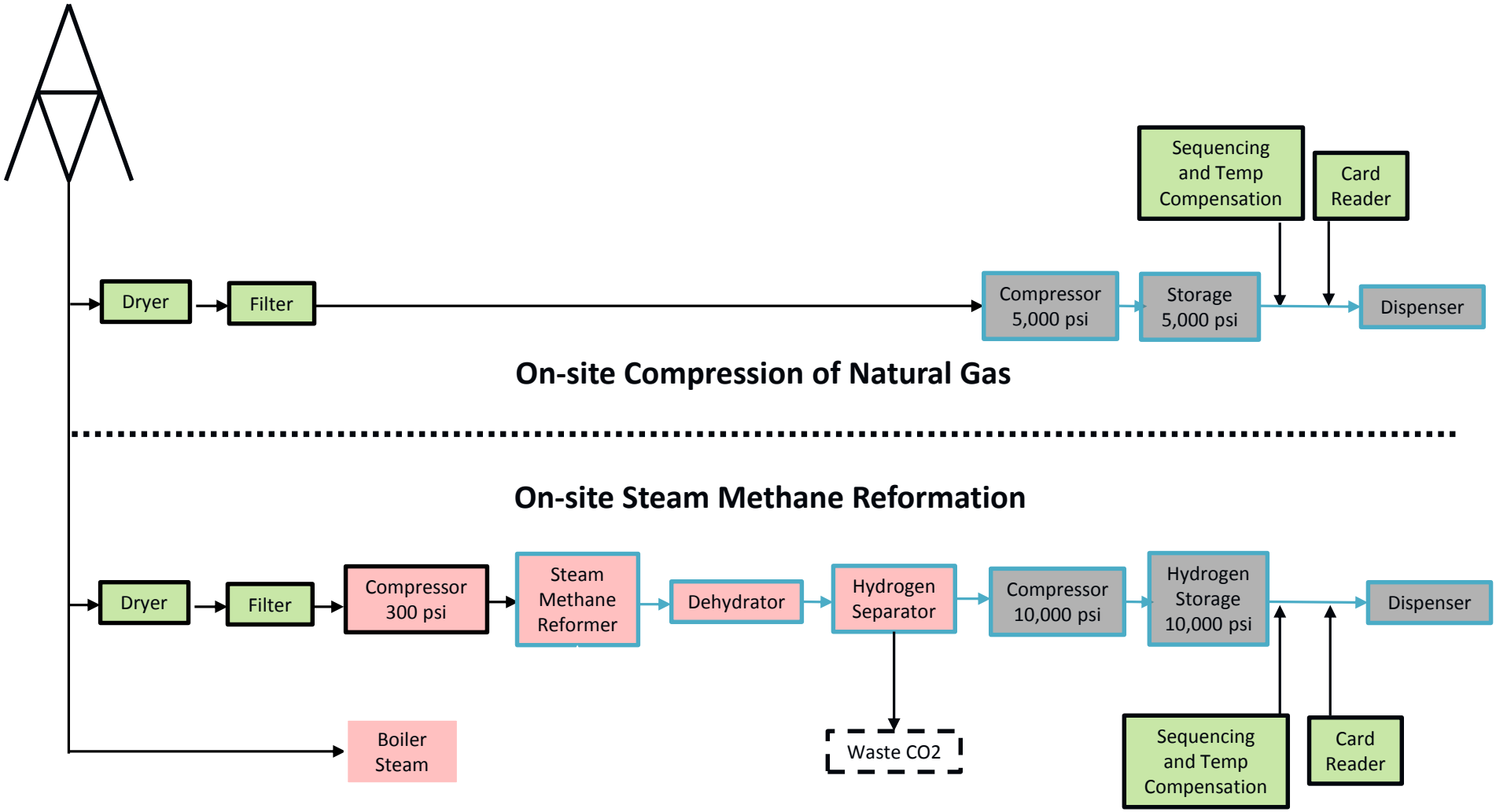
NG PATHWAYS

- **CNG (NG pipeline delivery)**
- LNG (LNG truck delivery) LNG storage not readily
- onsite LNG (NG pipeline delivery) adaptable to H2

H2 PATHWAYS (H2 from NG)

- **On-site H2 via SMR (NG pipeline delivery to H2 sta.)**
- central H2 via SMR (H2 Truck delivery) no overlap w/

Station Equipment: CNG v. Onsite H2 Production (SMR)



Potential Benefits of Blending H2 into NG

- Reduce GHG emissions ("green" NG by blending in renewable H2)
- Begin transition from NG to H2 by offering NG-H_2 mix
- Lower H2 transition cost by utilizing existing NG pipeline infrastructure to:
  - distribute H2 (as part of blend)
  - "store" H2, reducing need for external H2 storage tanks

Questions: Blending H2 into NG

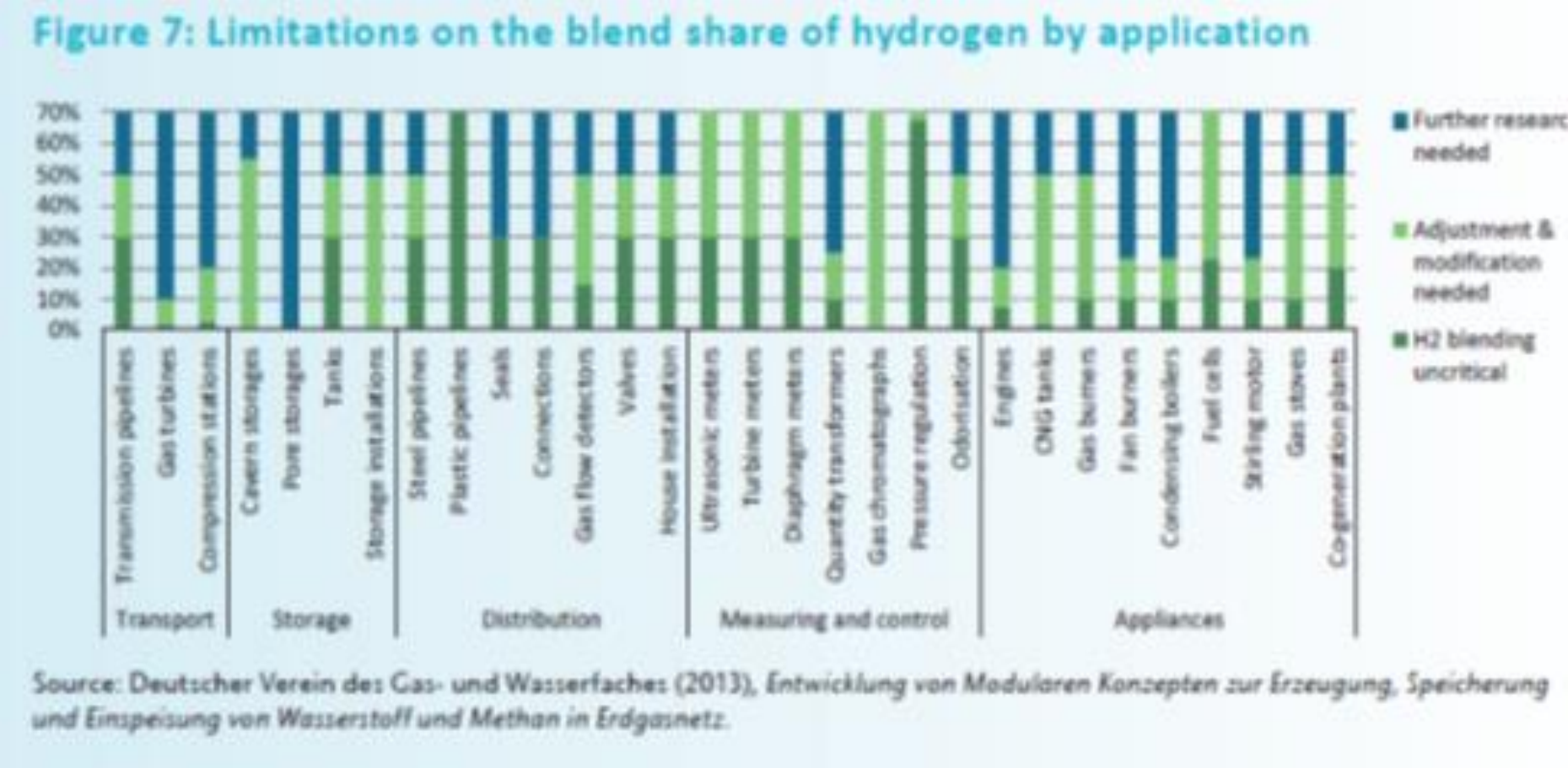
- How will adding H2 affect
  - integrity & safety of the natural gas delivery system?
  - Energy flow rate?
  - System cost?
  - Operation & safety of end-use systems designed for NG?
- What are potential greenhouse gas benefits of blending “green hydrogen” with natural gas?

H2/NG Blends in NG system: Safety & compatibility

- Blending at low conc. (<5%–15% H2 by vol.), appears viable w/o significant increase in end-use risks, overall public safety, or durability and integrity of existing NG pipeline network.
- Appropriate blend concentration may vary significantly between pipeline networks and NG compositions, and therefore must be assessed on case-by-case basis.
- Introduction of a H2 blend would require extensive study, testing & modifications to existing pipeline monitoring and maintenance practices.
- Additional costs must be weighed vs. benefit of providing more sustainable and low-carbon gas.

*Source: M. W. Melaina, O. Antonia, and M. Penev, "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues," Technical Report NREL/TP-5600-51995, March 2013. http://www.nrel.gov/docs/fy13osti/51995.pdf

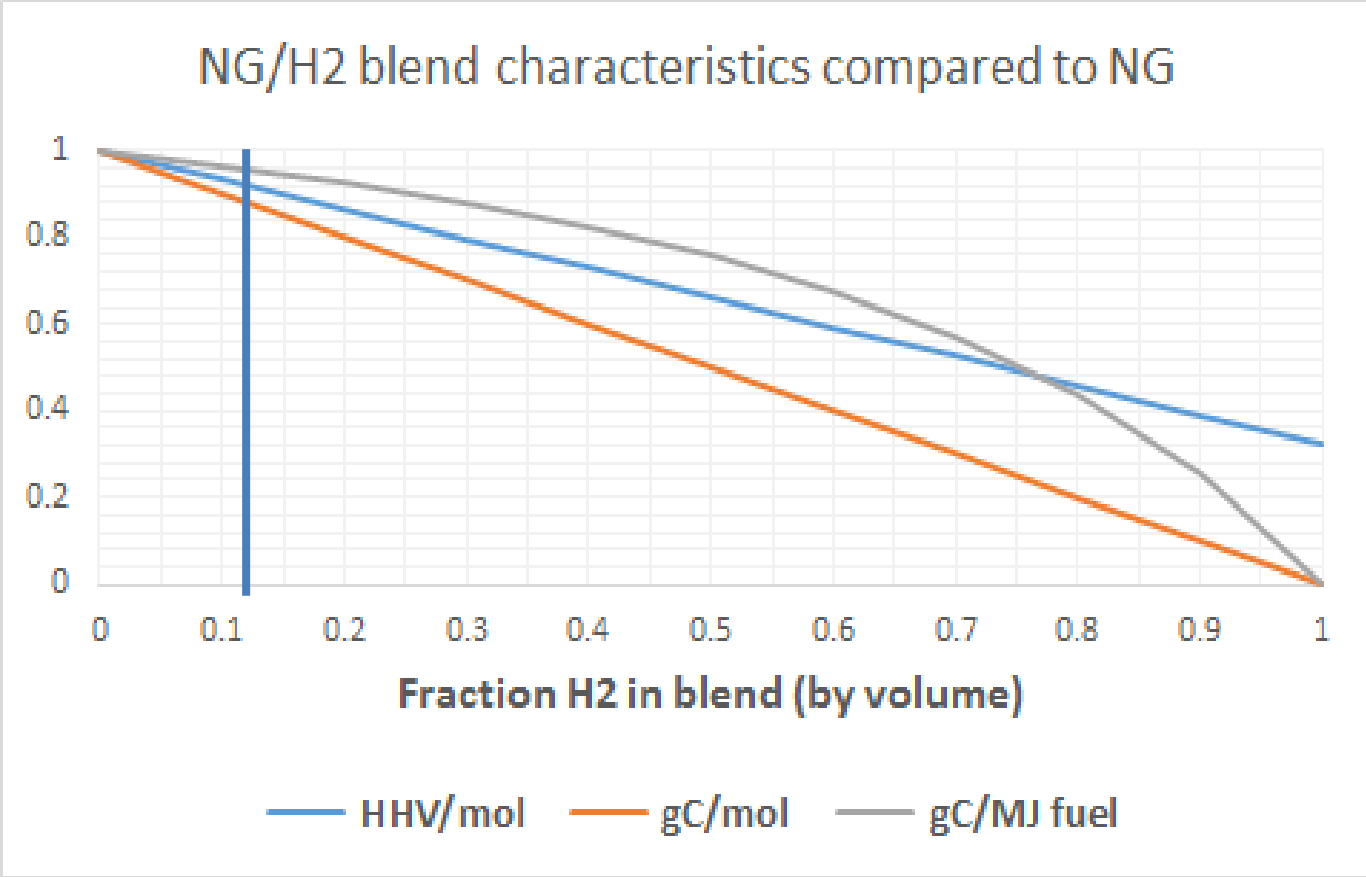
Limits on H2 Blend Share Vary Widely By Application



Source: Deutscher Verein des Gas- und Wasserfaches (2013), *Entwicklung von Modularen Konzepten zur Erzeugung, Speicherung und Einspeisung von Wasserstoff und Methan in Erdgasnetz.*

CURRENT EUROPEAN LIMITS FOR ALLOWABLE FRACTIONS OF H2 IN NG SYSTEM VARY FROM 0.1-12% BY VOLUME

Blending Renewable H2 w/NG: Carbon

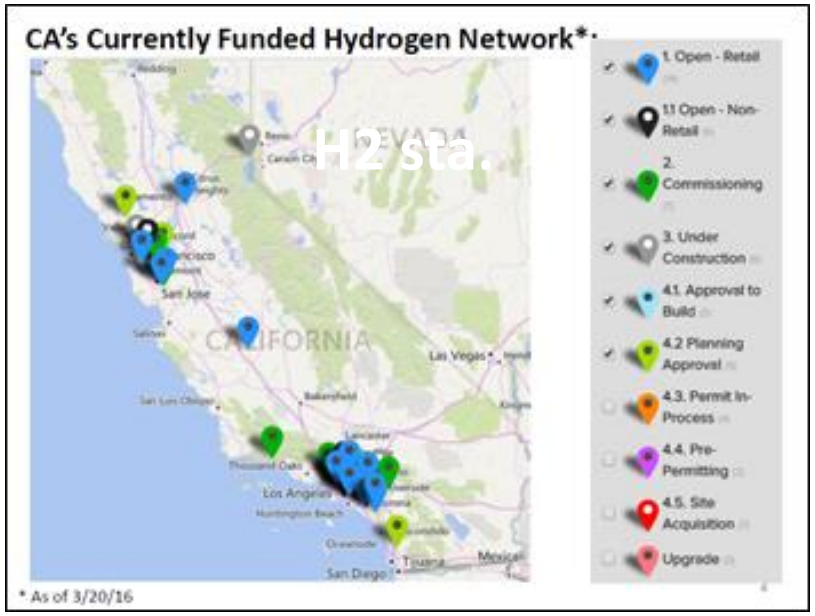


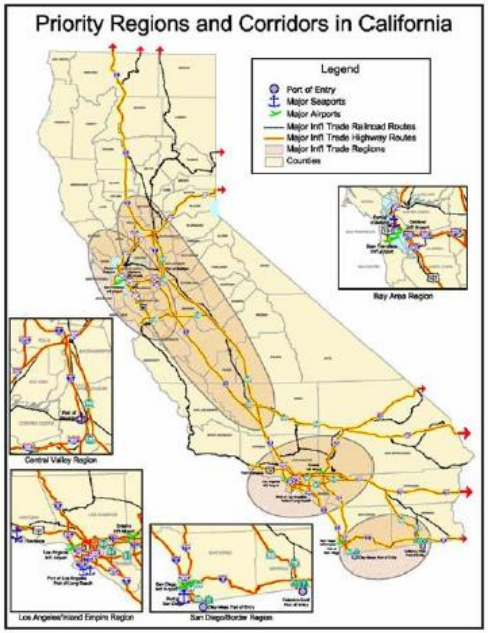
Add 15% zero-C

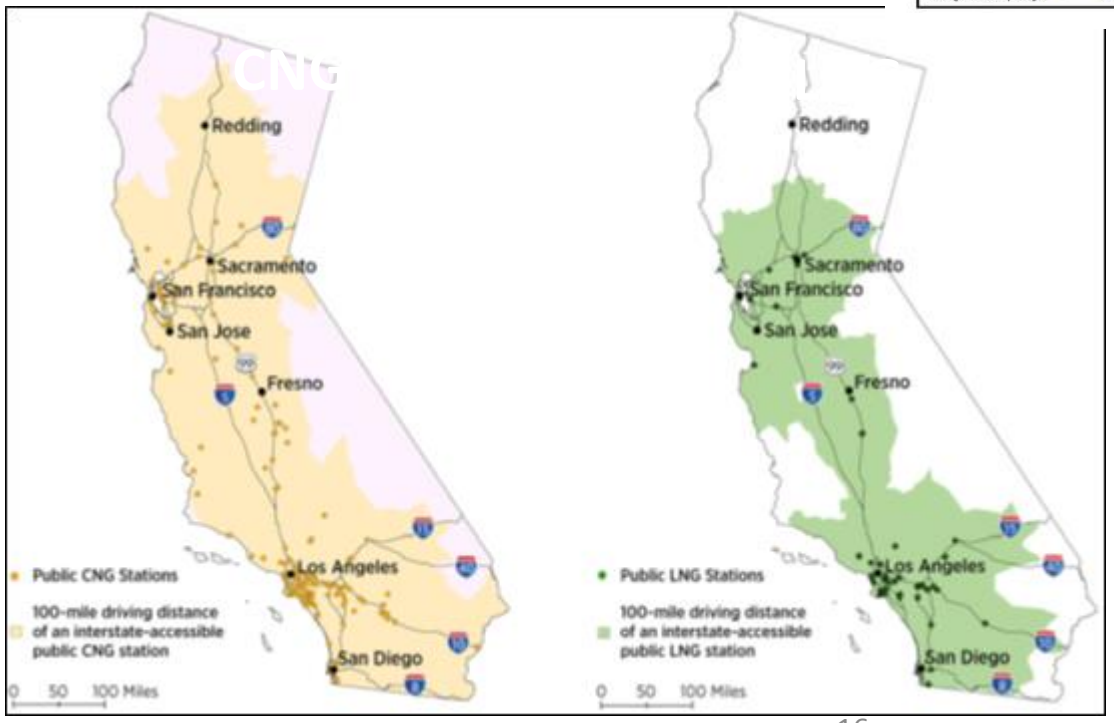
to NG, reduces

- gC/mol **15%**
- HHV/mol **10%**
- gC/MJ fuel **5%**

Combusting NG/H2 blend as direct NG replacement might not offer large C reduction,


CA's Currently Funded Hydrogen Network*
H2 sta.
1. Open - Retail
1.1 Open - Non-Retail
2. Commissioning
3. Under Construction
4.1. Approval to Build
4.2 Planning Approval
4.3. Permit In-Process
4.4. Pre-Permitting
4.5. Site Acquisition
Upgrade
San Jose
San Francisco
Los Angeles
San Diego
Las Vegas
* As of 3/20/16


Priority Regions and Corridors in California
Legend
Port of Entry
Major Seaports
Major Airports
Major Int'l Trade Railroad Routes
Major Int'l Trade Highway Routes
Major Int'l Trade Regions
Counties
Bay Area Region
Central Valley Region
Los Angeles/Inland Empire Region
San Diego/Border Region


CNG
Redding
Sacramento
San Francisco
San Jose
Fresno
Los Angeles
San Diego
Public CNG Stations
100-mile driving distance of an interstate-accessible public CNG station
0 50 100 Miles
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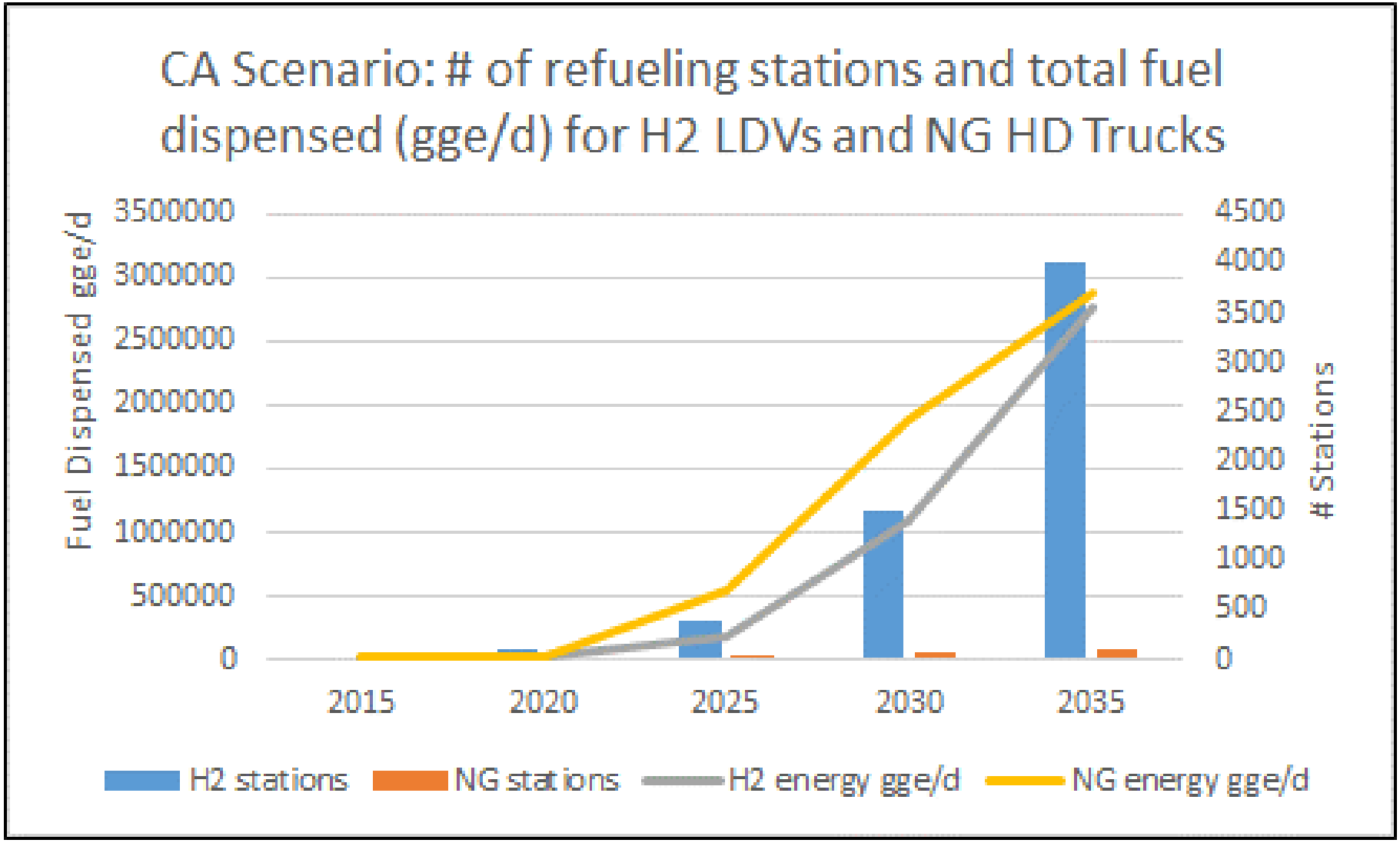
CA Scenario: # of refueling stations and total fuel dispensed (gge/d) for H2 LDVs and NG HD Trucks
Fuel Dispensed gge/d
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
Stations
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2015
2020
2025
2030
2035
H2 stations
NG stations
H2 energy gge/d
NG energy gge/d

Future Research

- Develop regional scenarios for buildout of NGV and H2 infrastructures.
  - How much do they interact?
  - Consider LDVs, buses, MD and HD trucks
- How do NG and H2 compare wrt long-term climate, energy security and other sustainability goals?
- Role of power to gas, energy storage, incorporation of renewable energy

References

- 2014 Hydrogen Technical Advisory Committee Annual Report to the US Dept of Energy (USDOE). http://www.hydrogen.energy.gov/htac_reports.html
- California Air Resources Board, "2015 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Deployment" July 2015. http://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2015.pdf .
- California Fuel Cell Partnership, Medium- & Heavy-duty Fuel Cell Electric Truck Action Plan For California http://cafcp.org/sites/default/files/MD-HD_FCET-AP-Webinar-Nov-8-2016.pdf
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- USDOE "Final Report: Transitioning the Transportation Sector: Exploring the Intersection of Hydrogen Fuel Cell and Natural Gas Vehicles," September 9, 2014. http://energy.gov/sites/prod/files/2015/02/f19/2015-01_H2NG-Report-FINAL.pdf

Thank you!