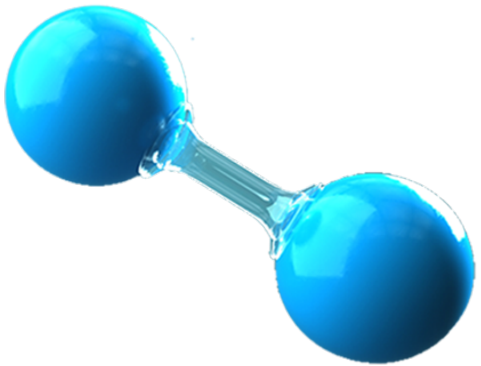


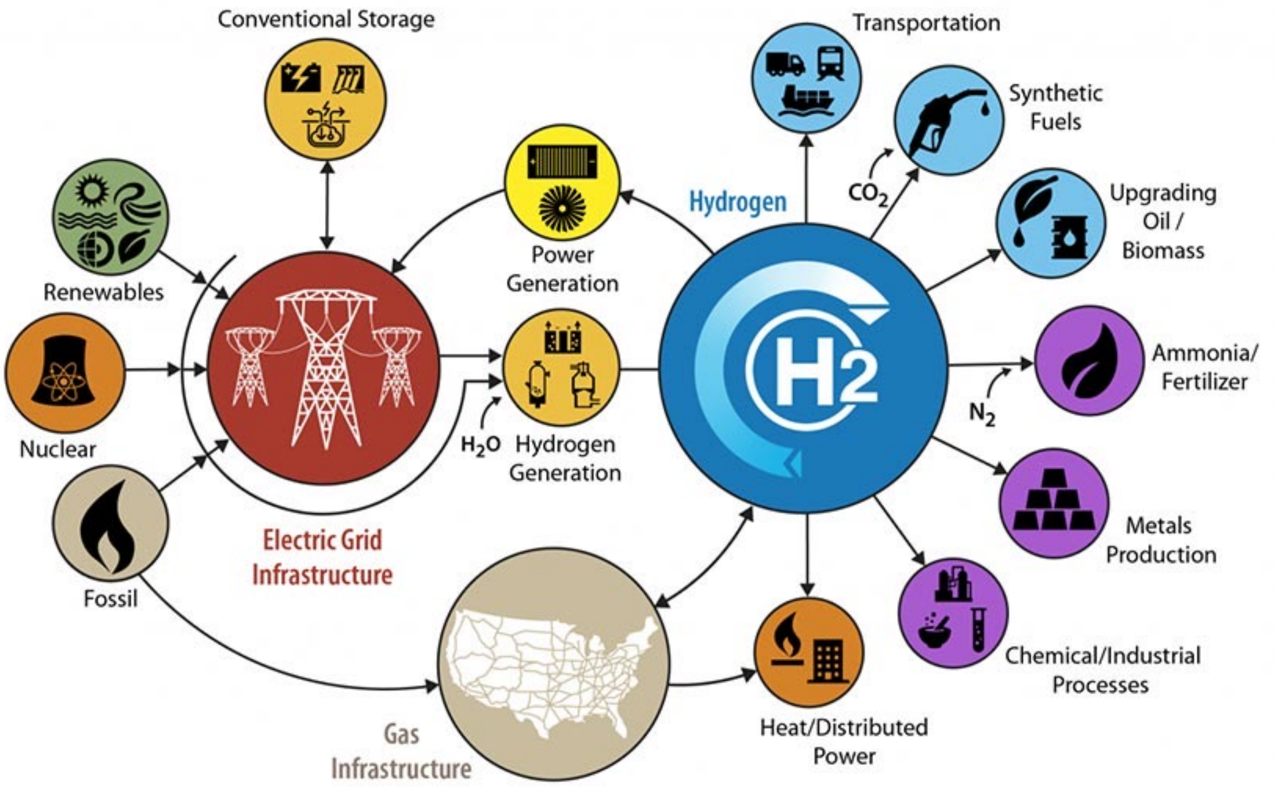
PRESENTATION
HYDROGEN OUR FUTURE

Mary Usovicz , Director of Business Development

The Future of Hydrogen
for the Commonwealth of Massachusetts

The Future of Hydrogen

for the Commonwealth of Massachusetts

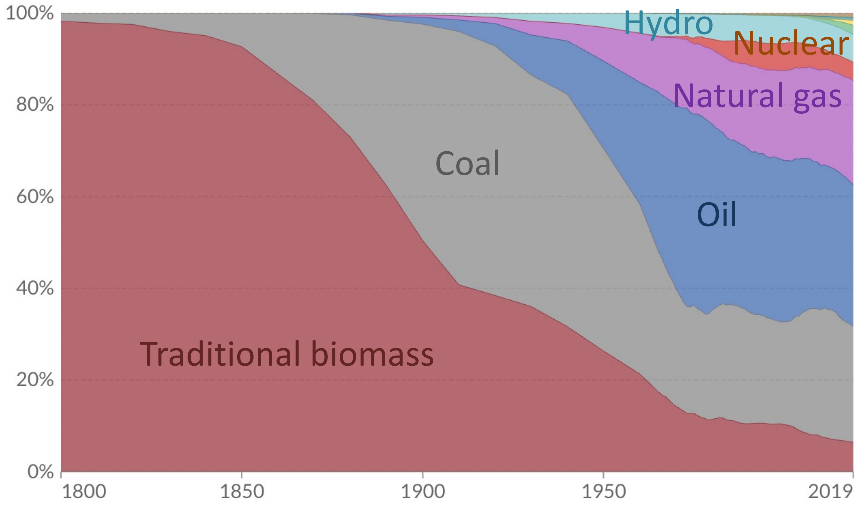


"Study Shows Abundant Opportunities for Hydrogen in a Future Integrated Energy System". *NREL Transforming Energy*, Oct.8, 2020

Evolution of Fuels

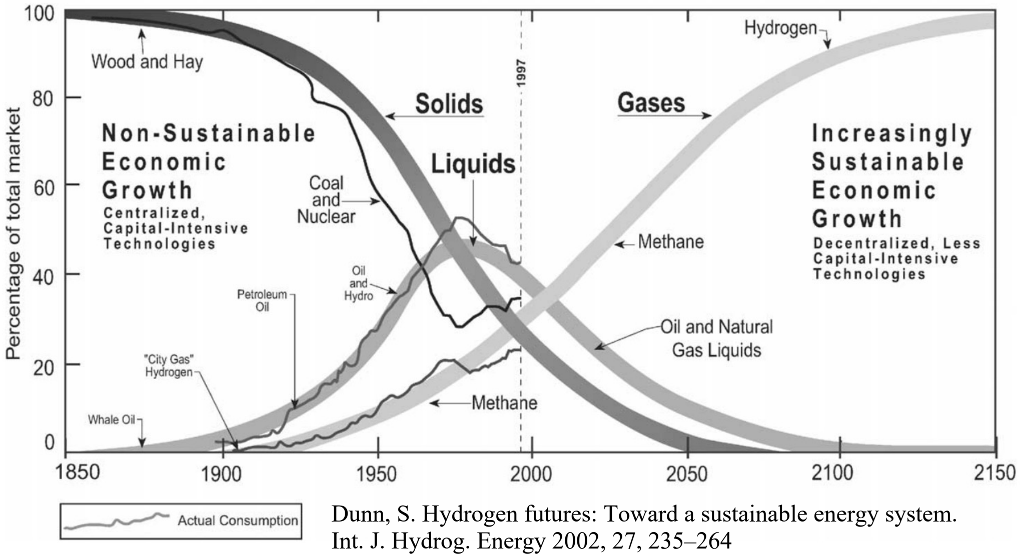
Humanity has been transitioning to ever more convenient energy sources

Global primary energy consumption by source



OurWorldInData.org/energy, source: Vaclav Smil, Energy Transitions (2017) & BP Statistical Review of World Energy

Fuel have been transitioning from solids, to liquid, to gases, with ever decreasing ratio of carbon-to-hydrogen: from 2 for coal, 0.5 for oil, 0.25 for natural gas, to 0 for hydrogen

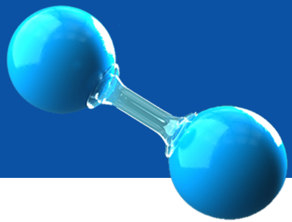


Dunn, S. Hydrogen futures: Toward a sustainable energy system. Int. J. Hydrog. Energy 2002, 27, 235–264

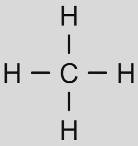
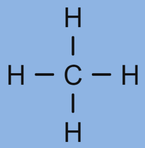
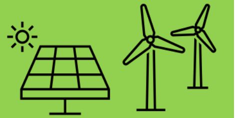
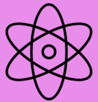
UMASS LOWELL

The Future of Hydrogen

for the Commonwealth of Massachusetts



Introduction To Hydrogen

	Grey Hydrogen	Blue Hydrogen	Green Hydrogen	Pink Hydrogen
Process	SMR	SMR with Carbon Capture	Electrolysis	Electrolysis
Source	Methane 	Methane 	Renewable Sources 	Nuclear Energy 

The Future of Hydrogen
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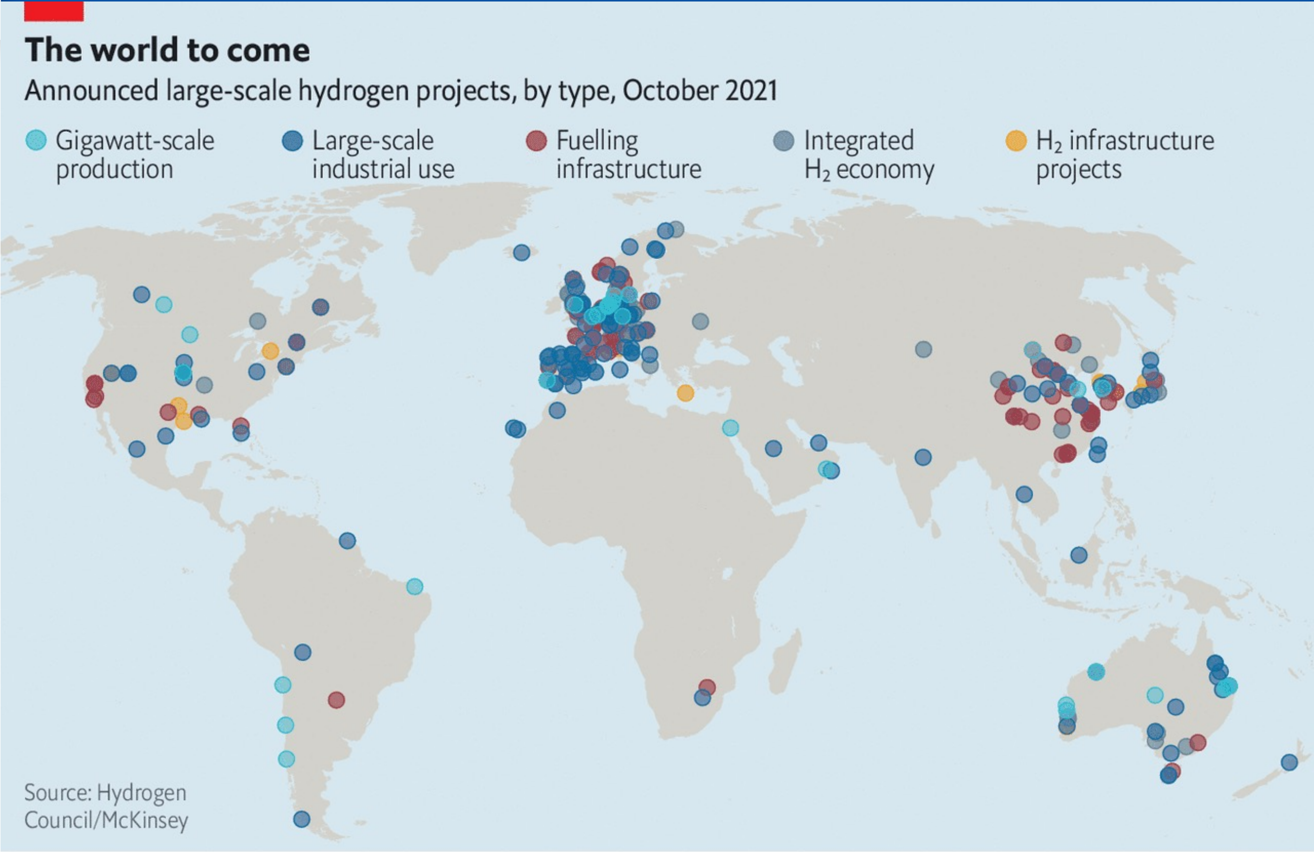
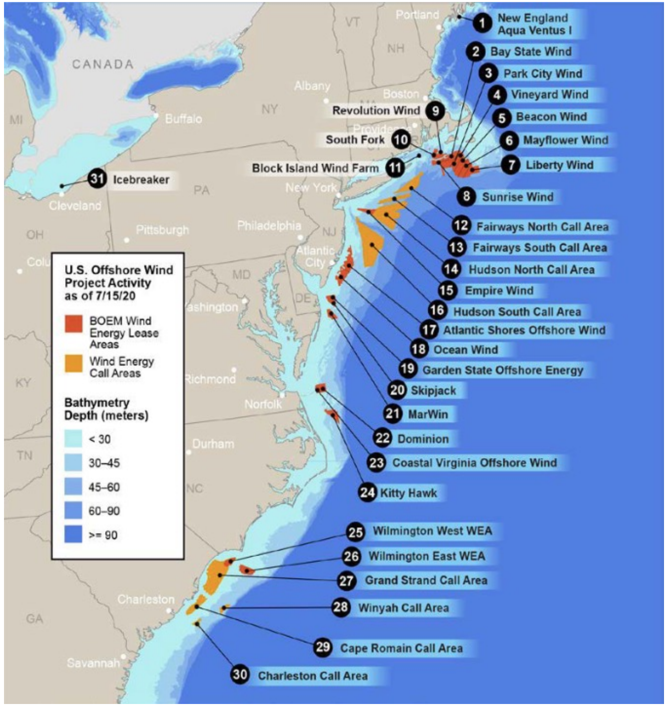


The Economist

https://www.economist.com/briefing/2021/10/09/creating-the-new-hydrogen-economy-is-a-massive-undertaking

MA READY FOR GREEN HYDROGEN

- Massachusetts has a goal to be carbon neutral by the year 2050
- Offshore wind projects are part of our energy future especially in Massachusetts
- With renewables comes intermittency and a need for energy resiliency
- Hydrogen may play a role in achieving net-zero climate goals (energy storage, transportation, natural gas replacement, etc.)
- Understand the opportunities, challenges, and concerns of using hydrogen



https://cleanenergy.org/blog/bidenboostsoffshorewind/

Energy Storage

Energy Storage

<u>Our energy generation landscape is changing:</u>

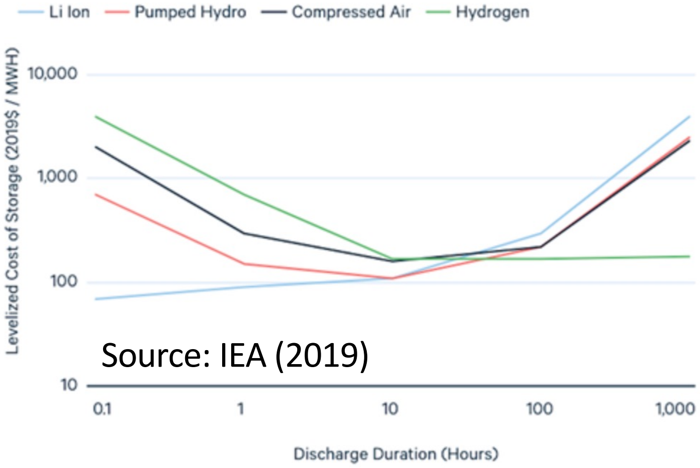
Planned installments of Gigawatts of offshore wind and solar.

<u>Intermittency on both short- and long-time scale:</u>

Energy Storage has become a “need to have” vs a “nice to have” to enable a renewable grid.

<u>Lithium-ion batteries: Current front-runner solution, **however**</u>

- Capacity fade and the associated limited lifetime for grid-scale applications
- Not cost effective in long-duration storage



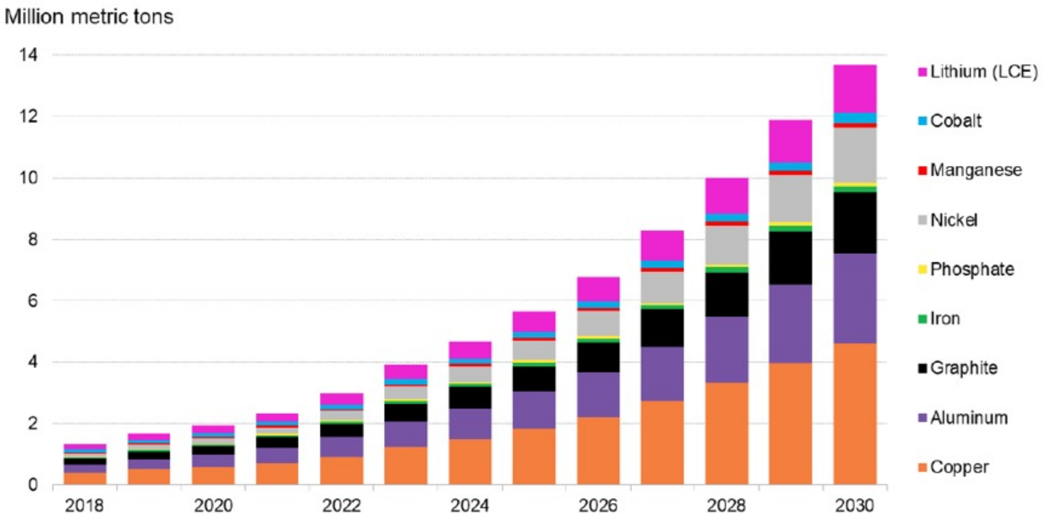
Source: IEA (2019)

Energy Storage

The use of hydrogen can be an effective method for storing large amounts of energy for long periods of time (e.g., days or weeks) either as a gas, liquid, or in the form of ammonia

<u>Relying only on batteries is not viable in the long-term</u>

- due to the expected increase in demand for lithium
- expected large deficits of potential extractable mineral deposits by 2050
- Similar concerns for Co and Ni.



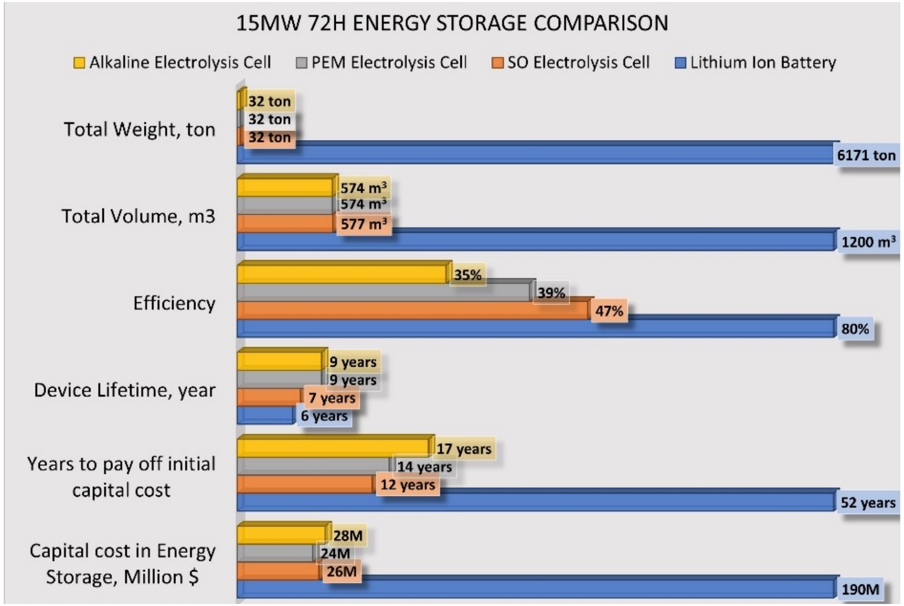
Environmental & Energy. "Electric Vehicles to Drive Massive Battery Demand: BNEF Chart". *Bloomberg Law*, 11 March 2021

Energy Storage

The use of hydrogen can be an effective method for storing large amounts of energy for long periods of time (e.g., days or weeks) either as a gas, liquid, or in the form of ammonia

<u>Techno-economic analysis comparing lithium-ion battery vs hydrogen for a 15 MW & 72 h storage system:</u>

- hydrogen is more viable in terms of **weight**, **volume**, **upfront capital cost** and years for **return on investment** than lithium-ion batteries



Industrial Processes and Thermal Heating

Industrial Processes

Most hydrogen consumed in the U.S. is used by industry for **petrochemical products** (oil refining, production of methanol, hydrochloric acid), **fertilizer production** (ammonia), processing of metals (reduction of metallic ores, welding), food processing (hydrogenation of fats and oils), and other materials and chemicals (e.g., glass, hydrogen peroxide).

EURACTIV, MARCH 2, 2021

MA industries largely rely on feedstock that are derived (e.g., methanol, steel) rather than primary (e.g., oil, ores). The use of hydrogen in industrial processes has a **secondary** – yet sizeable – impact on MA industries, particularly regarding **net-carbon-intensity of products & services**. Currently there are no incentives for the use of green hydrogen.

RECHARGE, APRIL 28, 2020

Thermal Heating

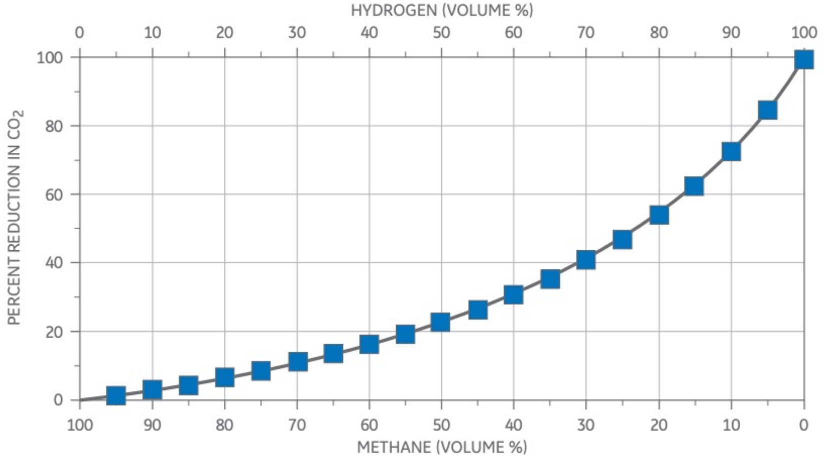
Thermal heating includes all home and commercial business, excluding agricultural and industrial activities

The use of hydrogen for thermal heating can:

- Prevent **stranded assets** (gas pipes), can facilitate detachment from natural gas
- Provide **flexibility to end-users** – residential (stoves, water heaters) and commercial (burners, boilers, heaters)
- Increase **energy resiliency** by complementing electrification by meeting energy demands during peak periods and periods of intermittent renewable energy production
- Primary advantage of the use hydrogen for thermal heating is **reduction in CO_2 emission**

For carbon reduction and blend percentage there is a **non-linear relationship** due to the different energy density of methane and hydrogen

5% blend = 1.5% reduction
20% blend = 6% reduction
75% blend = 50% reduction



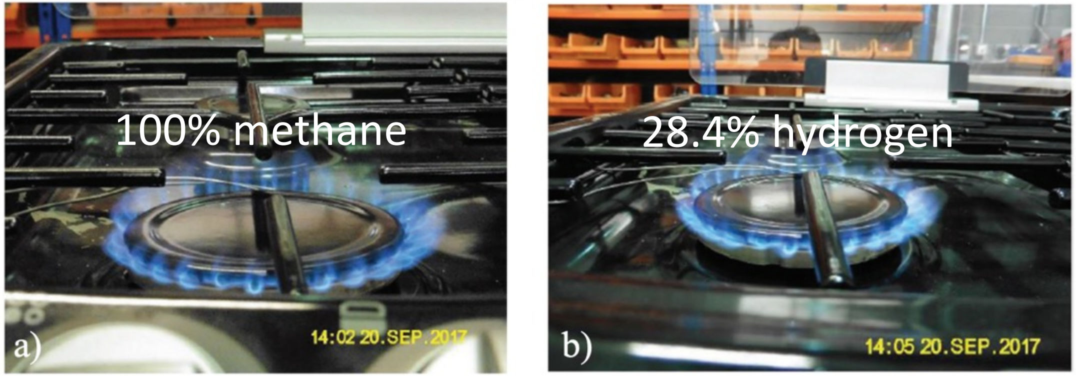
“Power to Gas: Hydrogen for Power Generation”. *GE Gas Power*, FEB 2019

Thermal Heating

Challenges of the use hydrogen for heating:

- Need for **standards and guidelines** on the effects of hydrogen-methane blends on gas appliances (e.g., blend limits, retrofitting, re-design, operation)
- Embrittlement of **cast iron pipes**. MA has a over 21,000 miles of gas distribution pipes, of which ~3000 miles are made of cast iron (~7000 miles of steel, ~11000 miles of plastic). Polyethylene and lower-strength steel pipelines are most compatible with hydrogen. The conversion of cast iron has been shown to be unsuitable for any blends or pure hydrogen.

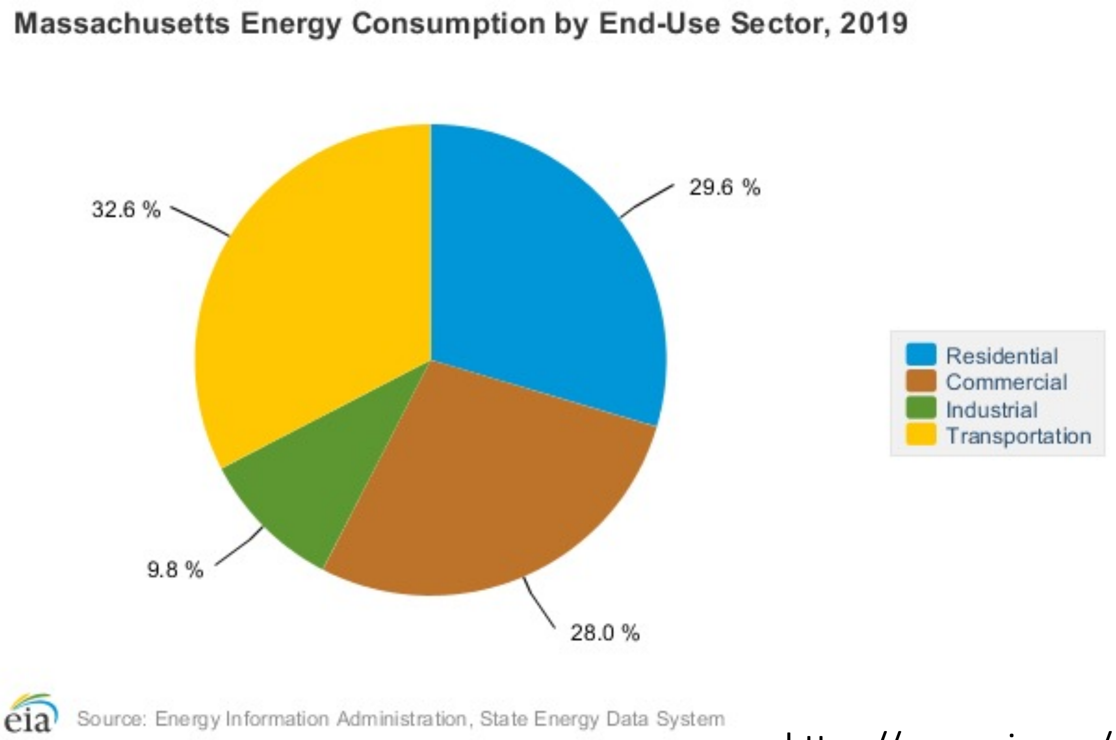
Large-scale pilot projects (Keele University) have shown **20% blend has no effect on end-user appliances**, and in laboratory test up to a 28% blend. Appliances with blends above these limits **may need to be retrofitted or replaced** and studies are still on going to show the effects of higher blends on end-user appliances



"HyDeploy: The UK's First Hydrogne Blending Deployment Project", *Clean Energy*, 9 MAY 2019

Transportation

Transportation



https://www.eia.gov/state/?sid=MA#tabs-2

The Future of Hydrogen
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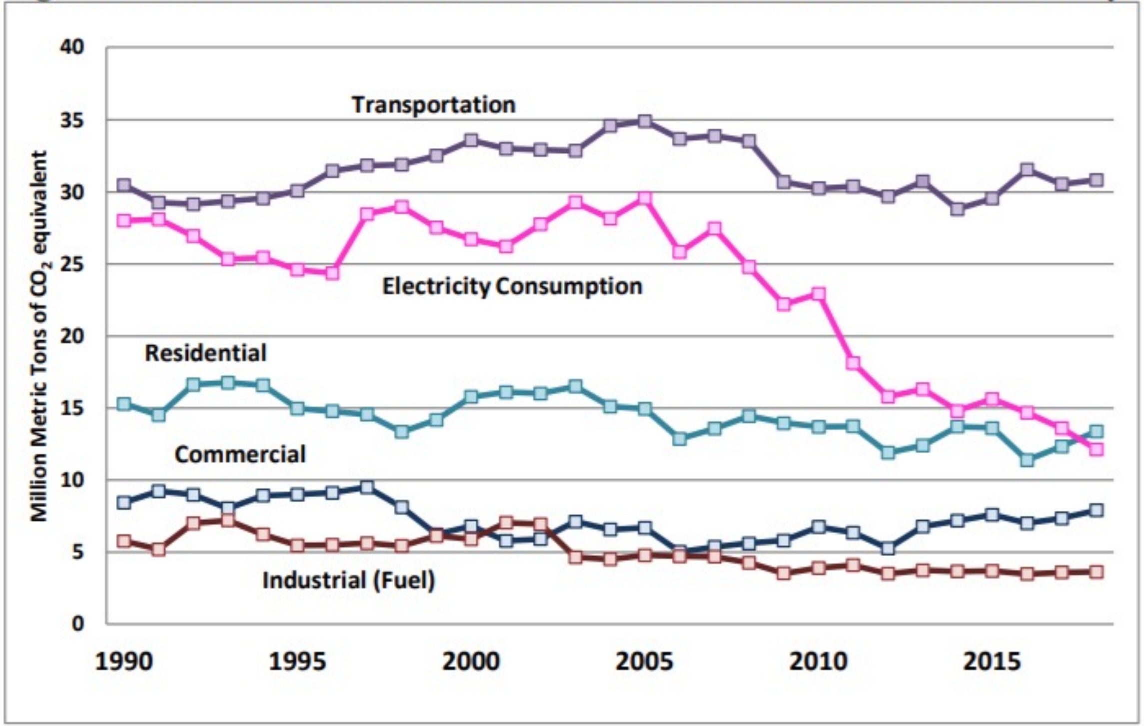
Figure 2A: Massachusetts 1990-2018 Fuel Combustion GHG Emissions by Sector



https://www.mass.gov/lists/massdep-emissions-inventories#greenhouse-gas-baseline,-inventory-&-projection-

How do we decarbonize all automobiles?

Hydrogen Fuel Cell Vehicles - Features

- Zero nitrogen oxides (NOx) emissions and CO_2 emissions
- A long-range driving alternative to BEVs, ~**300 mile range**
- Rapid refueling (~3 minutes)
- Driving range is not significantly affected by the cold temperature
- A 13 gallon tank of gasoline has ~ 3 times the flammable energy as hydrogen car carrying 4 kg of hydrogen
- If the fuel tank ruptures, gasoline will pool and wet the mating parts and roadway, while hydrogen leak dissipates quickly into the atmosphere

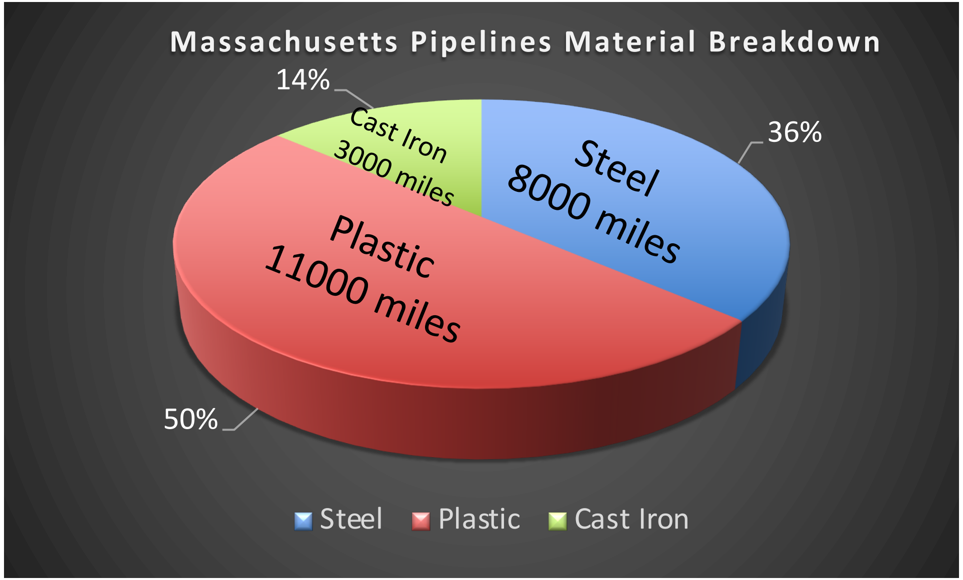
How do we decarbonize all automobiles?

Hydrogen Fuel Cell Vehicles – Challenges

- Lack of Infrastructure - 4,090 public and 299 private electric charging stations in MA, but **zero** public hydrogen refueling stations
- There is safety hazard perception (11,674 hydrogen-powered automobiles operating in California, there have been **no significant issues** with fires.
- Sandia National Lab Hydrogen Fuel Cell Electric Vehicle Tunnel Safety Study
- Regulations **restrict the operation** of hydrogen vehicles on some roadways (particularly tunnels) Massachusetts policies on transportation of hydrogen have hindered the growth of hydrogen in the transportation sector
- Cost of green hydrogen currently is ~$16/kg; **costs need to be reduced** with sector coupling and economy of scale

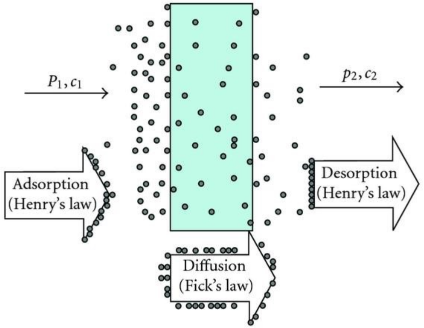
Pipeline Transportation

Massachusetts Pipeline Leakage

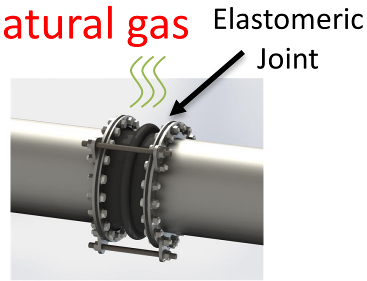


- Natural Gas Leakage Rate 0.0002%.
- Cast Iron pipes suffer from H_2 embrittlement.

Permeation

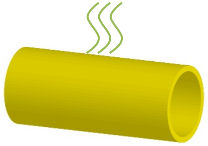


A factor of three higher than that for natural gas



Steel Pipe

0.0005% with a 17% H_2 blend



Plastic Pipe

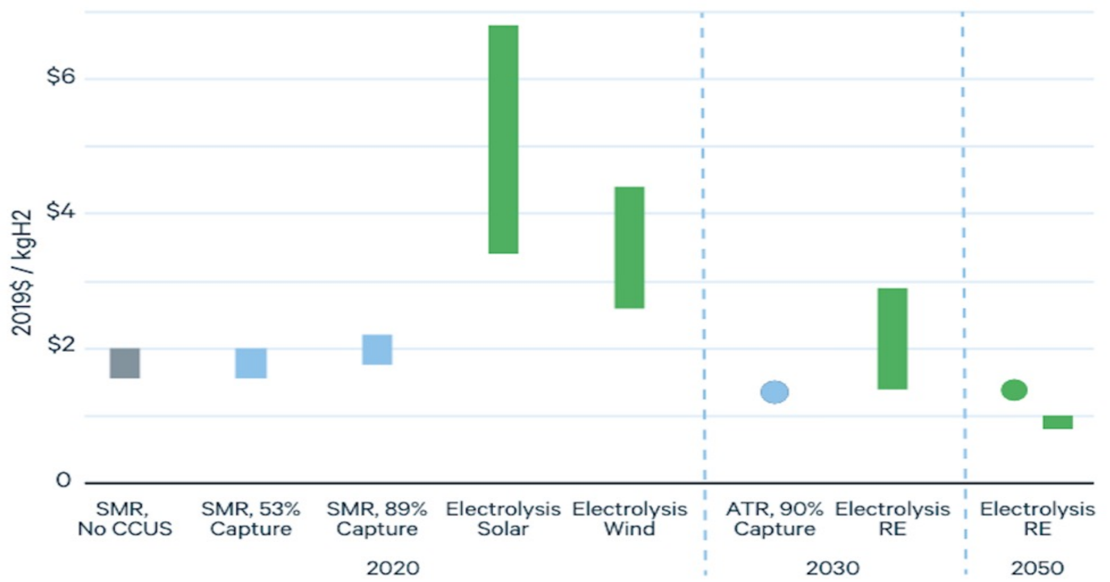
[Klopffer, et al., 2015; Wassenaar, Micic, 2020; Haines, at al., 2003]

Economic Viability and Benefits of Hydrogen

Production Scale-Up

Blue hydrogen with 90% carbon capture could be the least expensive production method by 2030.

Green hydrogen could compete with grey hydrogen as soon as 2030 as well.



Sources: Friedmann et al. 2019; IRENA 2019; Hydrogen Council 2020; Mathis and Thornhill 2019.
Notes: Bars indicate cost ranges; circles indicate point estimates. Gray and blue hydrogen assume a delivered natural gas price of $3.50/MMBtu. 2020 and 2030 costs assume social costs of carbon of $51/tCO_2$ and $61/tCO_2$, respectively, from IWG (2016), inflated from 2007$ to 2019$. Includes only CO_2 emissions from combustion and chemical conversion.

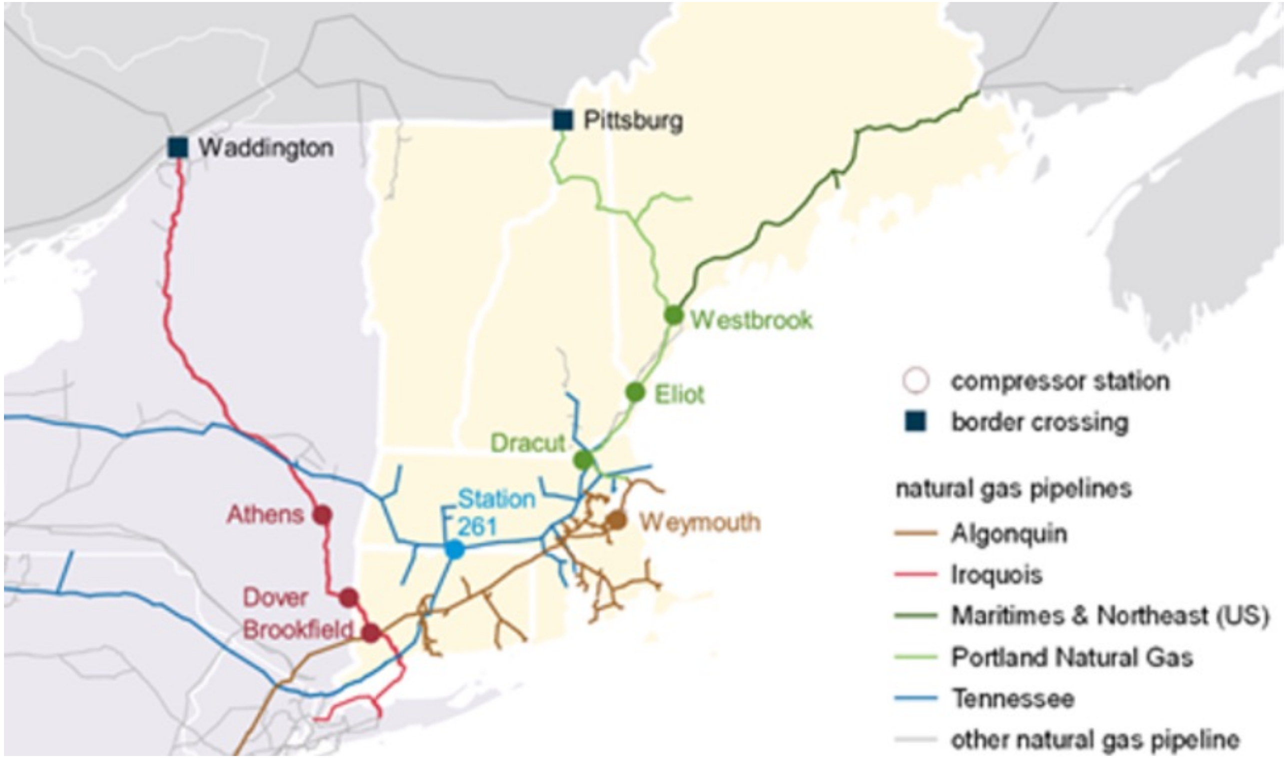
Bartlett and Krupnick (2020)

Hydrogen's Role in Decarbonization: Replacing Natural Gas

The benefits of using green hydrogen to replace natural gas:

- Natural gas is carbon-emitting and difficult to phase-out
  - According to the Massachusetts 2050 Decarbonization Roadmap "gas use continues in some quantity across all Net Zero pathways, including for space heating" [p. 51].
- Hydrogen can be used with modified, existing natural gas pipeline infrastructure.
- Hydrogen can complement electrification.

Capitalizing on Existing Infrastructure



https://www.eia.gov/dashboard/newengland/commentary/20200306