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Ohio Hydrogen Economy Outlook
February 2023

SARTA Hydrogen Fuel Cell Bus
Refueling Station

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MEC Conference
February 28, 2022

Department of Energy Hydrogen Earth Shot

- First of several DoE Earth Shots aimed at decarbonization of:
  - Transportation
  - Electricity generation
  - Manufacturing
- Goal: $1.00/kg clean hydrogen by 2030
  - Gray hydrogen already $1/kg
  - Green -- around $7/kg
  - Blue – around $3-4/kg
- But storage and distribution 2/3 of total cost at pump.
  - Currently $14/kg in California ($7/gal-equivalent)
- Hydrogen Shot seeks infrastructure cost reduction of 80% by 2030.
  - Department of Energy 6/20/21 Press Release (Energy.gov)

Hydrogen Funding Opportunities

- **Infrastructure Investment and Jobs Act (IIJA)**
  - Bipartisan Infrastructure Law (BIL)
  - \$9.5 billion for clean hydrogen initiatives
    - $500 million: mfg. & recycling initiatives to support domestic supply chains
    - $1 billion: electrolysis R&D to reduce costs of H_2 from renewable power
    - ***$8 billion: 6-10 regional clean H_2 hubs***

DOE's concept of a clean H_2 hub

Dept of Energy Clean Hydrogen Hub Timeline

Application	Phase 1: Detailed Plan	Phase 2: Develop, Permit, Finance	Phase 3: Install, Integrate, Construct	Phase 4: Ramp-Up & Operate
FOA Full Applications Due April 7, 2022	1-2 years	2 - 3 Years	2 - 4 Years	2 - 4 Years

Funding of between $400M and $1.25B for phases 2-4 combined.

- **Concept papers Submitted November 2022**
  - 33 (of 79) concepts have been "encouraged" by the DoE
  - 6-10 hubs expected to be funded
  - $7 billion available (of total $8 B program)
  - Target of 4 kg CO2e per kgH2 for lifecycle greenhouse gas emissions

- **Objectives, Requirements, and Guiding Principles**
  - Feedstock, End-use, and Geographic Diversity
    - At least 2 hubs in regions with abundant natural gas resources
  - Production capacity of at least 50 to 100 metric tons/day
  - 50% non-federal cost share
  - Justice40 and Employment goals (priority for hubs creating long term jobs)

Sources of Hydrogen

- Steam Reforming of Natural Gas
  - Most cost-effective strategy
    - Without carbon capture: ***Gray***
    - With carbon capture: ***Blue***
- Electrolysis
  - Wind, Solar Energy: ***Green***
  - Nuclear Power: ***Pink***
  - Grid: ***Gray***
- Other
  - Biomass: ***Green***

Steam Methane Reformer

Regional Hub Concepts Encouraged

- **Appalachian Regional Clean Hydrogen Hub (ARCH2):**
  - Focused on natural gas from Appalachia (Blue H2)
    - At least 9 other Blue H2 encouraged concepts
  - Led by Battelle, GTI
  - Public Collaborators:
    - MOUs from WV, Ohio, KY
    - OH2 Hub, SARTA
    - OH: Chamber of Commerce, Business Roundtable, JobsOhio
    - Universities, MHCoE
  - Private Collaborators:
    - Over 150 companies
    - Includes: EQT, Dominion, B&W, Long Ridge, AEP
- **Great Lakes Clean H2 Coalition**
  - Pink H2 Strategy (Energy Harbor)
  - Focused on Toledo markets
- **Midwest Alliance for Clean Hydrogen (MachH2)**
  - Multi-state, from MN to Ohio (NW Indiana focus?)
  - Ohio signed MOU
  - Pink, Green H2
- **Decarbonization Network of Appalachia (DNA)**
  - Blue H2 (natural gas)
  - Shell, Equinor
  - Team Pennsylvania

Inflation Reduction Act H2 Opportunities

- H_2 production tax credit up to $3/kg depending on lifecycle CO_2 intensity

kg of CO_2 per kg of H_2	Maximum credit
2.5 – 4 kg of CO_2	20%
1.5 – 2.5 kg of CO_2	25%
0.45 – 1.5 kg of CO_2	33.4%
0 kg – 0.45 kg of CO_2	100%

Carbon intensity of gray hydrogen ~9 kg CO_2/kg H_2

  - Maximum credit depends on satisfying prevailing wage requirements
  - Not stackable with 45Q carbon sequestration credits

- H_2 storage qualifies as "energy storage technology" eligible for investment tax credit (ITC) up to 30% of installed equipment cost.
  - Conditions for maximizing ITC same as for production tax credit

- Transportation-related credits
  - 15% of the cost of commercial fuel cell vehicles (up to $40k if over 14,000 lbs.)
  - 30% of cost of hydrogen refueling station up to $100k

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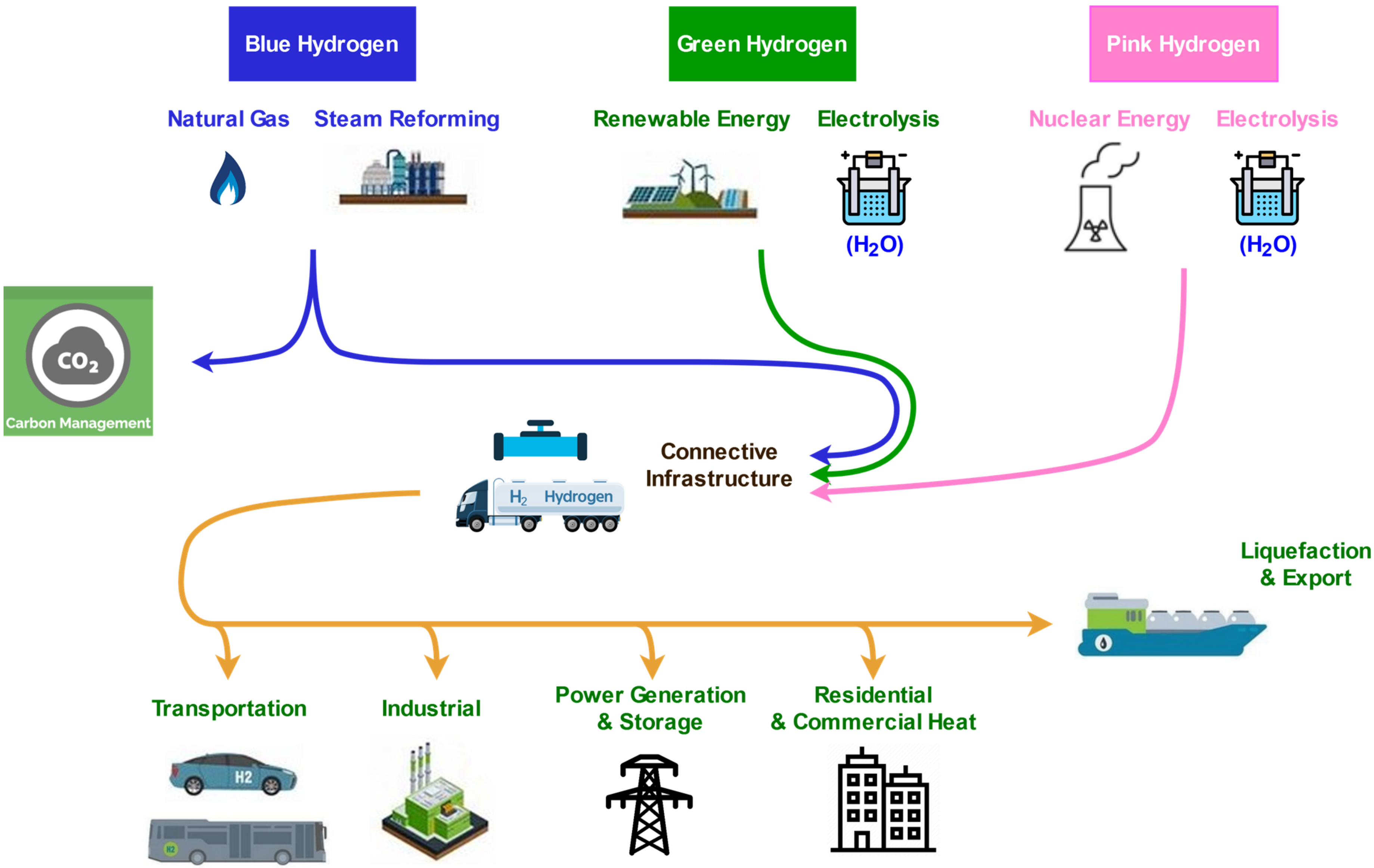
Mapping a Clean Hydrogen Economy



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Comparison of Cost and Carbon Intensity for Various Small-Scale Hydrogen Production Options at SARTA (500 kg/day H2)

Method	Cost ($/kg H_2)	Carbon Intensity ($kgCO_2e/kg\ H_2$)
SMR: delivered via LH_2[a]	5.93	9.81[b]
SMR: onsite, no capture	3.22	8.98
SMR: RNG, no capture	4.49	2.22 – 5.32[c]
SMR: onsite with capture (blue)		
- With geological storage	3.65	2.44
- w EOR/East Canton	3.52	4.17
- w EOR/Morrow	3.47	4.40
- Ready Mix Concrete	3.27	2.44
Electrolysis (green) – no grid	7.43	2.58

- **This hydrogen is compressed and liquified in Sarnia, Ontario, Canada, and delivered ca. 270 miles in LH_2 tanker trailers to SARTA. Importantly, this method of delivery arrives under pressure, and little or no additional on-site hydrogen compression is required for storage. This cost needs to be accounted for in a true apples to apples comparison.**
- **The incremental carbon footprint assumes negligible boil-off losses at the Sarnia trailer refill and during transit, and emissions of 220 gCO_2e/tonne/mile due to fuel consumption.**
- **The lower bound represents WWTP RNG at 19.34 gCO_2e/MJ and the upper bound represents landfill RNG at 46.42 gCO_2e/MJ.**

Foothill Transit Study

Lifecycle Cost of Hydrogen Fuel Cell Electric Versus Battery Electric Bus Fleets

Foothill Transit

Executive Board Meeting

Executive Board Meeting – 07/24/2020
Cost Comparison – BEB vs. FCEB

12-Year Lifecycle Cost Comparison		
	34 BEBs	**20 FCEBs**
Capital Cost – Buses	$30,260,000	$25,300,000
Capital Cost - Fueling Infrastructure	$10,948,000	$4,000,000
12 Year Fuel Cost	$11,839,973	$15,661,340
12 Year PMI Cost	$626,453.58	$1,879,361
Mid-life Maintenance Cost	$6,800,000	$690,000
	$60,474,426	$47,530,700
Cost Savings with FCEB	$12,943,726	

San Gabriel and Pomona Valleys
Greater Los Angeles, California

http://foothilltransit.org/wp-content/uploads/2020/07/07-24-2020-Agenda-Packet-Executive-Board.pdf

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Potential Economic Impact of Transition to H_2 Economy

McKinsey & Co. Report on H2 Economy Job Creation/Retention
January 2021

Year	U.S. Jobs	Ohio's Projected Share*
2030	700,00	35,000
2050	3,400,000	170,000

Source: https://www.fchea.org/us-hydrogen-study

50 MMSCFD (120,000 kg/d) capacity
Steam Methane Reformer
Air Products
Geismar, LA

*Based on Ohio's approximate 5% national manufacturing share.

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OHIO CLEAN HYDROGEN HUB ALLIANCE

The Energy of Tomorrow driving economic growth and innovation Today

Visit OH2hub.org to join the OH2 Alliance.

Together we will make Ohio a leader in the development and deployment of clean hydrogen, the energy source that will power America and the world in the 21st Century.

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Regulation of CO_2 Injection Wells in Ohio

- CO_2 injection wells are classified as **Class VI** wells (Safe Drinking Water Act).
  - CO_2 injected into subsurface formations below drinking aquifers for long-term storage.
  - Considered "geologic sequestration."
  - Only two Class VI wells in operation nationally.
  - Regulated by US EPA. States can be granted primary regulatory authority ("primacy") for CO_2 injection wells by US EPA.
- State-level primacy can expedite approval process.
  - The two operational CO_2 injection wells (in IL) went through U.S. EPA permitting process; approval took 6 years.
  - Two states (ND and WY) have received primacy and have started approving wells; approval time has taken less than 1 year.
- **BIL** set aside $75 mm to support states seeking primacy for Class VI wells.
- Ohio General Assembly passed (governor signed) HB 175, effective July 2022.
  - Requires ODNR to begin Class VI well primacy application process within 90 days.

SARTA
HYDROGEN
FUEL CELL

SARTA Key Facts

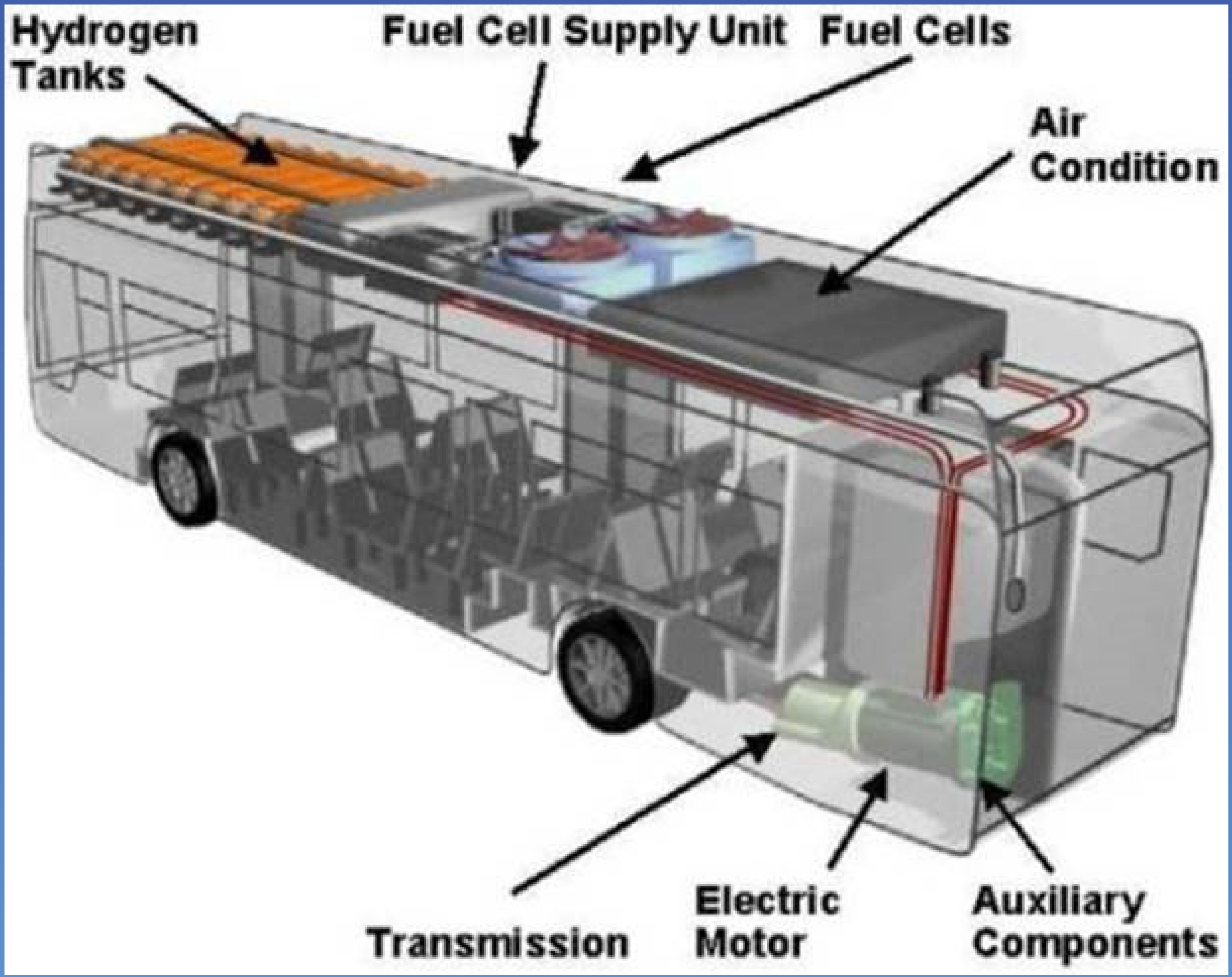
- Transport 2.8 million passengers
- 212 employees
- $23 million budget
- Operates express routes to Akron and Cleveland (the longest route in Ohio)
- 30 routes and countywide paratransit

National Fuel Cell Bus Program

- Part of a $90 million Federal Transit Administration program
- Goal is to demonstrate fuel cell buses
- Set goals for performance and demonstration of vehicles
- Deployed vehicles IN NY, CA, MA, and SC
- 2 fuel cell buses will be in Canton
- Total federal funding is $5.54 million

Bus at the Statehouse

System Layout



Hydrogen compressors

Compressor Pad

Station Controls

Operations

- Range 220 miles
- Operate every day
- 15 minute fill
- Getting about 7 mpg compared to 4 for diesel
- Program evaluated by NREL

Efforts of Midwest Center

May 5, 2017 Green on the Green – Worthington, OH - Hydrogen bus demonstration

Apr 17-19 2017 OPTA Conference - Columbus, OH – Booth and Hydrogen bus demonstration

Jul 25-26, 2017 – 2 day Hydrogen Workshop at Stark State College/ SARTA

Aug 2017 EcoFest - Grove City, OH - Hydrogen bus demonstration

Sep 13-14, 2017 – 2 day Hydrogen Workshop at Stark State College/ SARTA

Jul 26- Aug 6 2017 Ohio State Fair – Columbus, OH - Booth and Hydrogen bus demonstration – Blue Ribbon Award of Merit – Technology Education

Data loggers installed Jul 2018 for CTE study completed and published Jul 22, 2020 (Using the Birmingham NFCBP Bus for Regional Outreach in Ohio)

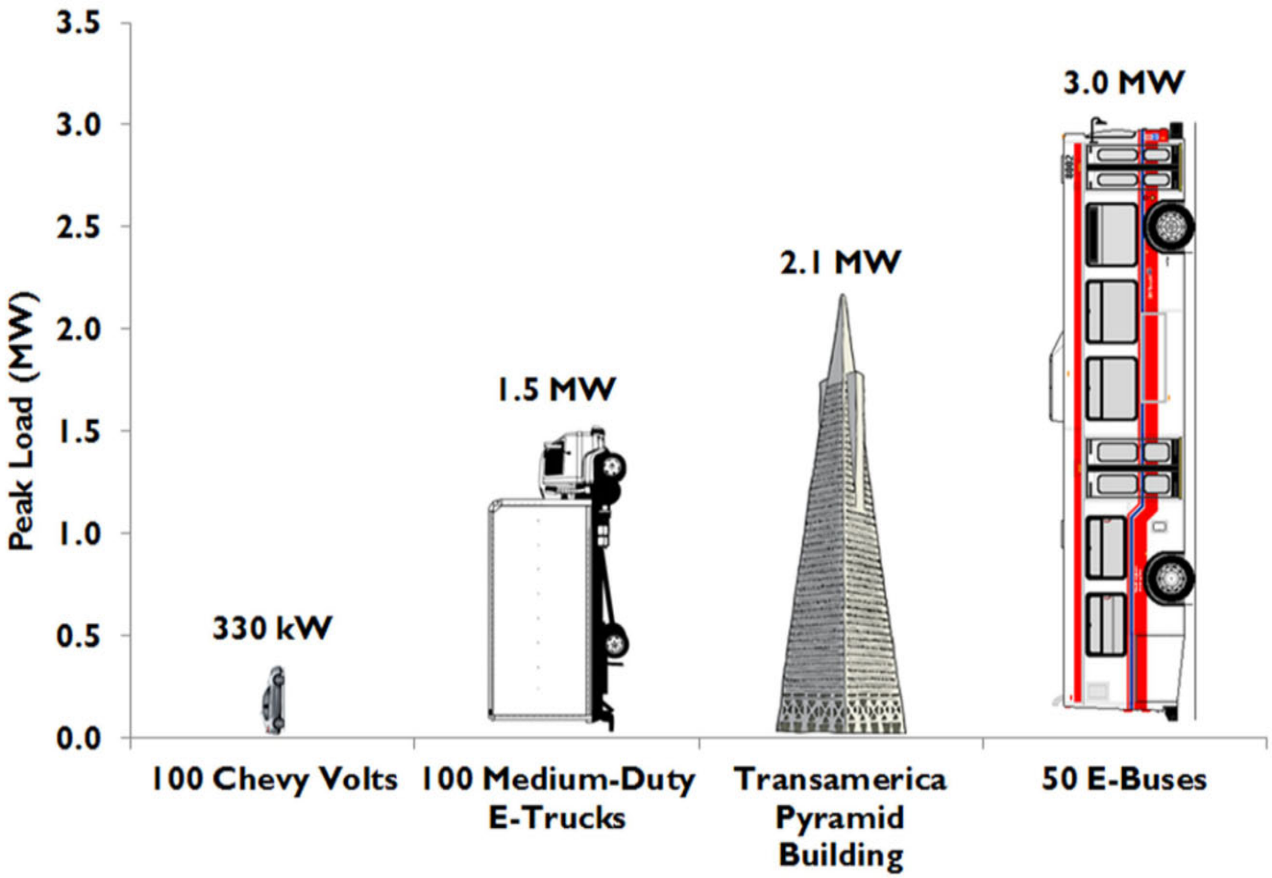
Experiment

OSU President Drake @ Horseshoe

The Prince

Walking Behind the Prince

Infrastructure the Near Term Challenge for ZEBs
Peak Loads Considerations for Battery Electric Buses



Assumptions: the Chevy Volt charging rate is 3.3 kW, the medium-duty E-Truck charging rate is 15 kW and the E-Bus charging rate is 60 kW.

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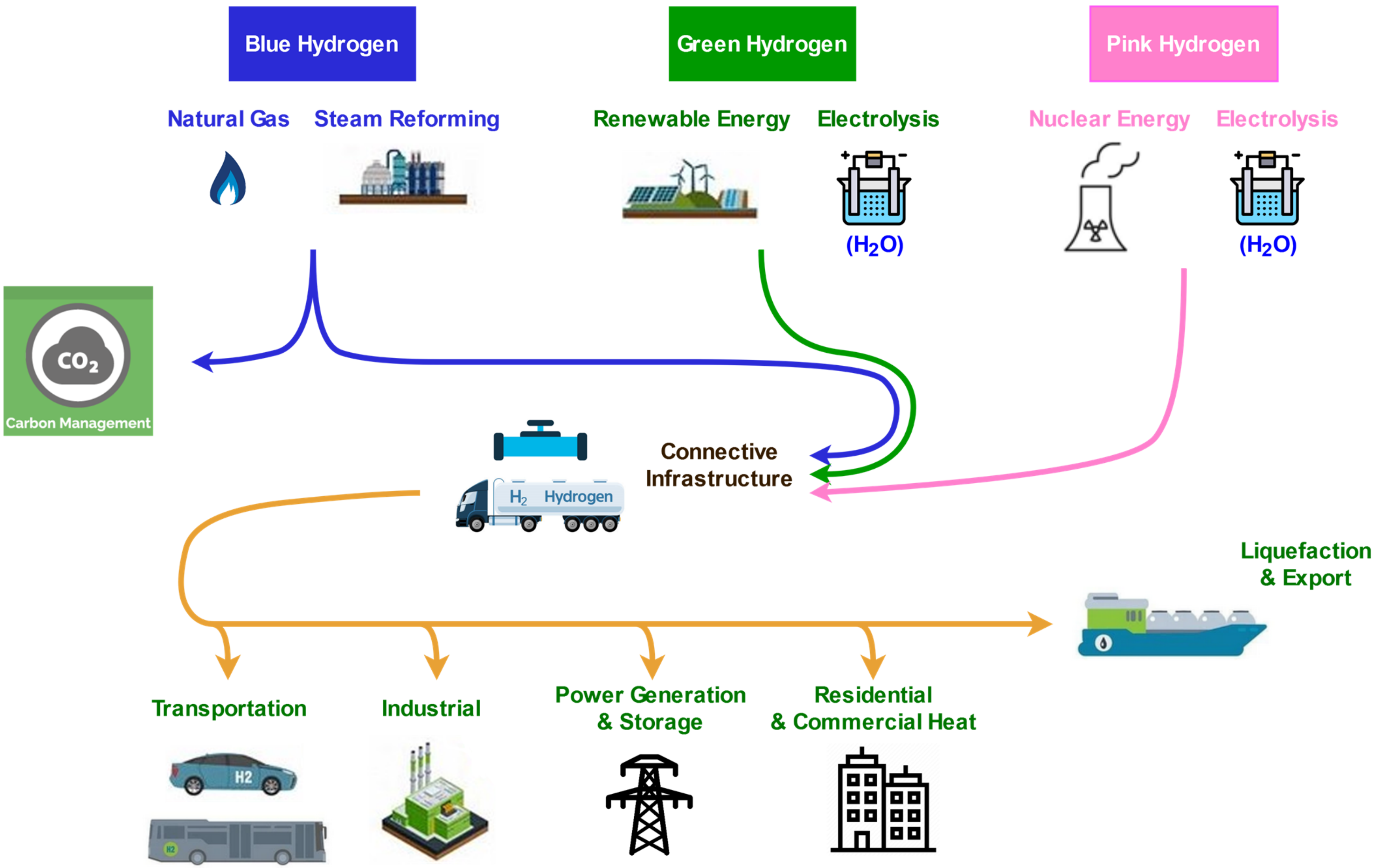
Mapping a Clean Hydrogen Economy



Decarbonization: Hydrogen's Role in a Clean Energy Economy

Transportation

- 27% of U.S. CO_2 emissions.
- 5.1 tons of CO_2 per year for a typical passenger vehicle.

SARTA (Canton)

Power Generation

- 25% of U.S. CO_2 emissions.
- 0.4 tons of CO_2 per megawatt hour of electricity generation.

LONG RIDGE ENERGY TERMINAL (Monroe County)

Steel

- 1% of U.S. CO_2 emissions.
- 1.9 tons of CO_2 per ton of produced steel.

CLIFFS (Toledo)

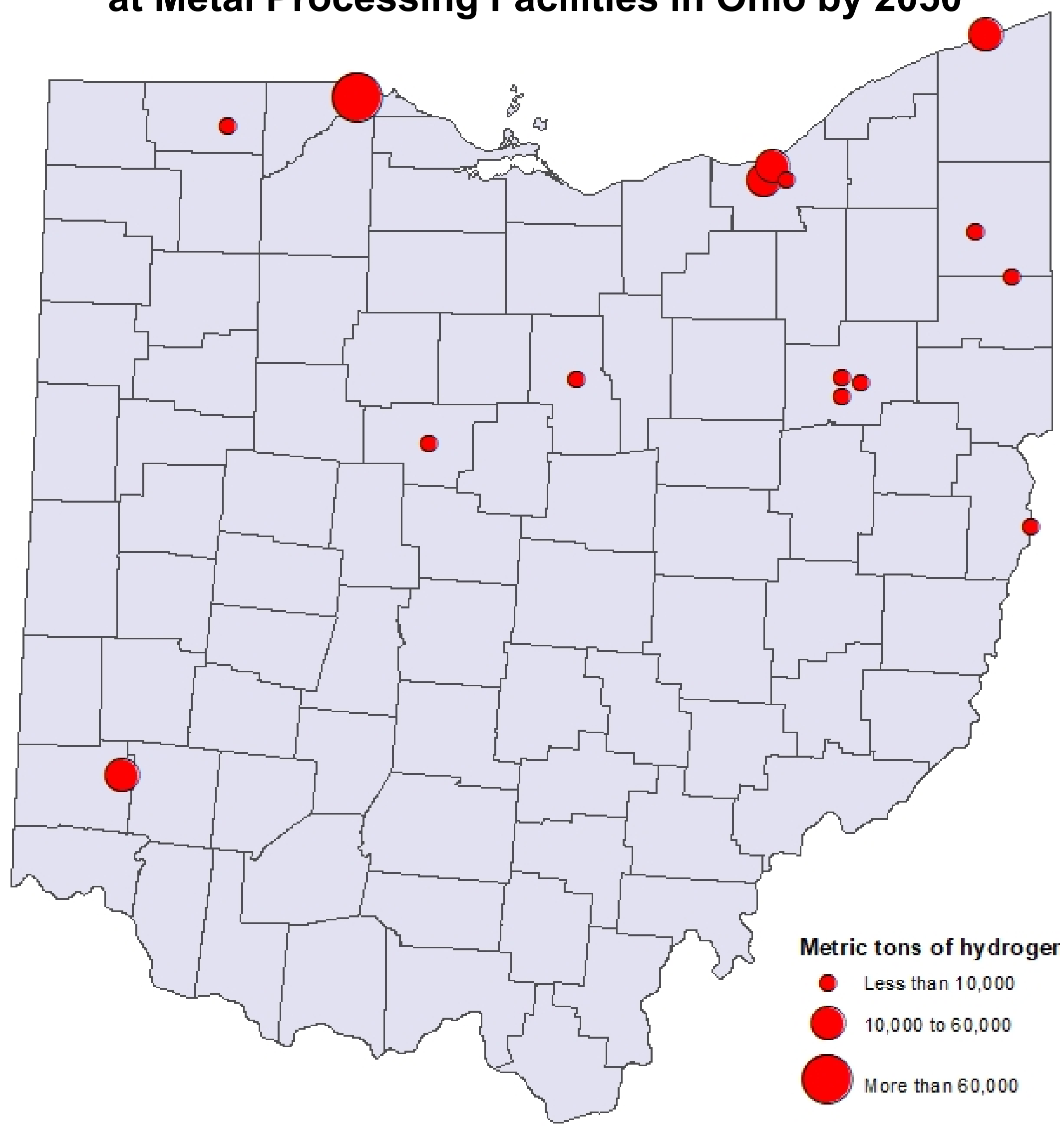
Sources: U.S. EPA (1), U.S. EPA (2), EIA, World Steel Association

Example of Industrial Use of H2 in Ohio: *Transition to H_2 Economy for Iron & Steel*

- World Steel Association describes hydrogen as a "breakthrough technology" for reducing emissions in metal refining.

- Cleveland Cliffs: *"We have committed to partnering with hydrogen producers to evaluate the partial replacement of natural gas with hydrogen when it becomes commercially available in quantities sufficient to support our (Toledo) facility."*

Argonne Projection of Annual H_2 Consumption at Metal Processing Facilities in Ohio by 2050



Annual Hydrogen Consumption in Ohio by 2050 (All Sectors)

Nutrien

bp

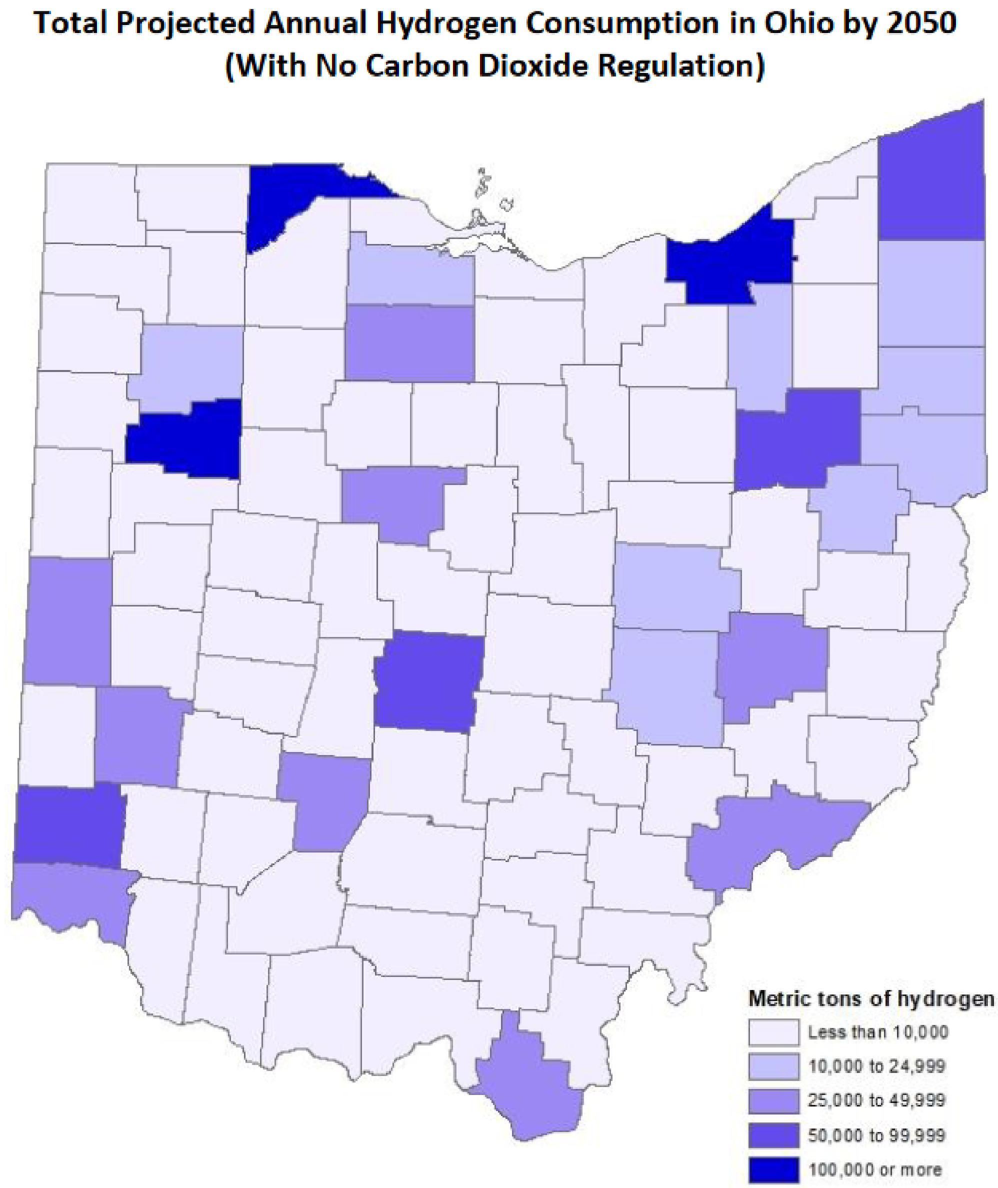
Alpont Methanol

PBF Energy

cenovus ENERGY

MARATHON

intel



Projecting Demand for Hydrogen in Ohio

Sector	2030	2040	2050
Power generation	31,100	88,400	251,200
FCEVs	2,900	35,400	430,600
Forklifts	4,700	8,400	12,700
Oil refining	188,700	202,400	217,000
Metal refining	23,900	96,600	391,000
Ammonia production	114,200	119,600	125,400
Biofuels	400	7,900	148,000
Synthetic hydrocarbons	63,600	85,800	397,700
Other Mfg. markets	8,100	9,100	10,300
TOTAL	**437,600**	**653,600**	**1,983,900**

Units are in metric tons.

- Assumes no state-level carbon regulation such as vehicle mandates.
- Hydrogen for power generation limited to 15% of capacity.

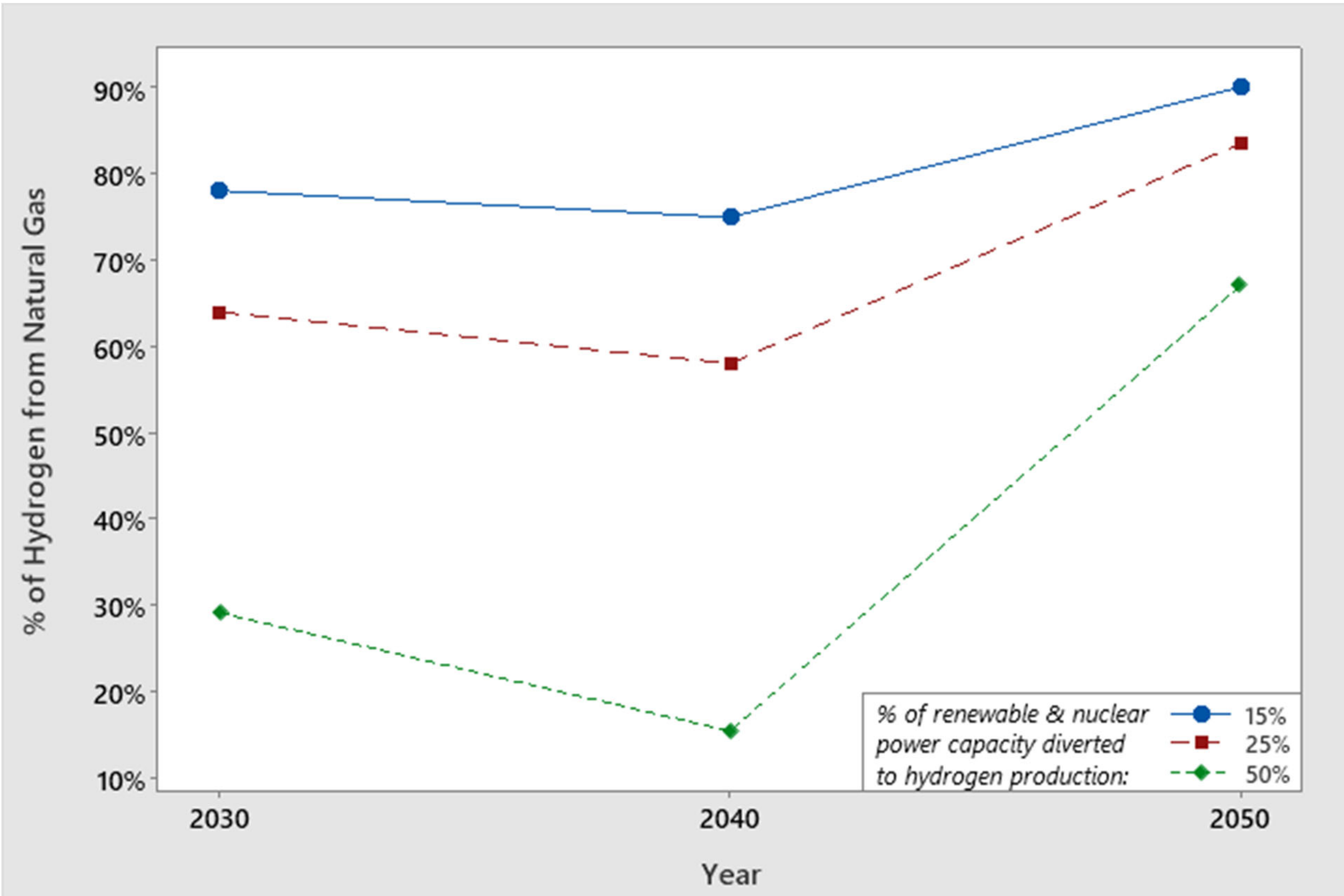
Projecting Supply for Hydrogen in Ohio by Source

Source	2030	2040	2050
Electrolysis via Nuclear Power	9,300	50,700	59,600
Electrolysis via Renewable Sources	86,600	112,800	135,900
Natural Gas (SMR)	341,700	490,100	1,788,400
TOTAL	**437,600**	**653,600**	**1,983,900**

Units are in metric tons.

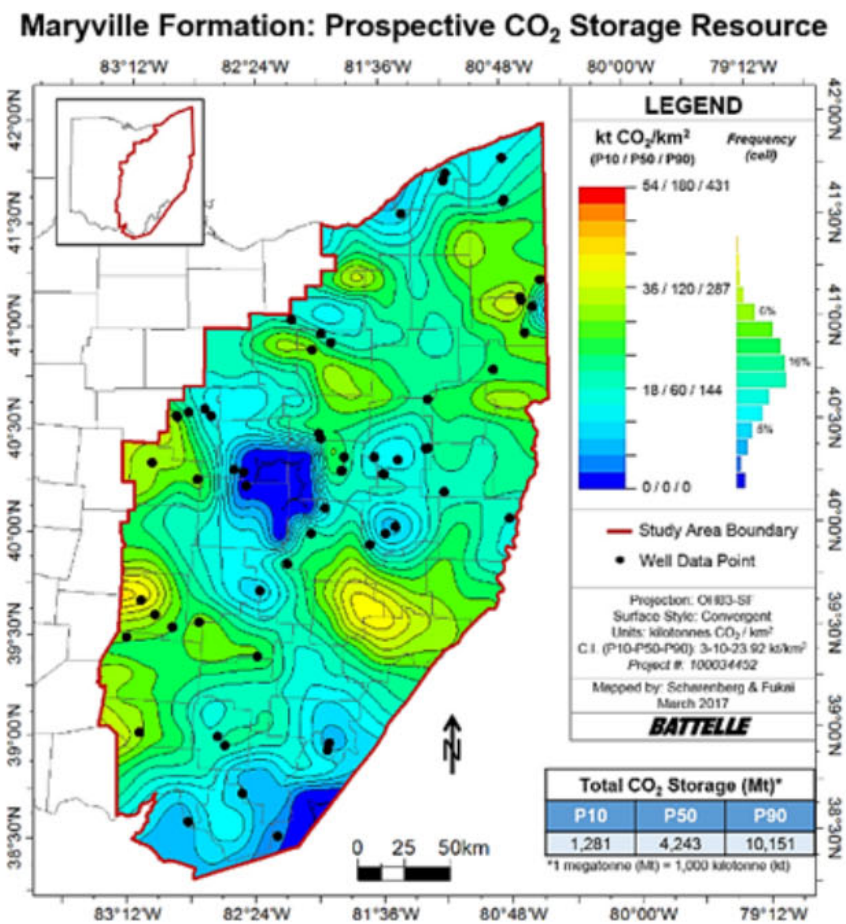
- Electrolytic production limited to 15% of power generation capacity.
- Hydrogen from natural gas is what must be supplied to meet demand after accounting for pink and green hydrogen.
- 1.8 million metric tons of hydrogen supplied via SMR would require around 280 bcf of natural gas.
    - 280 bcf ≈12.5% of what Ohio shale wells produced annually.

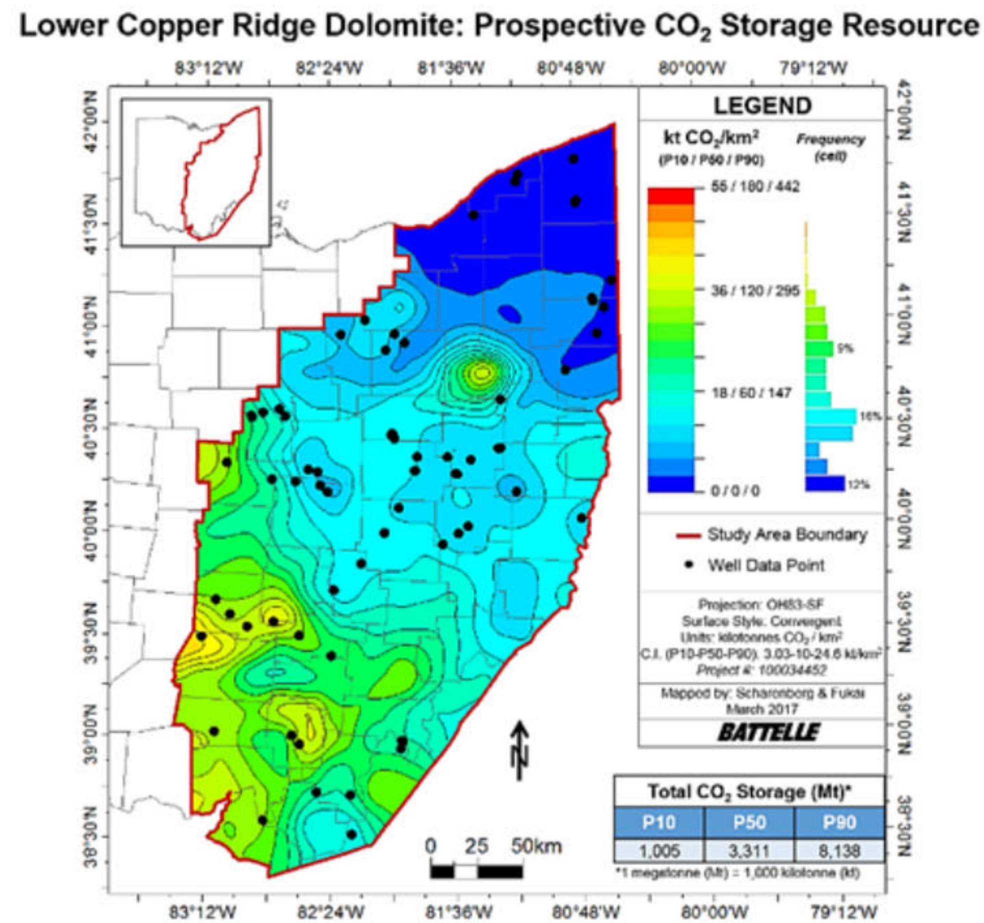
What if more nuclear/renewable power were diverted? How much natural gas would be needed then for hydrogen production?



Carbon Management with Blue Hydrogen

- 2 million metric tons (MMT) of blue H_2 would yield around 18 MMT of CO_2.
- <u>Battelle</u> projects over 10 *billion* metric tons of CO_2 storage capacity in Ohio.





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Carbon Management and Pore Space Rights

- CO_2 storage would occur in pore space, the tiny voids in subsurface rock that are unoccupied by solid material.

- Pore space ownership is unsettled in Ohio.
  - Surface or mineral estate?

- MT, WY, and ND have enacted statutes.
  - Pore space belongs to surface owner.

- Majority of case law elsewhere → "American Rule"
  - Supports surface owner as owner of pore space.

- What about unitization?
  - States enacting statutes establishing pore space ownership also adopt language on conditions for unitization.
    - Wyoming: owners of 80% of land overlying a pore space unit must approve.
    - Montana and North Dakota: 60% approval required.

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