Synergies: H2 & NG as Transport Fuels
Recent Insights & Research Questions

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QUESTIONS FOR NG AND H2 IN TRANSPORTATION

- What are likely roles/economics of NG and H2 in various transport applications?
- What's needed to launch H2 and NG as transport fuels?
- Is NG a "Bridge" to H2?
  - Can H2 infrastructure "grow" out of NG infrastructure?
- How do NG and H2 compare wrt long-term climate, energy security and other sustainability goals?

TRANSPORTATION APPLICATIONS for NG and H2 (incl. NG-derived fuels and electricity)

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.

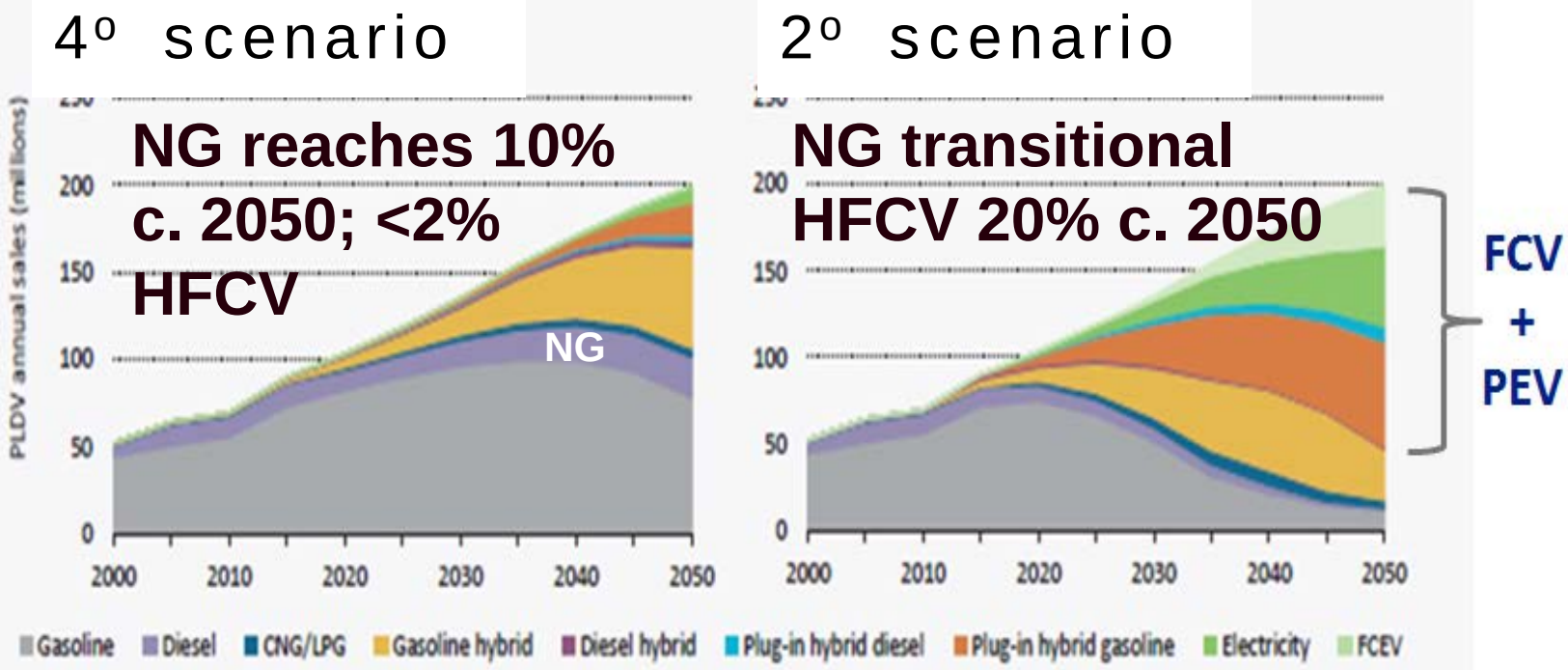
Markets for H2 & NG Vehicles will naturally segment

- "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 signals indicate that H2 and NG will likely segment into different transportation application areas."

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

LIGHT DUTY VEH: ROLE OF NG, H2 IN DEPENDS ON LONG TERM CARBON GOALS (4º & 2º scenarios-IEA)

Figure 13.18 Global portfolio of technologies for passenger LDVs



Key point *In the Improve case, electric, PHEV and FCEVs together account for nearly three-quarters of new vehicle sales in 2050.*

Source: International Energy Agency, Energy Technology Perspectives, 2012.

Is NG a Bridge to H2? (1)
Technical Synergies

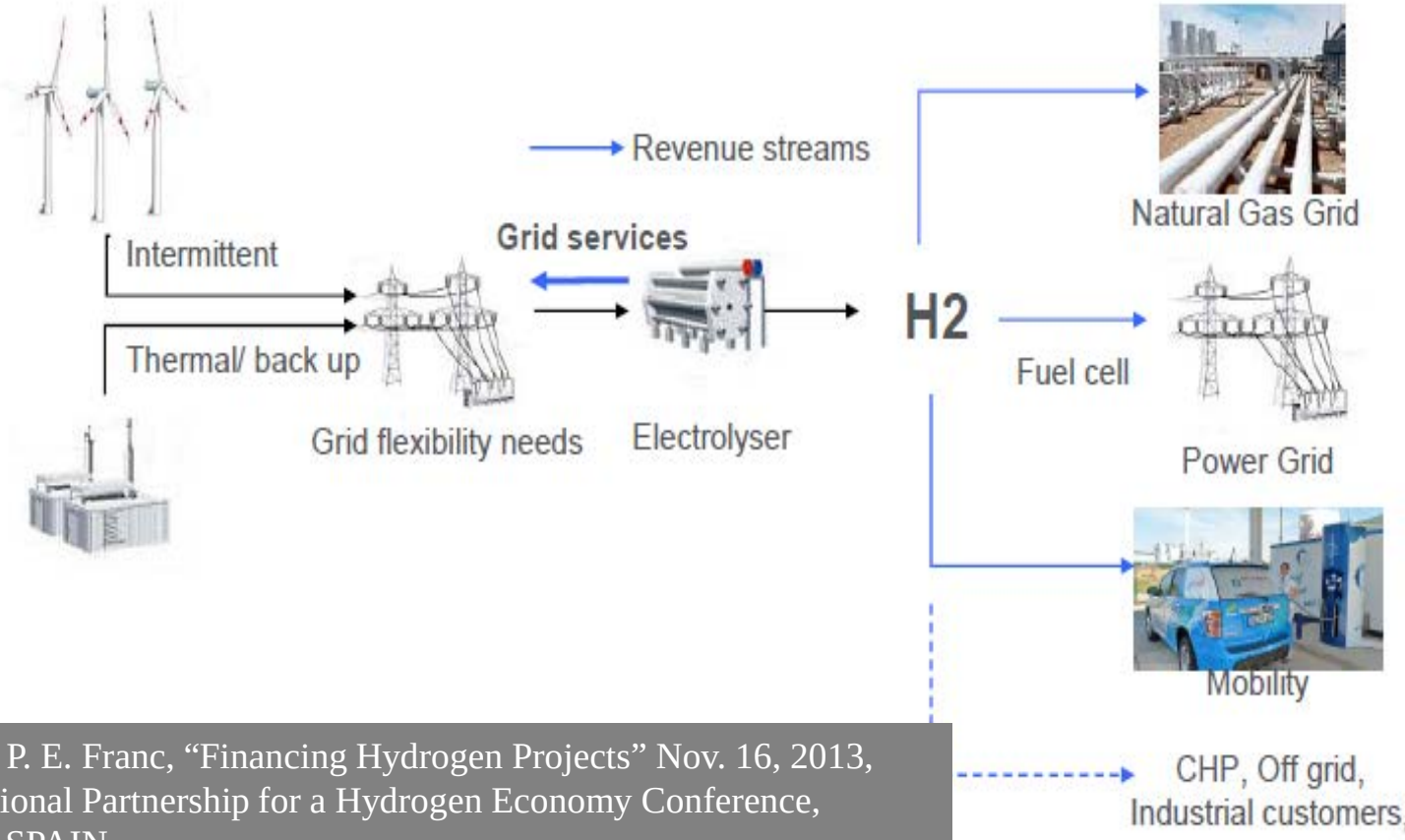
H2 and NG have some physical similarities. Both can be stored as compressed gas or cryogenic liquids.

“Starting from common standards and equipment may enable synergistic development of both hydrogen and natural gas.”*

*Source: 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

Studies => H2 Long Term Potential: Flexible Storage for Renewable Electricity

Versatility of Hydrogen is a key advantage for energy storage



Source: P. E. Franc, "Financing Hydrogen Projects" Nov. 16, 2013, International Partnership for a Hydrogen Economy Conference, Seville, SPAIN

Is NG a Bridge to H2? (2)
H2/NG Blends and "Power to Gas"

Over 30 "Power to gas" projects in Europe. Interest in storing intermittent renewable electricity as H2 (e.g. wind farms).

Blending H2 into NG pipelines offers a way of bringing H2 into the energy system.

If renewable H2 is blended in => Lower Carbon Emissions for Natural 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

Is NG a Bridge to H2? (3)
Tech issues for H2/NG Blends -> NG system

- Blending relatively low concentrations (<5%–15% H2 by volume), appears viable without significantly increasing risks of using the gas blend in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing NG pipeline network.
- The appropriate blend concentration may vary significantly between pipeline network systems and natural gas compositions and must therefore be assessed on a case-by-case basis.
- Any introduction of a H2 blend concentration would require extensive study, testing, and modifications to existing pipeline monitoring and maintenance practices (e.g., integrity management systems).
- Additional costs must be weighed against the benefit of providing a more sustainable and low-carbon gas product to consumers.

*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

Is NG a Bridge to H2? (4)
Can NGV Infrastructure Help Launch H2 FCVs?

- NGV infrastructure serves trucks and LDV fleets.
  - NG corridors for long distance trucks + urban fleets
- H2 infrastructure will likely serve passenger FC cars.
  - Current H2 station rollout plans built on regional "cluster strategy": ex: CA first 100 H2 sta. in urban early adopter areas + key inter-urban "connector" stations.
  - Initial H2 supply via compressed gas or LH2 truck. (SMRs economic at larger sta size, later.)
- NG truck stations may be located in different places than early H2 stations.
- Infrastructure location may be driven by different factors, timing for each fuel/market.

Is NG a Bridge to H2? (5)
NG + H2 Fueling = New Business Opportunity?

Add H2 sta to NGV stations? "Co-location of H2 and NG fueling stations would create new business opportunities."* Further analysis needed to understand these possibilities.

Tri-generation (co-production of Electricity, Heat and H2 from NG) improves system economics by offering 3 high value co-products.** (Maybe even 4 co-products counting NG fuel for NGVs?)

*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

** Li, Xuping, Joan M. Ogden, and Christopher Yang. 2013. *Analysis of the Design and Economics of Molten Carbonate Fuel Cell Tri-generation Systems Providing Heat and Power for Commercial Buildings and H2 for FC Vehicles.* Journal of Power Sources, pp. 668-679. DOI information: 10.1016/j.jpowsour.2013.04.068

Research Questions

- Develop regional scenarios for development of NGV and H2 infrastructures.
  - How much do they interact?
- What are economic opportunities for
  - co-locating NG and H2 stations?
  - tri-generation systems?
  - Power to gas; H2 storage
- How do NG and H2 compare wrt long-term climate, energy security and other sustainability goals?
- Near term and long term roles for NG and H2 in transportation?

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 .
- Li, Xuping, Joan M. Ogden, and Christopher Yang. 2013. *Analysis of the Design and Economics of Molten Carbonate Fuel Cell Tri-generation Systems Providing Heat and Power for Commercial Buildings and H2 for FC Vehicles.* Journal of Power Sources, pp. 668-679. DOI information: 10.1016/j.jpowsour.2013.04.068
- 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
- Ogden, Joan M., Christopher Yang, Michael A. Nicholas, Lewis Fulton. 2014. *NextSTEPS White Paper: The Hydrogen Transition.* Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-14-11. http://www.its.ucdavis.edu/research/publications/publication-detail/?pub_id=2312
- 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