Prospects for H_2 in the Future Energy System

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Presented at the
Hydrogen Economy Workshop
Sponsored by Shell and the Energy Bioscience Institute, University of California, Berkeley
May 13-14, 2020

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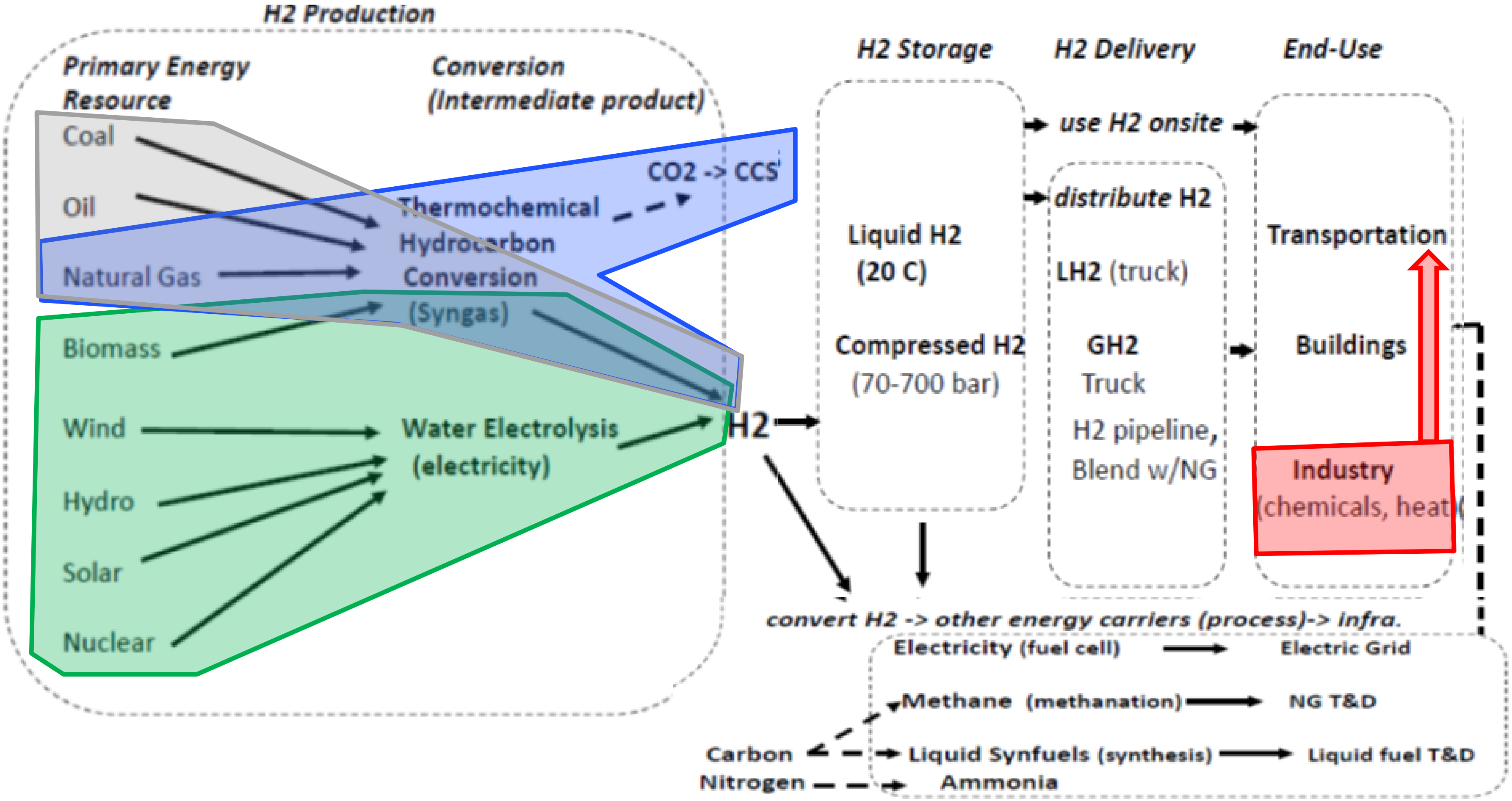
Potential Pathways for H_2 in the Energy System



Source: Ogden, Joan M. (2018) Prospects for Hydrogen in the Future Energy System. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-18-07. https://its.ucdavis.edu/research/publications/

CONTEXT: motivation for expanding use of Hydrogen

- **Potential Benefits of H2**
  - Flexible Energy Carrier that can be used efficiently and cleanly for transport, power, heating and industry
  - H2 can be produced from diverse primary resources including very low carbon pathways: H2 from NG w/CCS (blue H2) and renewable (green) H2
  - Climate: Deep Reduction of GHG emissions
  - Health: Deep Reduction of air pollutant emissions
- **Integration of low carbon sources within energy system/infrastructure**
  - Complementarity of H2 and electricity
    - Integration of renewables (electrolytic H2 from curtailed power)
    - H2 as energy storage (long term or seasonal)
    - Power to X (H2 as fuel or feedstock)
  - H2 in NG grid (H2/NG blends)
  - H2 from NG w/CCS
- **H2 Enables Long term Strategies toward zero emission energy**

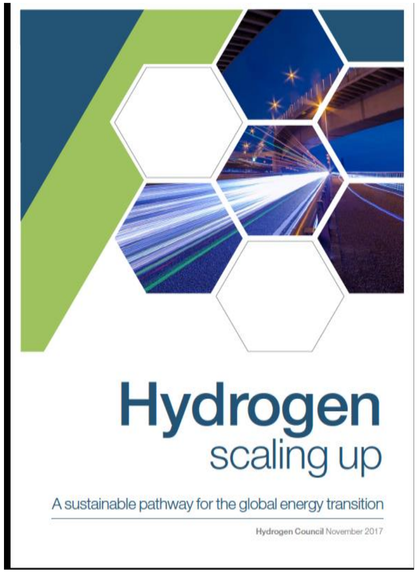
Recent Studies Assess Promise of H_2 Economy

Hydrogen Economy Outlook

Key messages

March 30, 2020

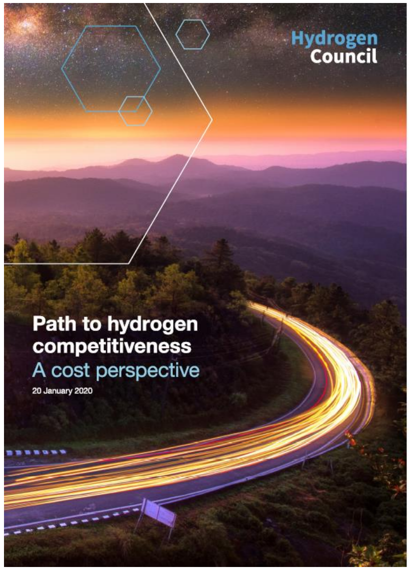
BloombergNEF



Hydrogen scaling up

A sustainable pathway for the global energy transition

Hydrogen Council November 2017

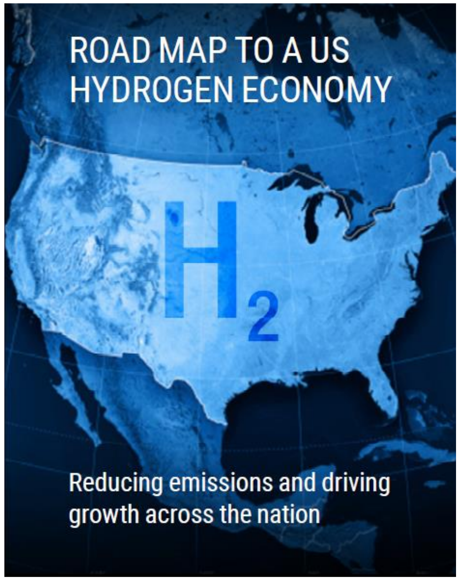


Hydrogen Council

Path to hydrogen competitiveness

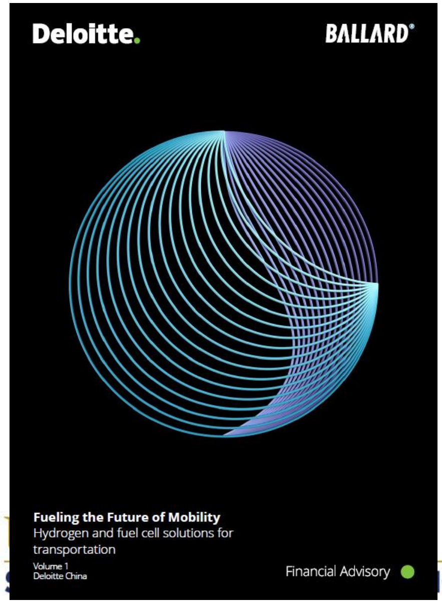
A cost perspective

20 January 2020



ROAD MAP TO A US HYDROGEN ECONOMY

Reducing emissions and driving growth across the nation



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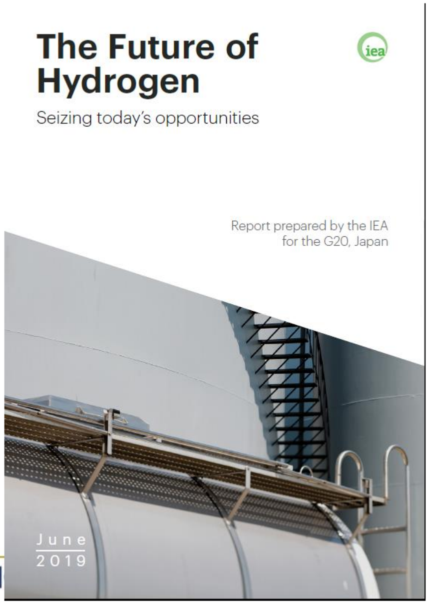


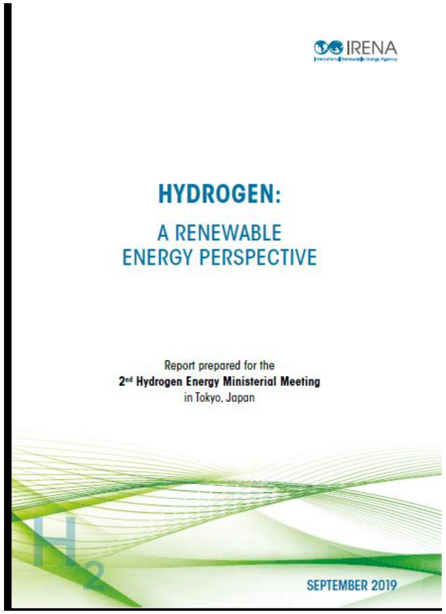
The Future of Hydrogen

Seizing today's opportunities

iea

Report prepared by the IEA for the G20, Japan

June 2019



IRENA

HYDROGEN:

A RENEWABLE ENERGY PERSPECTIVE

Report prepared for the 2nd Hydrogen Energy Ministerial Meeting in Tokyo, Japan

SEPTEMBER 2019

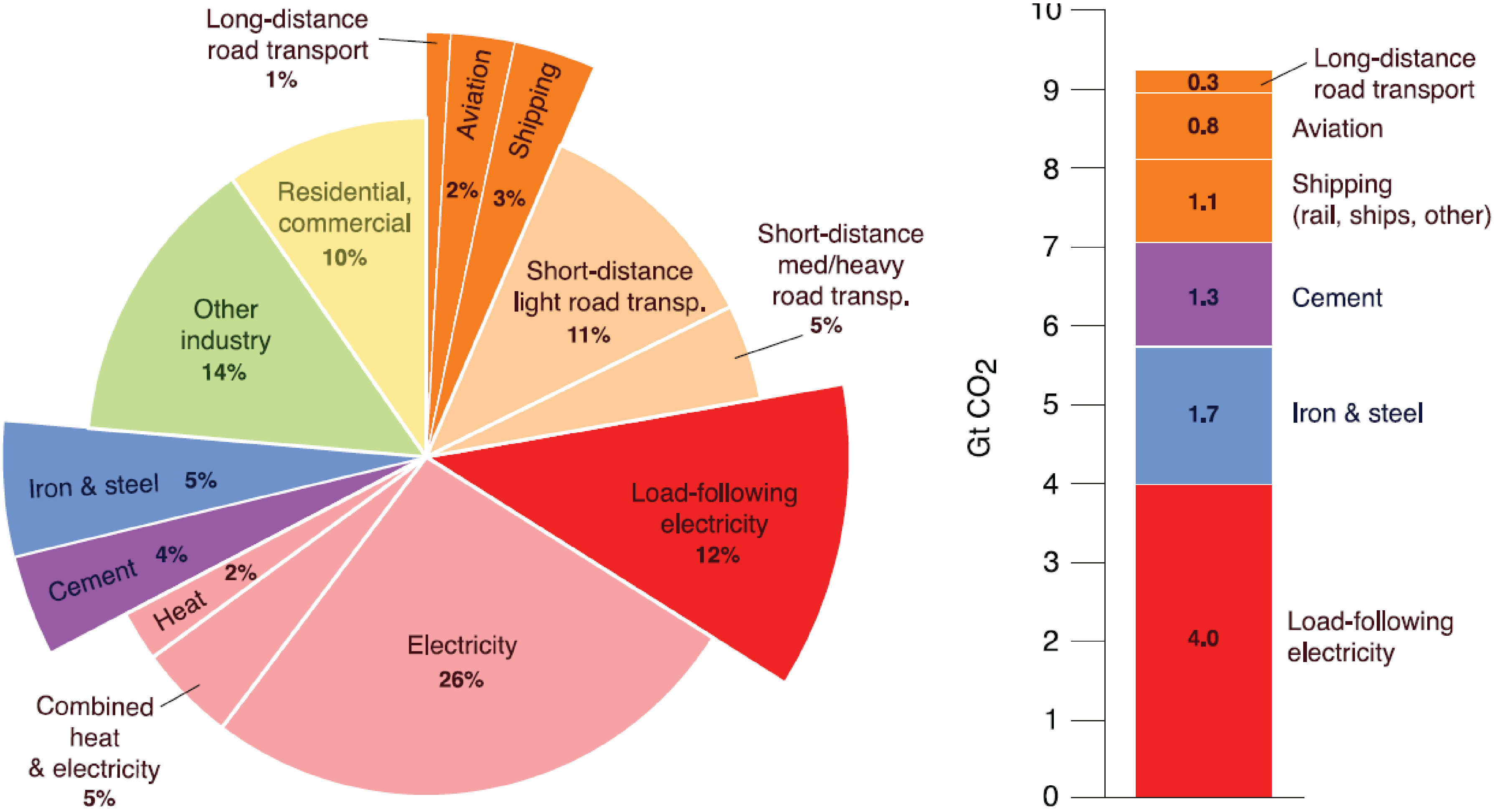
MOVE THE WORLD FORW>RD MITSUBISHI HEAVY INDUSTRIES GROUP

HYDROGEN – POWERING A NET ZERO FUTURE

THE TECHNOLOGIES TO GET US THERE

MITSUBISHI HEAVY INDUSTRIES

Some energy sectors are difficult to decarbonize (~27% of GHG)
H_2 could play a major role in many of these.



A Global fossil fuel & industry emissions, 2014 (33.9 Gt CO_2)

B Difficult-to-eliminate emissions, 2014 (9.2 Gt CO_2)

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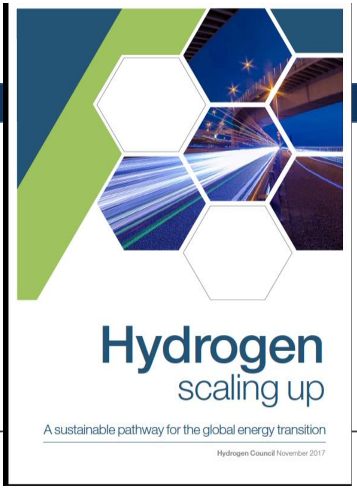
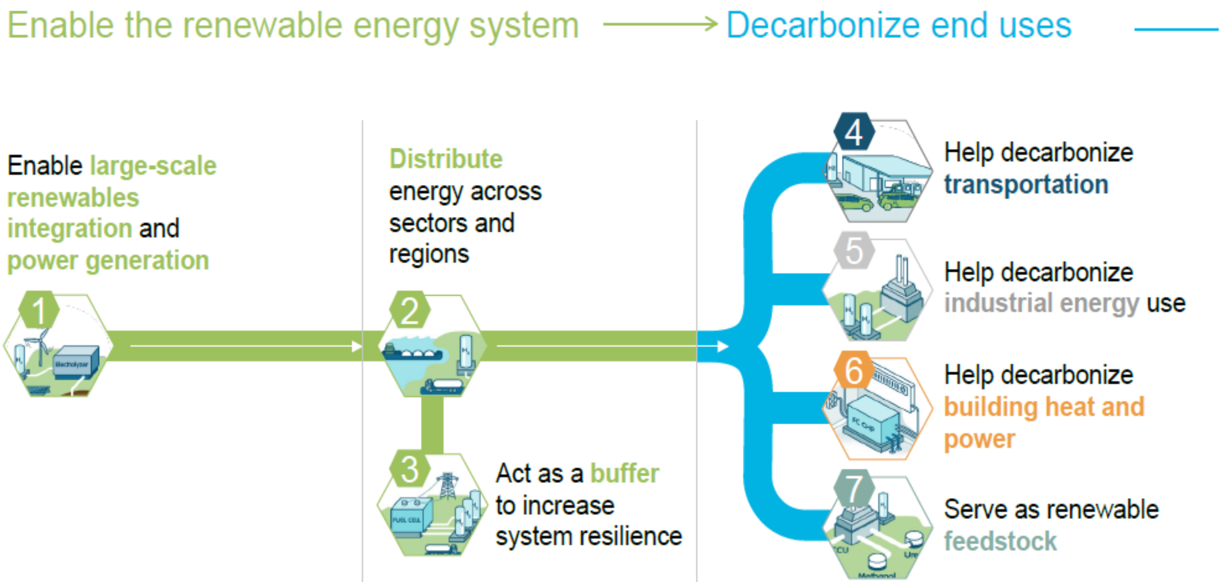
Hydrogen Council: Hydrogen Scaling Up



Hydrogen
scaling up
A sustainable pathway for the global energy transition
Hydrogen Council November 2017

H2 can play major roles in deep decarbonization:



Enable the renewable energy system → Decarbonize end uses

1 Enable large-scale renewables integration and power generation

2 Distribute energy across sectors and regions

3 Act as a buffer to increase system resilience

4 Help decarbonize transportation

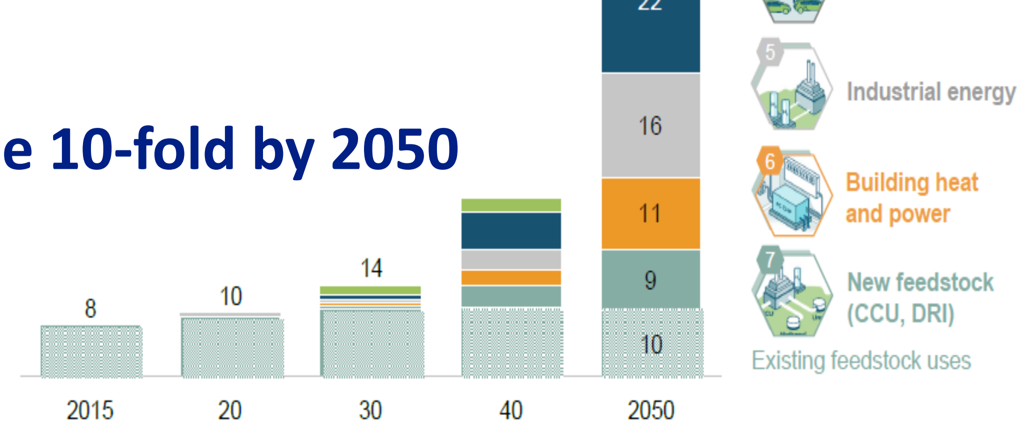
5 Help decarbonize industrial energy use

6 Help decarbonize building heat and power

7 Serve as renewable feedstock

SOURCE: Hydrogen Council

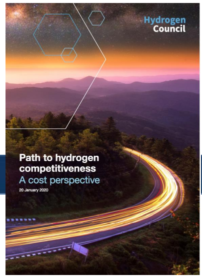
H2 Demand Could Increase 10-fold by 2050



SOURCE: Hydrogen Council

Hydrogen Council, Hydrogen. Scaling Up. 2017. Report. https://hydrogencouncil.com/en/study-hydrogen-scaling-up

Hydrogen Council: H2 Competitiveness



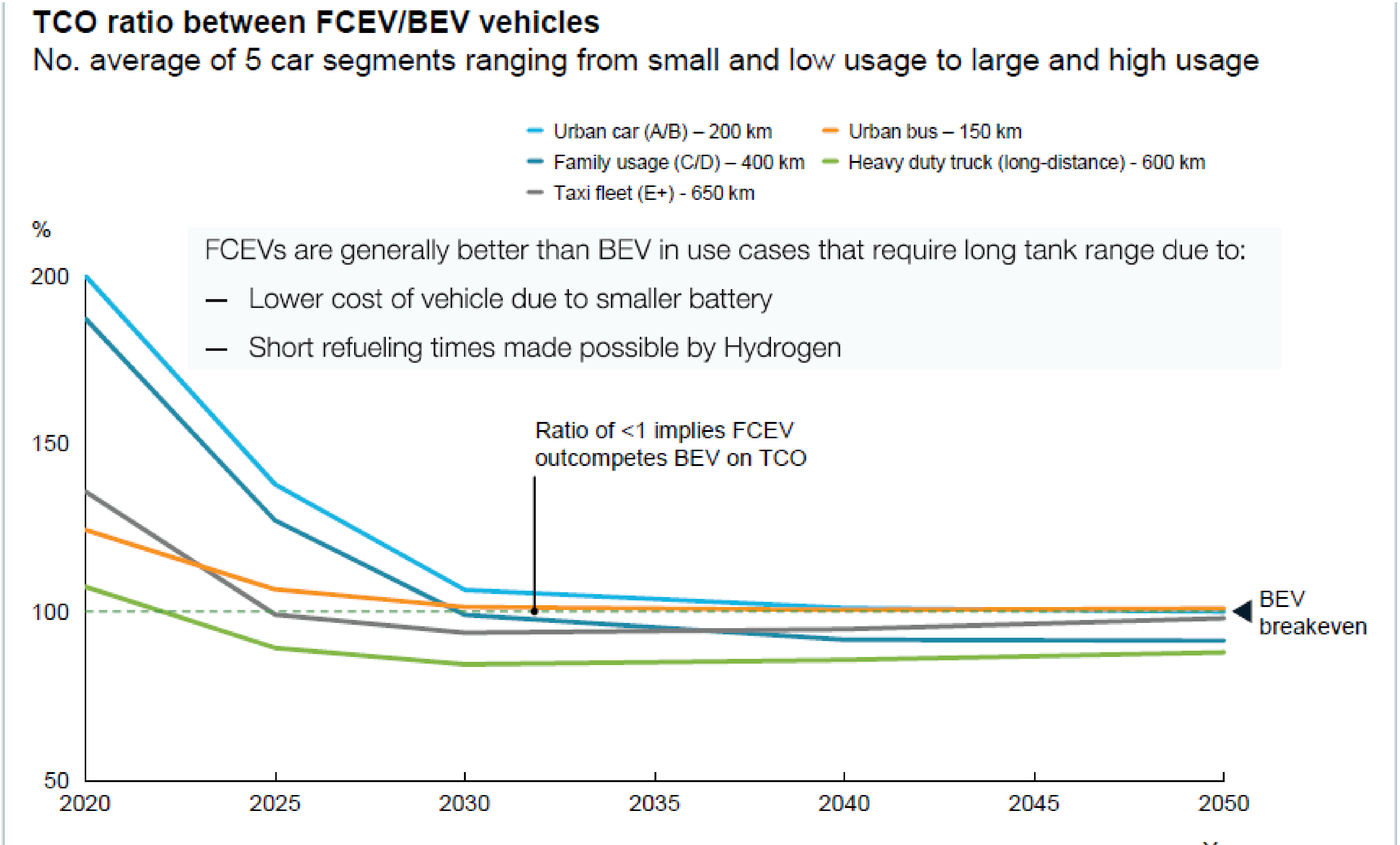
H2 cost competitive for many applications by 2030

- **Commercial vehicles, trains, long-range transport** applications compete w/ low-carbon alternatives d.t. lower equipment and refueling costs
- **H2 boilers** compete w/low-carbon building heating alternatives
- H2 may be only viable option to decarbonize **industrial heating** in some cases
- H2 plays increasing role in **balancing power system**
- Low carbon and renewable H2 become competitive with grey H2 as **industrial feedstock**, as H2 costs fall and carbon prices rise.
- In some cases, low-C or renewable H2 competes with conventional options (**heavy trucks, long-range buses, forklifts**)

Need for policy alignment: level playing field to accelerate scale-up

Hydrogen Council, Path to Hydrogen Competitiveness: A Cost Perspective. 2020. Report.
https://Hydrogencouncil.Com/En/Path-To-Hydrogen-Competitiveness-A-Cost-Perspective

H2 Council: H2 FCEV Competes w/BEV on Total Cost of Ownership for Heavier, Longer Range Vehicles



TCO ratio between FCEV/BEV vehicles

No. average of 5 car segments ranging from small and low usage to large and high usage

FCEVs are generally better than BEV in use cases that require long tank range due to:

- Lower cost of vehicle due to smaller battery
- Short refueling times made possible by Hydrogen

Ratio of <1 implies FCEV outcompetes BEV on TCO

SOURCE: McKinsey Center for Future Mobility

Hydrogen Council, Path to Hydrogen Competitiveness: A Cost Perspective. 2020. Report. https://Hydrogencouncil.Com/En/Path-To-Hydrogen-Competitiveness-A-Cost-Perspective

FCHEA/McKinsey: US H2 Economy Roadmap
H2 demand across sectors in 2030 and 2050

ROAD MAP TO A US HYDROGEN ECONOMY

Reducing emissions and driving growth across the nation

Growing H2 Demand 2015-2050

2015 **2030** **2050**

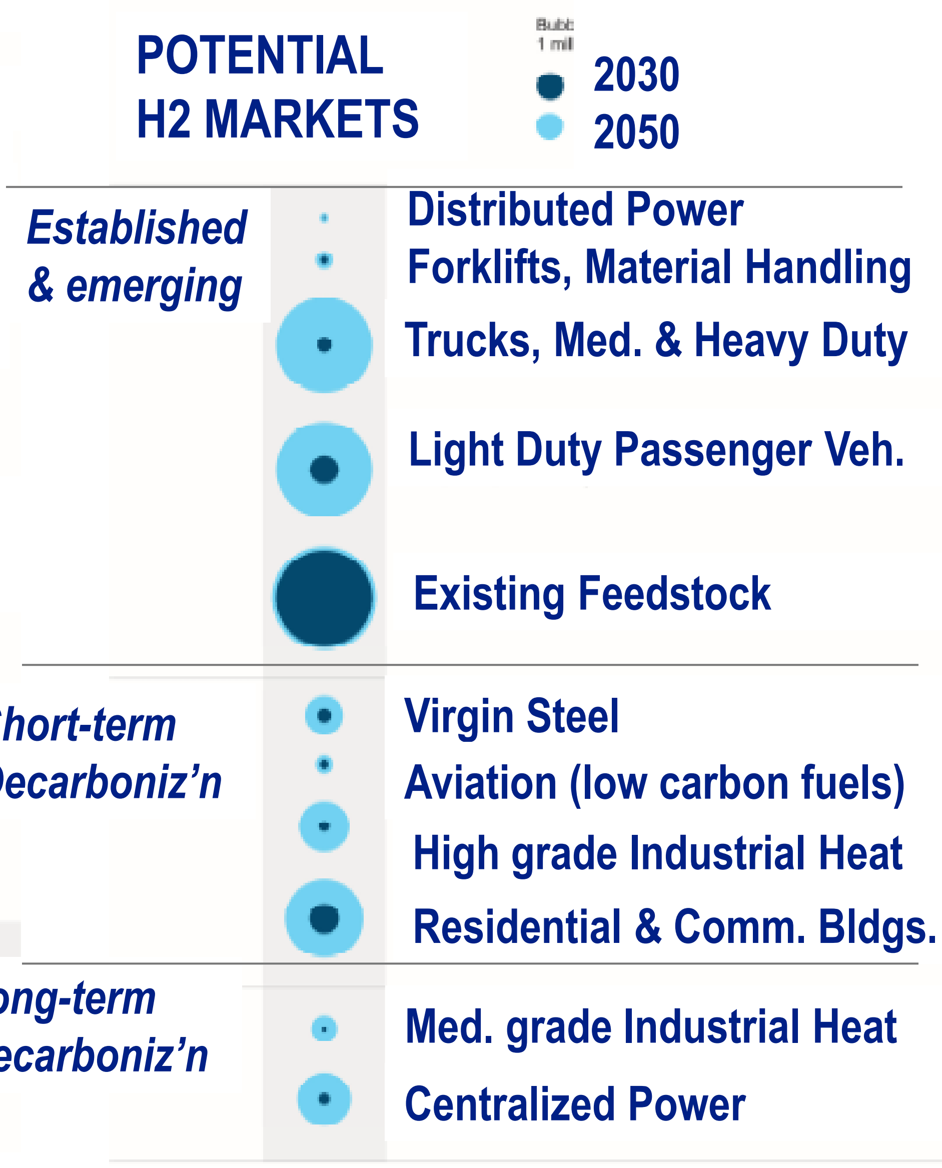
[1] Assuming that 20% of jet fuel demand would be met by synthetic fuel and 20% of marine bunker fuel by ammonia

[2] Demand excluding feedstock, based on IEA final energy demand for the US

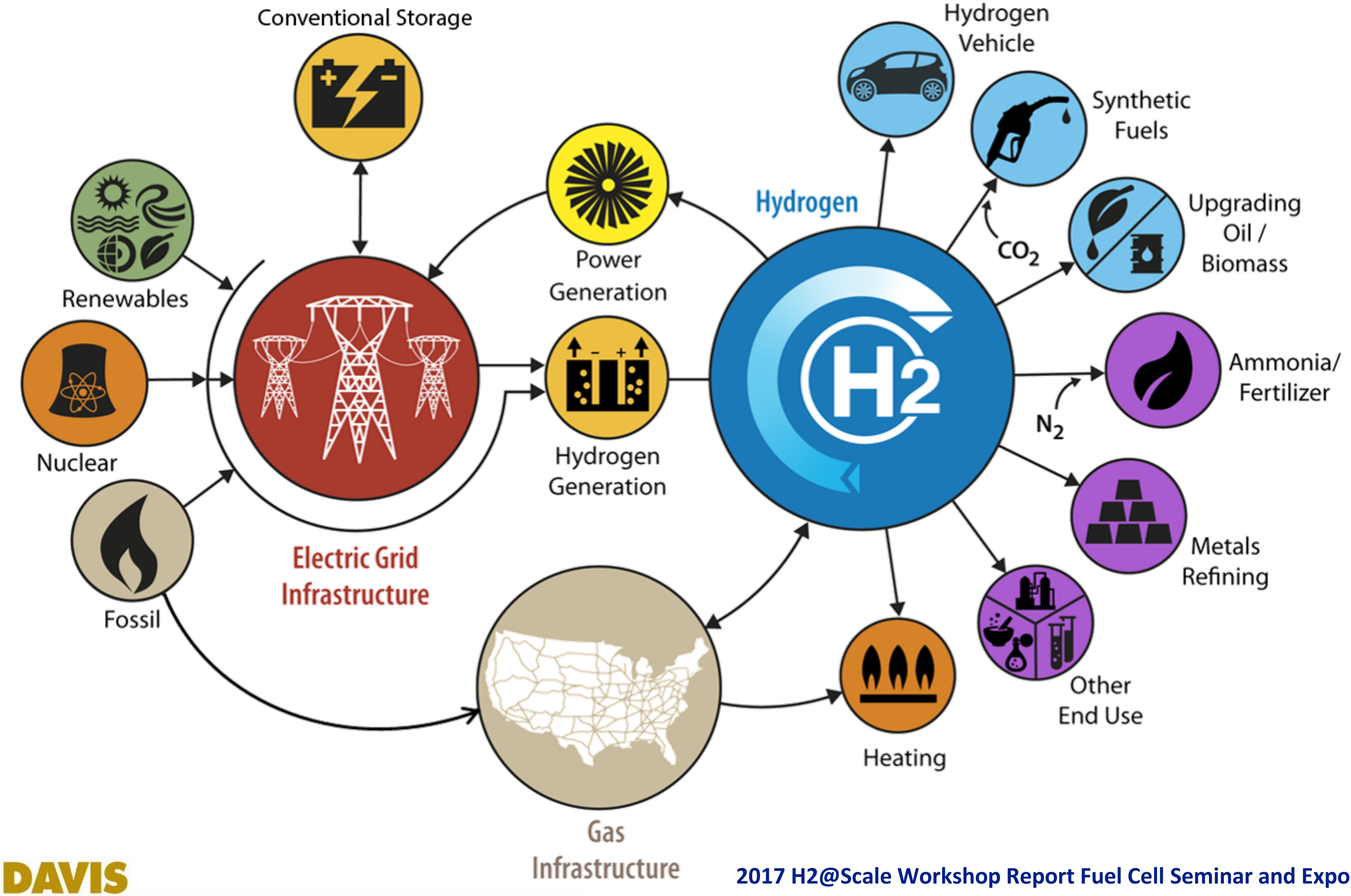
Note: Some numbers may not add up due to rounding

Exhibit 3

There are already many industrial applications in motion that are short-term moves



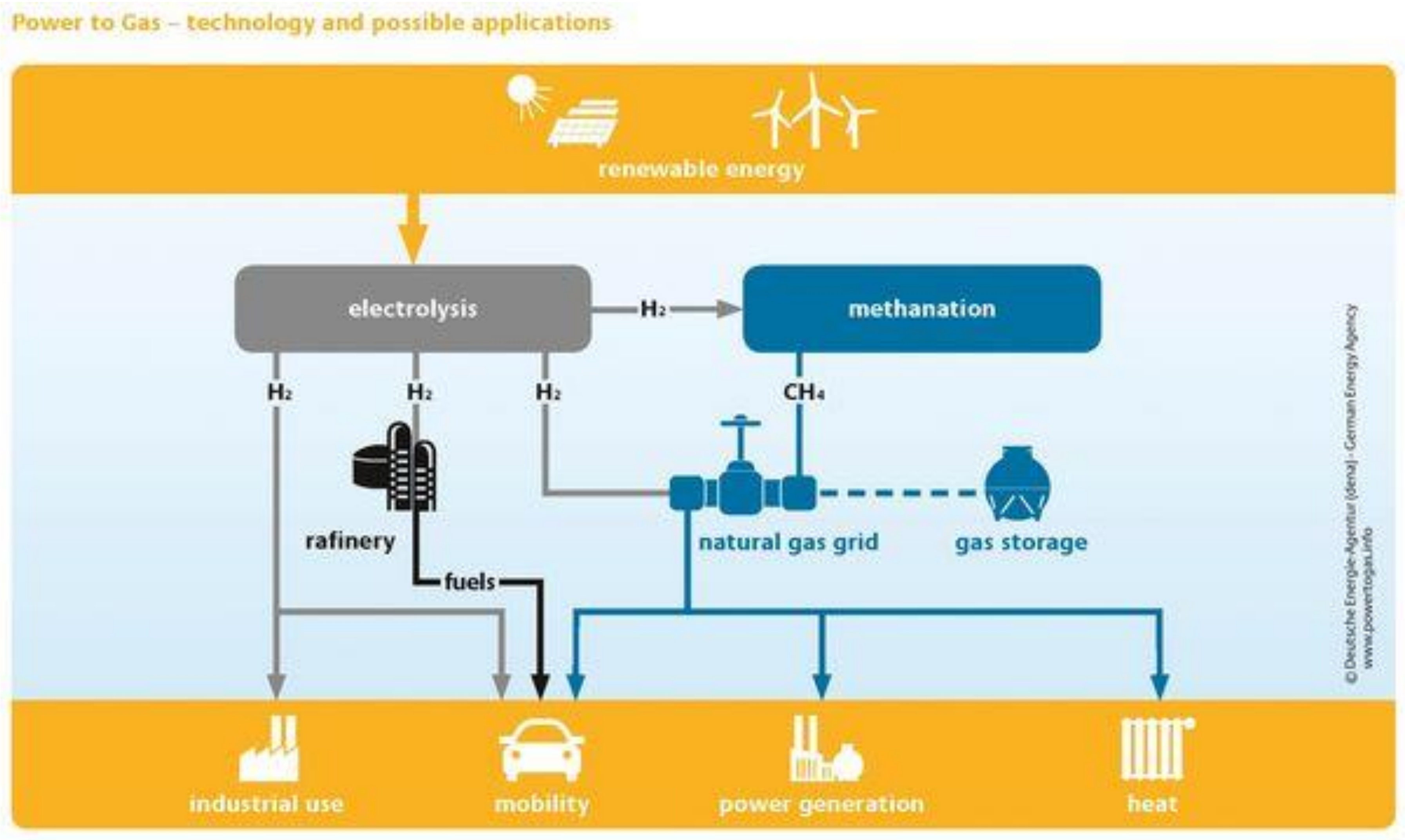
LONG TERM VISION FOR ZERO CARBON ENERGY:
H2@SCALE: Linking Natural Gas, Electric and H2 Grids
How does H2 fit, and how can we make a transition?



UCDAVIS
SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

2017 H2@Scale Workshop Report Fuel Cell Seminar and Exposition
November 7, 2017 Long Beach Convention Center Long Beach, CA

POWER to GAS: key link for elec, NG & H2 infrastructure



SOURCE: E4 The Fuel Cell Industry Review 2018.

Blending H2 into Natural Gas Grid

FEASIBILITY:

- Technically possible to blend 5-15% H2 (by vol.) into NG; requires careful case by case assessment of NG network.
- For heating applications, blending green H2 in NG yields 2-5% reduction in GHG emissions.
- For transport applications major GHG reductions require H2 separation & use in hi-eff FCVs.

Near to Mid Term:

- H2 blending could help build H2 demand.
- If 10% H2 is blended w/NG, H2 demand would be comparable to today's industrial H2 use.
- Make electrolytic H2 from excess renewable power, blend w/NG for pipeline delivery. For transport applications separate H2 and use in FCVs.

Long Term:

- Blend limits => difficult for existing NG system to deliver enough green H2 to enable deep cuts in transportation related GHGs.
- In 2^o world, demand for H2 transportation fuel might far exceed ability of NG system to deliver H2 as part of a blend.
- In Long-term, dedicated, low-C H2 infrastructure needed.

Recurring themes in H2 Economy studies

- H2 can help enable zero carbon energy system
  - Integrate Green H2 (renewables) and Blue H2 (fossil w/CCS) into energy system
  - Decarbonize Natural gas grid (H2 blending)
  - Electric Grid stability and energy storage
- "Hard-to-abate" energy uses are a key opportunity for H2
  - Heavy duty trucks, shipping, aviation, industrial H2
- H2 Scale up is important for competitiveness
  - Scale up fuel supply chain to bring down H2 cost
  - Scale up component manuf. (fuel cells, etc.) to bring down TCO
- Adapt existing (elec, NG) and build new infrastructures (H2, CCS)
- Policy is needed to accelerate scale-up, guide H2 transition

Historically Energy Transitions Take Decades

Factors Affecting Rate of Change (Grubler 2012)

- **Scale or market size**. More difficult to transform large market than small system.
  - Transitions begin on small local scales, evolve into nationwide developments, then become truly global phenomena
- **Infrastructure.** The more complex the infrastructure, the slower the change.
- **Uncertainty** about policy and technology can lead to risk averse behavior.
- **Preexistence of niche markets** offering an early test bed for experimentation can help speed technology adoption
- **Comparative advantage across multiple dimensions can encourage transitions.**
- **Changing patterns of behavior (**e.g. in transport: new mobility, vehicle ownership**)**

Source: Arnulf Grubler, “Energy Transitions Research: Insights and Cautionary Tales,” Energy Policy, 50, p. 8-16. (2012)

Policy Needed During H2 Transition

Complex processes involved in developing and deploying H2 mean that carefully crafted policy support will be critical.

IEA suggested 5 H2 policy actions are needed to 2030:

(1) establish long-term signals to foster investor confidence

(2) stimulate commercial H2 demand in multiple applications

(3) help mitigate risks, such as value chain complexity

(4) promote R&D and knowledge sharing

(5) harmonise standards and remove barriers.

To start transition to a H2 economy, BNEF proposes large-scale deployment initiatives supported by long-term policy frameworks in countries that are early adopters. Build on current activities and scale their successes nationally and later globally.

The Hydrogen Council estimated that a total of $70 B in subsidies to 2030 might bring key hydrogen systems to cost competitiveness. This transition cost is small compared to money flows in the energy system overall.

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