
LEADING THE WAY
CampusEnergy2022
Feb. 15-18 | Westin Boston Seaport District Hotel | Boston, Mass.
INTERNATIONAL DISTRICT ENERGY ASSOCIATION

Decarbonizing District Energy: What Role Does H_2 Play and When?

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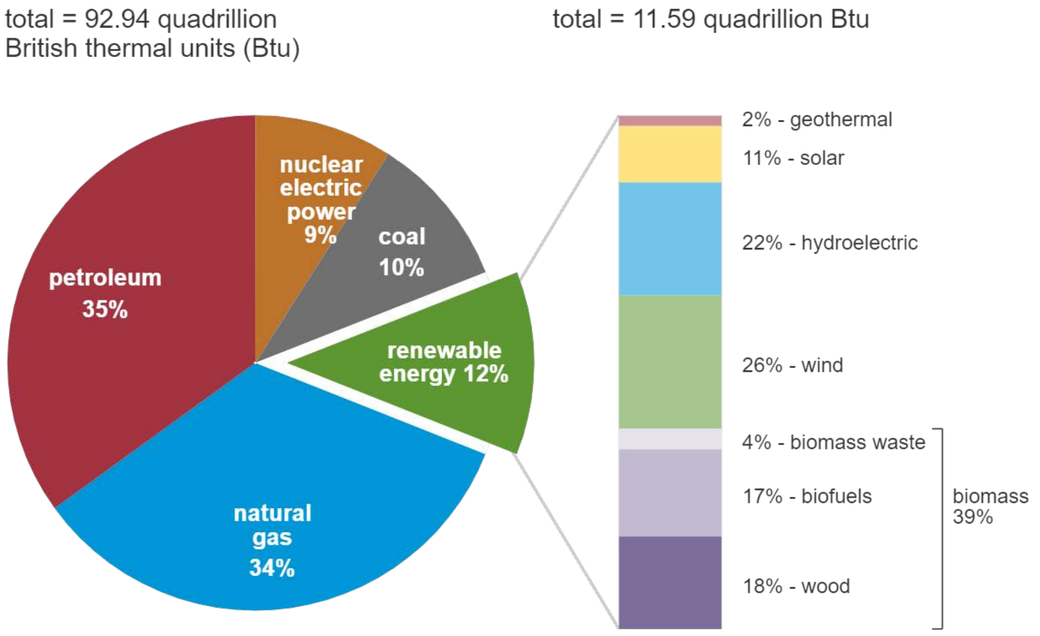
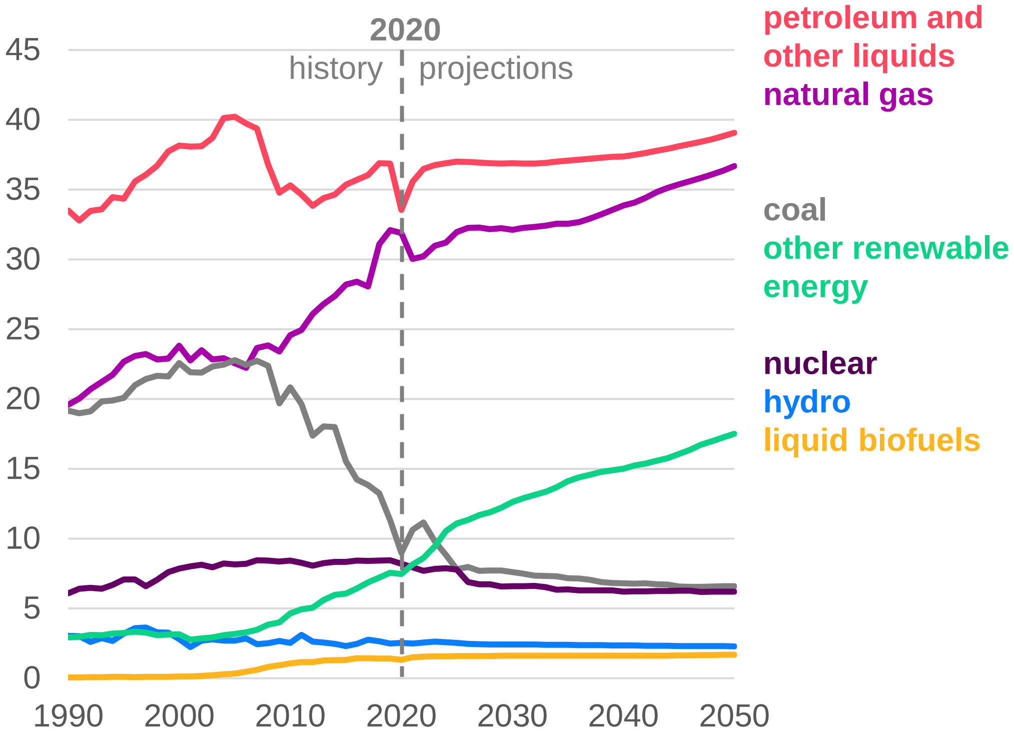
Achieving Net-Zero Goals: Requires an Unprecedent Pace in Clean Energy Deployment

US Primary Energy Consumption by Energy Source, 2020



Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2021, preliminary data
Note: Sum of components may not equal 100% because of independent rounding.

Energy Consumption by Fuel AEO2021 Reference Case
(in quadrillion BTU)



Decarbonizing Strategies to Support Net-Zero Goals

1. End-use energy efficiency and electrification
2. Clean electricity: wind & solar generation, transmission, **firm power**
3. Clean fuels: bioenergy, **hydrogen**, and synthesized fuels
4. CO_2 capture and utilization or storage
5. Reduced non-CO_2 emissions
6. Enhanced land sinks

A Renewed Interest in H_2

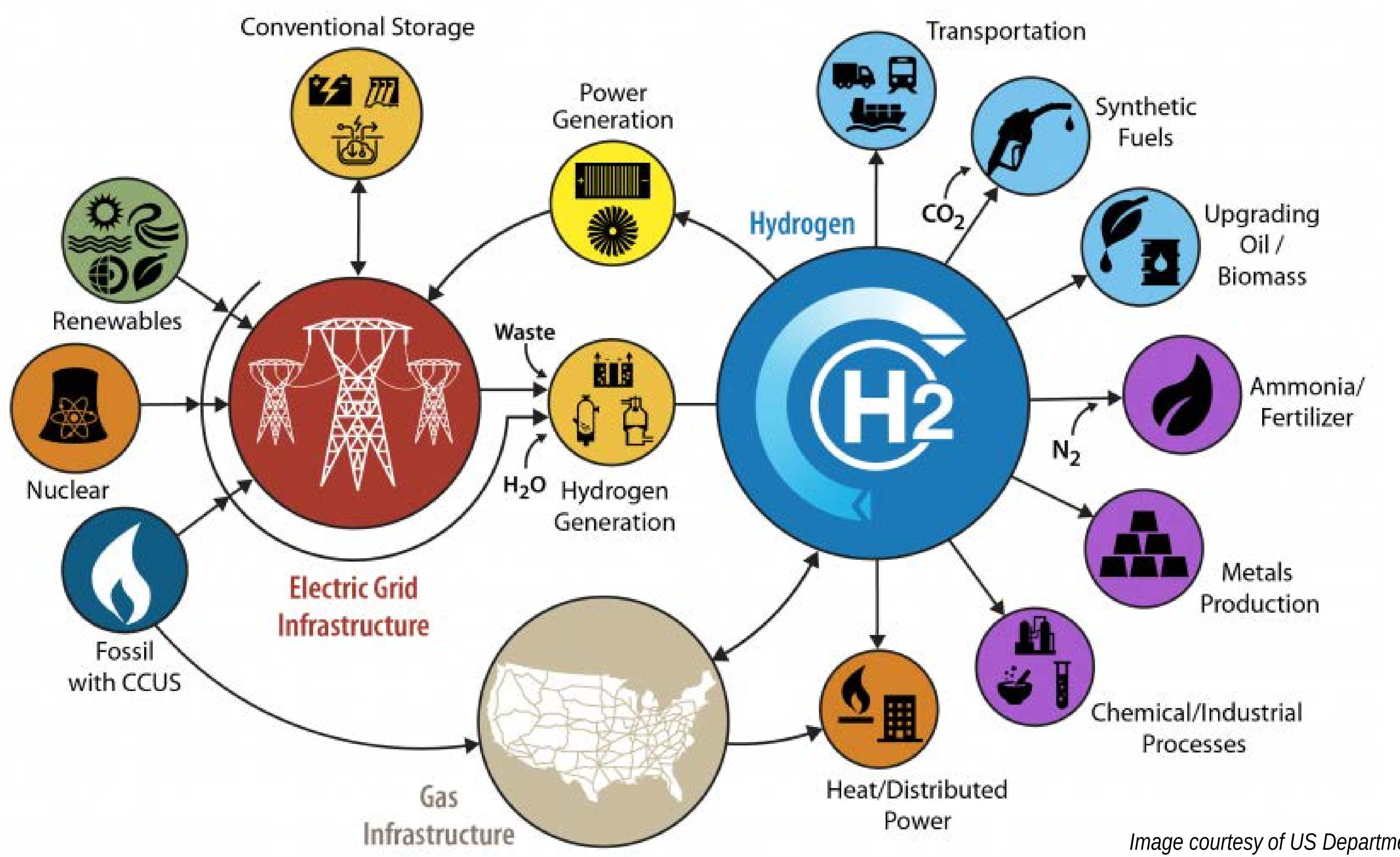
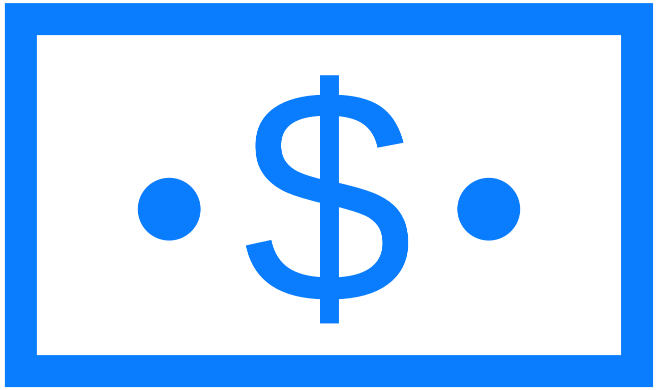


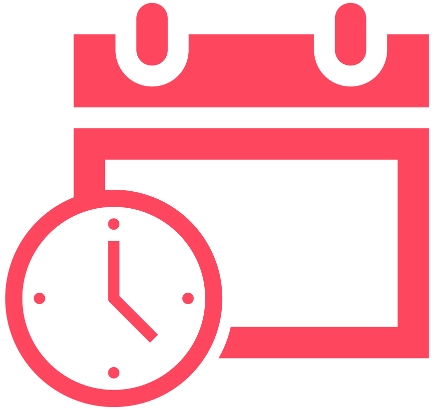
Image courtesy of US Department of Energy

Hydrogen Energy Earthshot



1 Dollar

1 Kilogram



1 Decade

Production of H_2 and its various colors

Grey H_2

Hydrogen extracted from natural gas using steam methane reformation. Most common form of hydrogen today

Blue H_2

Hydrogen produced by fossil and CO_2 is capture and stored or utilized

Green H_2

Hydrogen is produced by electrolysis of water using electricity generated by renewables

Pink H_2

Hydrogen produced by electrolysis of water using electricity generated by nuclear

Brown H_2

Hydrogen extracted from coal using gasification

Production Cost of Green H_2

Levelized cost of hydrogen										
Utilization rate	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average cost of electricity cents/kWh	**"Gate" cost per kg of H2 (prior to transportation, storage, distribution)**									
0	$3.07	$1.54	$1.02	$0.77	$0.61	$0.51	$0.44	$0.38	$0.34	$0.31
0.5	$3.30	$1.77	$1.26	$1.00	$0.85	$0.74	$0.67	$0.62	$0.57	$0.54
1	$3.53	$2.00	$1.49	$1.23	$1.08	$0.97	$0.90	$0.85	$0.80	$0.77
2	$4.00	$2.46	$1.95	$1.69	$1.54	$1.44	$1.36	$1.31	$1.27	$1.23
3	$4.46	$2.92	$2.41	$2.15	$2.00	$1.90	$1.82	$1.77	$1.73	$1.69
4	$4.92	$3.38	$2.87	$2.62	$2.46	$2.36	$2.29	$2.23	$2.19	$2.16
5	$5.38	$3.85	$3.33	$3.08	$2.92	$2.82	$2.75	$2.69	$2.65	$2.62

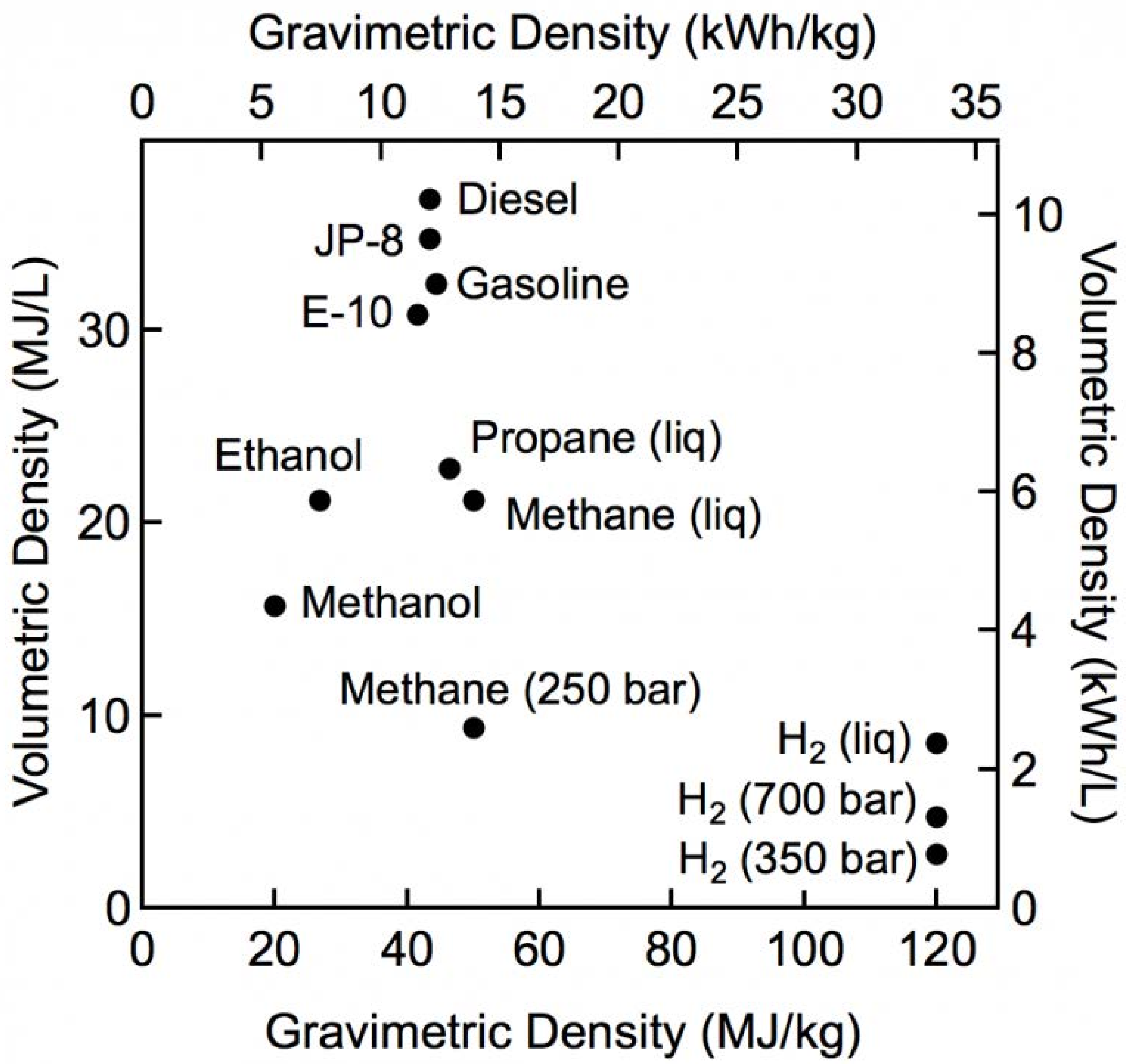
Utilization rate	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average cost of electricity cents/kWh	**"Gate" cost per MMBtu of H2 (prior to transportation, storage, distribution)**									
0	$27.08	$13.54	$9.03	$6.77	$5.42	$4.51	$3.87	$3.38	$3.01	$2.71
0.5	$29.11	$15.57	$11.06	$8.80	$7.45	$6.55	$5.90	$5.42	$5.04	$4.74
1	$31.15	$17.61	$13.10	$10.84	$9.49	$8.58	$7.94	$7.46	$7.08	$6.78
2	$35.22	$21.68	$17.17	$14.91	$13.56	$12.65	$12.01	$11.53	$11.15	$10.85
3	$39.29	$25.75	$21.24	$18.98	$17.63	$16.72	$16.08	$15.60	$15.22	$14.92
4	$43.36	$29.82	$25.31	$23.05	$21.70	$20.79	$20.15	$19.67	$19.29	$18.99
5	$47.43	$33.89	$29.38	$27.12	$25.77	$24.87	$24.22	$23.74	$23.36	$23.06

H_2 Storage

Storage options today include insulated liquid and gaseous storage tanks

High density storage is **challenging** because of the low volumetric density relative to other fuels

Advanced storage options include materials-based storage technologies



Example calculations for on-site electrolysis (power to gas to power)

Electrolysis Requirements Supporting 100% Hydrogen Operation

Gas Turbine	Output (kW)	Heat Input (mmBtu/hr)	Electrolysis power required (GWh) *	Kg of H_2 produced
Solar Titan 130	16,530	~160	1.73 GWh per day 631 GWh per 8,760 hrs	~28,500 kg of H_2 per day ~10.4 M kg of H_2 per 8,760
Solar Taurus 60	5,670	~61	0.67 GWh per day 243 GWh per 8,760 hrs	~11,000 kg of H_2 per day ~4.02 M kg of H_2 per 8,760

**Efficiency of electrolyzer is assumed 65% and gas turbine output operates at full load*

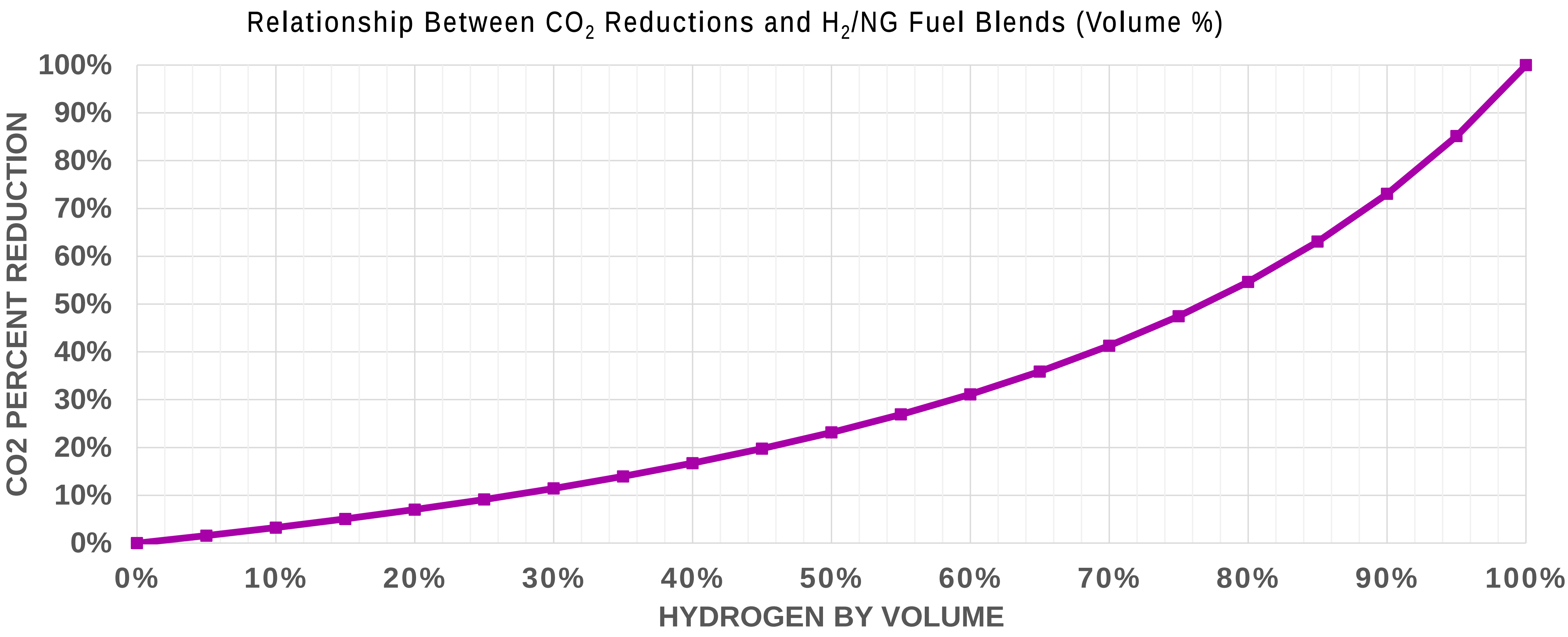
Example calculations for on-site storage

On-site Storage Requirements For 100% Hydrogen Operation

Gas Turbine	Storage Method	Storage Volume 1 day of H_2*	Storage Volume 3 days of H_2*	Storage Volume 7 days of H_2*
Solar Titan 130	Compressed	~52,544 ft^3 ~4.89 miles of pipe	~157,648 ft^3 ~14.67 miles of pipe	~368,024 ft^3 ~34.26 miles of pipe
Solar Taurus 60	Compressed	~20,275 ft^3 ~1.89 miles of pipe	~60,841 ft^3 ~5.66 miles of pipe	~141,856 ft^3 ~13.2 miles of pipe

**Gas storage is assumed to be in 24" NPS - Sch 160 piping, using A-106, Grade C pipe @3500 psig*

Decarbonizing Benefits of Blending Fuels

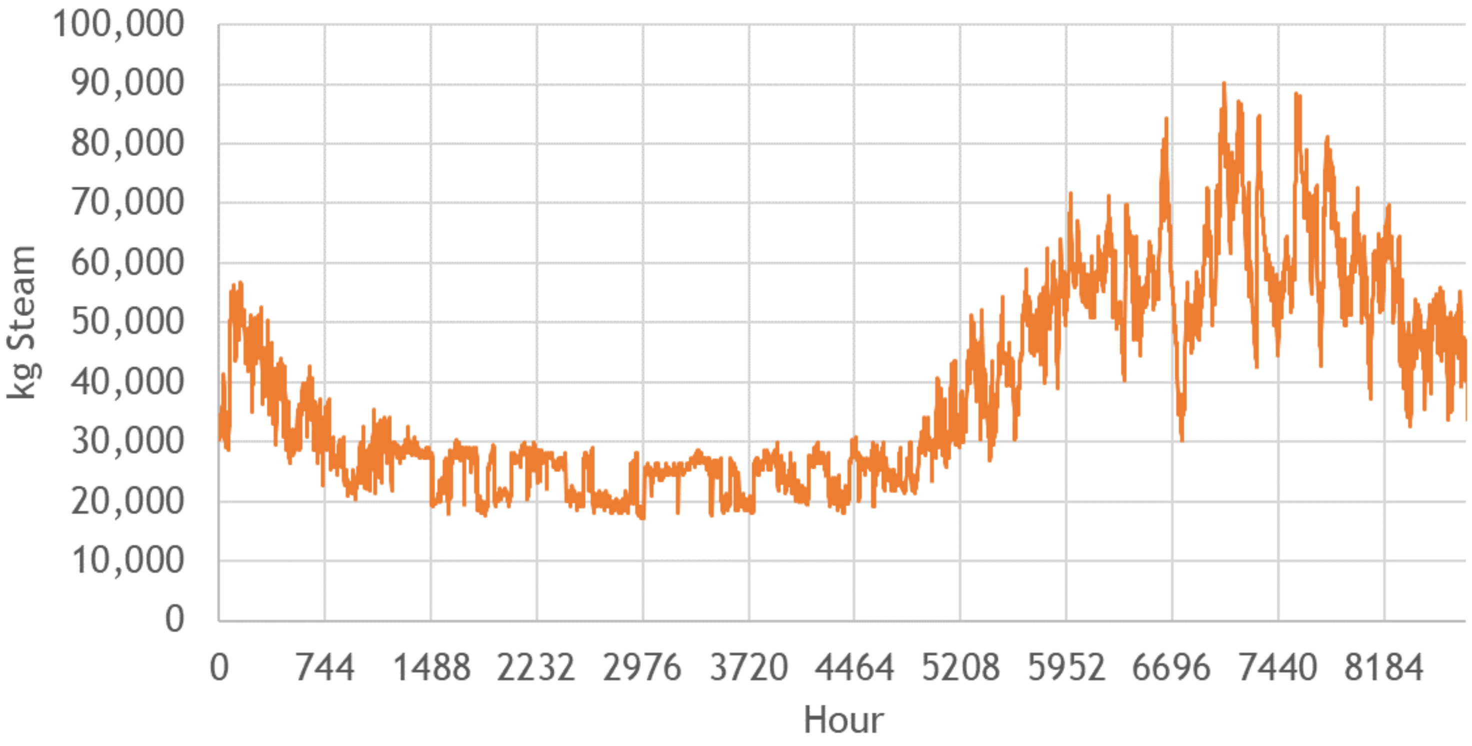


Case Study 1: Confidential Client – Hydrogen Feasibility Study

Confidential client is renovating boilers and wants to decarbonize by 2040

The dynamic combustion chamber boiler from Hydrogen Technologies Inc. reacts hydrogen and oxygen to form steam with no emissions

Boiler pairs well with electrolysis



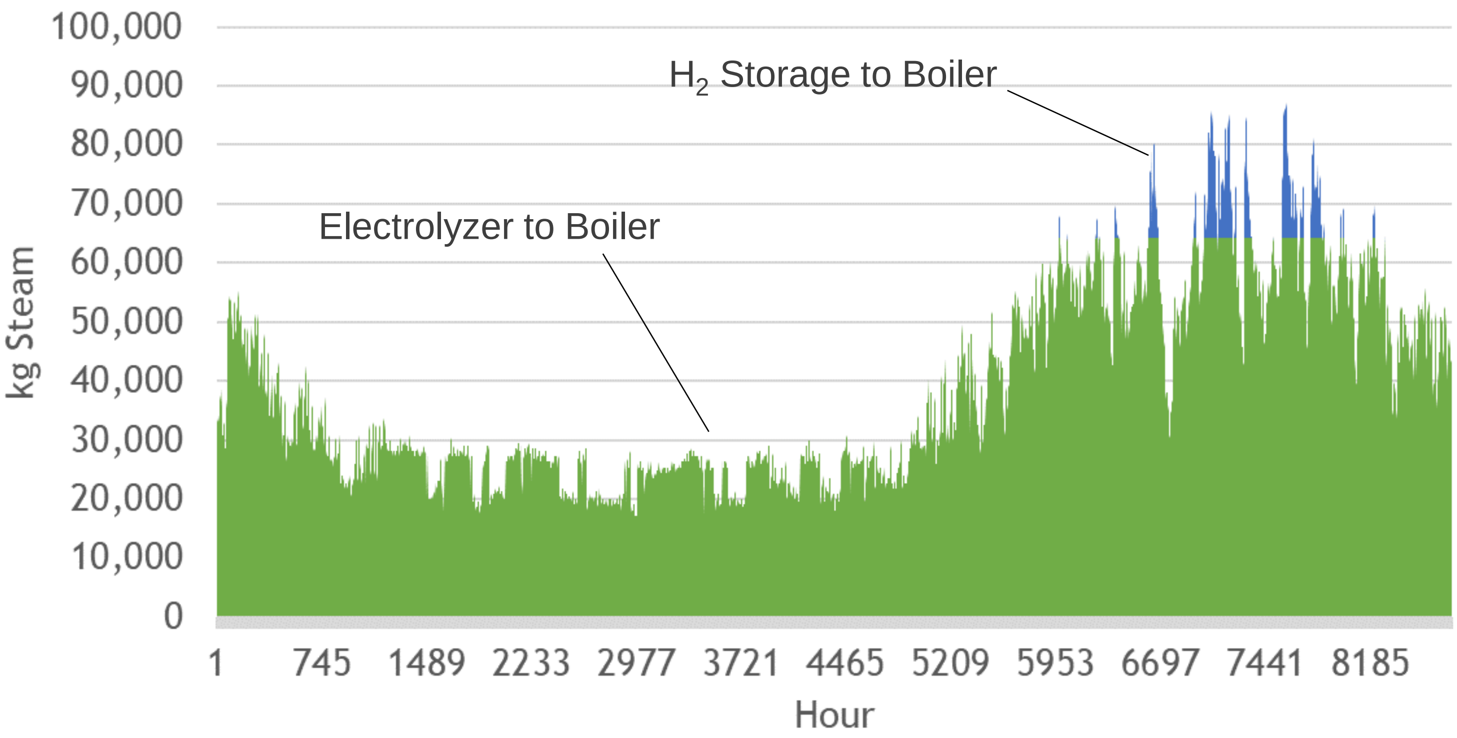
Case Study 1: Optimized Solution – H_2 Generation and Storage

Equipment initially sized to meet maximum steam load throughout the year

However, steam load was well below maximum throughout the year

Adding storage reduces electrolyzer size

Found that least cost solution reduced cost 23% relative to no storage solution



Case Study 2: Yarra Valley Water Aurora Wastewater Treatment Plant

Look to improve the cost competitiveness of green hydrogen

Explore the relationship between both outputs – hydrogen and pure oxygen

Could a co-located hydrogen facility create enough savings for the WWTP to subsidize cost of hydrogen to increase commercial viability?

[Toward a Zero Carbon Future]

Case Study 2: Why is co-located H_2 to a WWTP a unique opportunity?

Electrolysis produces two products: hydrogen and pure oxygen

Oxygen-based treatments can improve the efficiency of wastewater treatment

- Switching from air to pure oxygen in the treatment process could increase treatment capability and reduce associated costs
- Treatment technologies, such as Membrane Aerated Biofilm Reactor (MABR), have improved the delivery of oxygen relative to conventional aeration technologies.

Securing demand for oxygen will improve the economics of electrolysis

Case Study 2: Yarra Valley Water (YVW)

Consists of a sewage treatment plant and recycled water treatment plant

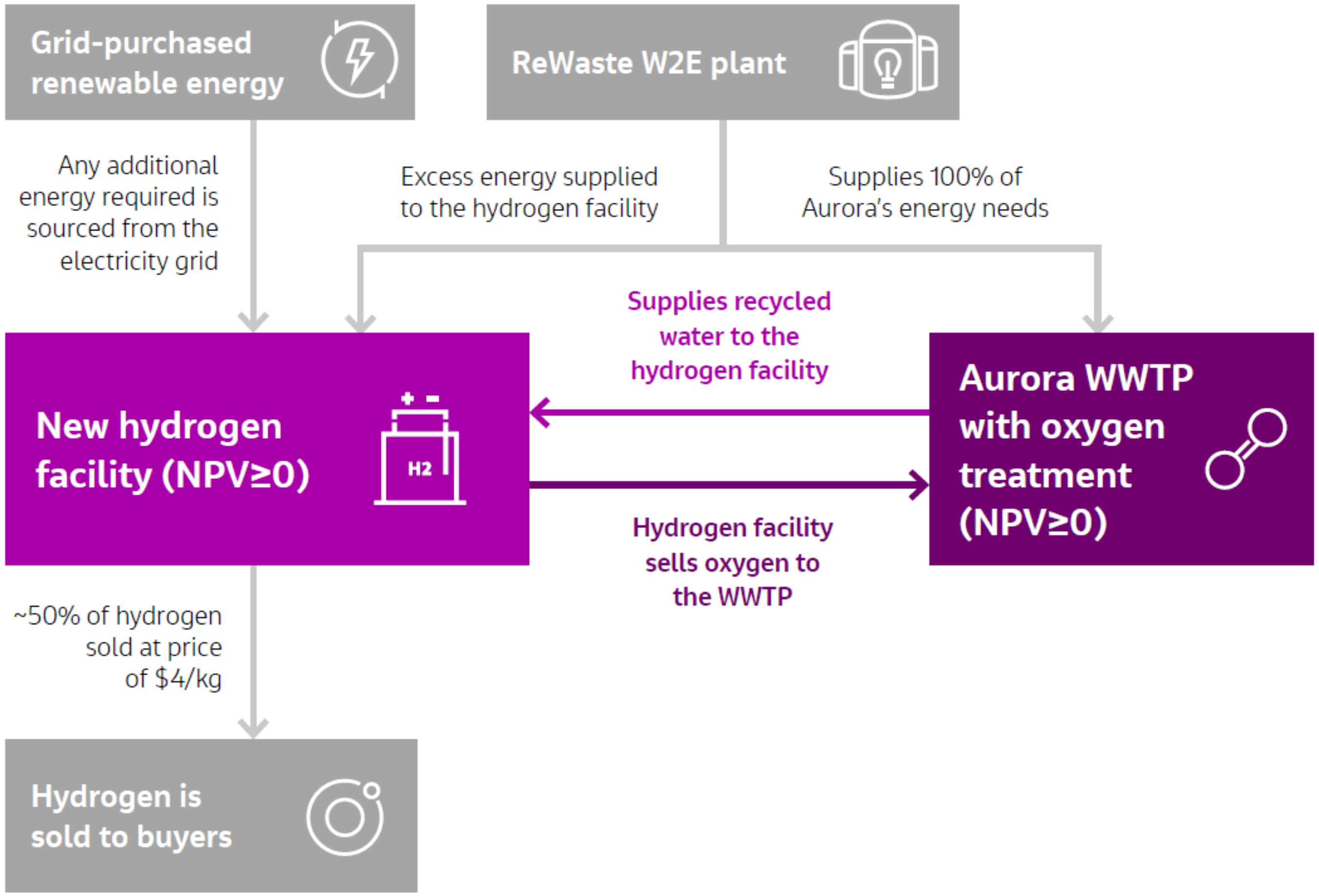
Access to renewable energy: YVW built a waste-to-energy facility (ReWaste) adjacent to Aurora WWTP in 2017

Abundant supply of recycled water

Demand for oxygen

Case Study 2: Yarra Valley Water

Reflection of the flows of costs and revenues between the proposed hydrogen facility, the Aurora WWTP and ReWaste.



iii. NPV for the Aurora WWTP refers to a situation where incremental benefits are greater than the incremental costs of implementing oxygen treatment processes.

Case Study 2: YVW Findings

Analysis Conclusions

Implementing oxygen-based treatment MABR at Aurora WWTP could deliver savings

→ Guaranteed demand for oxygen was instrumental to enable a co-located hydrogen facility

→ Implications to both water sector and for Australia's hydrogen strategy

Case Study 3: Confidential Client – Using H_2 Generation + Storage to Decarbonize

Created a basis of design (basis of estimate) to allow for costing of a hydrogen system

Operational design requirements

- ✓ Electrolyzer rating ~91 MW
- ✓ Technology polymer electrolyte membrane (PEM)
- ✓ Individual state rating 2.5 MW
- ✓ Storage capacity of 900 tons (storage pressure ~3,400 psig)
- ✓ Above ground steel piping in linear configuration

Case Study 3: Confidential Client – Using H_2 Generation + Storage to Decarbonize

Storing 900 tons of H_2 at stated conditions requires

~346 acres

Capex estimated at

$1.4 billion

Lessons Learned

H_2 is a flexible fuel carrier that has a significant role in decarbonization

- Fuel blending and “drop-in” fuel into existing technology
- Energy storage applications

H_2 costs are currently expensive

- Co-locating H_2 hubs next to water assets could aid in cost reductions
- Optimizing H_2 production and storage will lower costs

H_2 storage is a challenge from a space perspective

Questions?

Thank you!

Steven Jenks

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