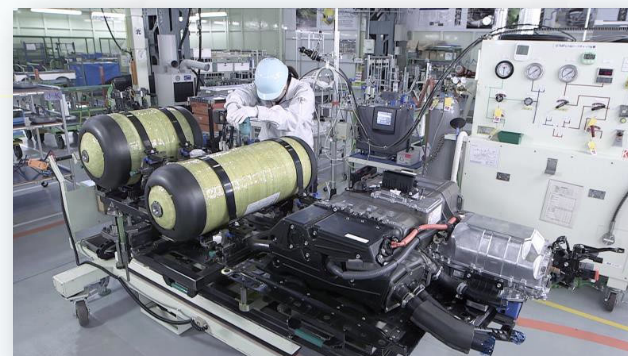
Ohio: Poised to lead the hydrogen powered zero-emission future...

Every component of a clean hydrogen hub creates opportunity for Ohio and Ohioans…



SARTA Receives Federal Grant for Pollution Free Buses

The Stark Area Regional Transit Authority says it will be the Only public transit system in Ohio next year to have a fuel-cell Bus that will emit no pollution.

The office of Rep. Bob Gibbs told SARTA that the FTA Has approved a $2.7 million grant to buy a hydrogen fuel cell bus. September 24, 2014

Ask anyone to identify the epicenter of innovation in zero-emissions transportation and they are likely to answer San Francisco, Seattle, San Diego, Denver, Denmark, Germany, Japan or China.

They would all be wrong.

Ground zero of the alternative fuel revolution is located in the middle of a quiet neighborhood in Canton, Ohio where SARTA operates one of the largest fleets of hydrogen fuel cell-powered (HFC) transit vehicles in North America.


The Washington Post

Transportation

A hydrogen-powered bus goes to Washington

But only for a visit, as officials from an Ohio public transit agency spread the word about zero emissions.

SARTA's borrow a bus zero-emissions tour begins eight-stop swing through California

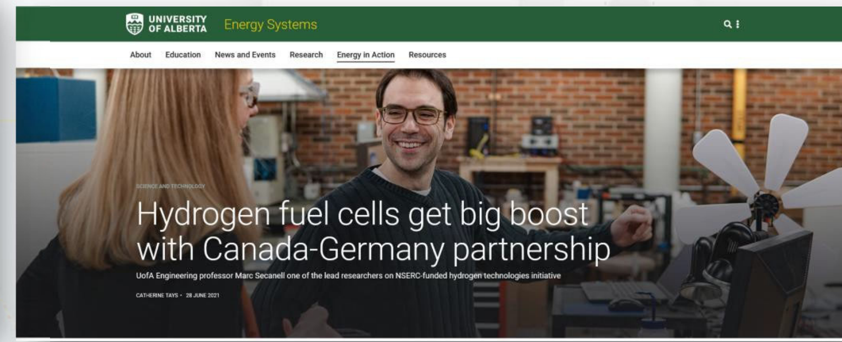
Transit managers will be able to review hundreds of thousands of miles worth of real-world data SARTA has collected while operating HFC buses on the streets of Stark County in Canton, Ohio, in a multitude of various weather conditions over the past 10 years. *Mass Transit,* June 7, 2021

BORROW A BUS
Zero Emissions Tour

Since making its first trip to the Central Midlands Transit Authority in Columbia, S.C. the BaB tour has visited 50 cities in the U.S. and Canada including Washington, D.C., Alexandria, Va., Chicago, Ill., Portland, Ore., Seattle, Wash., Tampa, Fort Lauderdale, and Orlando, Fla., Lansing, Mich., Los Angeles, CA, San Francisco, CA, Sacramento, CA and New Brunswick, N.J. Next up: New York City, Philadelphia, Ann Arbor, Hawaii, Australia, Equator and the invites continue to pour in…

Concern about climate change is driving interest and investment in clean hydrogen across the globe…

Concern about climate change is driving interest and investment in clean hydrogen across the globe…



Cummins, once synonymous with "diesel," is going all in on clean hydrogen…

PRODUCTS PARTS AND SERVICE INDUSTRIES ABOUT NEWS CAREERS SUPPORT

NEW POWER Overview Applications Technology About Hydrogen

Innovations in Focus

Worldwide, Cummins has over 500 electrolyzers in operation, and over 2,000 fuel cells powering hundreds of vehicles. The stats speak for themselves. Cummins has the technology and real-world experience to fuel the future.

Largest PEM Electrolyzer in the United States

Cummins using hydrogen technology to enable renewable energy for public utilities in Washington state.

Cummins leads in SOFC technology

Cummins is quickly becoming the leader in a power technology for commercial and industrial uses that could be an important bridge to a carbon-neutral future and beyond.

Hydrogen fuel cell trains accelerating

Cummins-powered hydrogen fuel cell trains are heading further down the track in Austria.

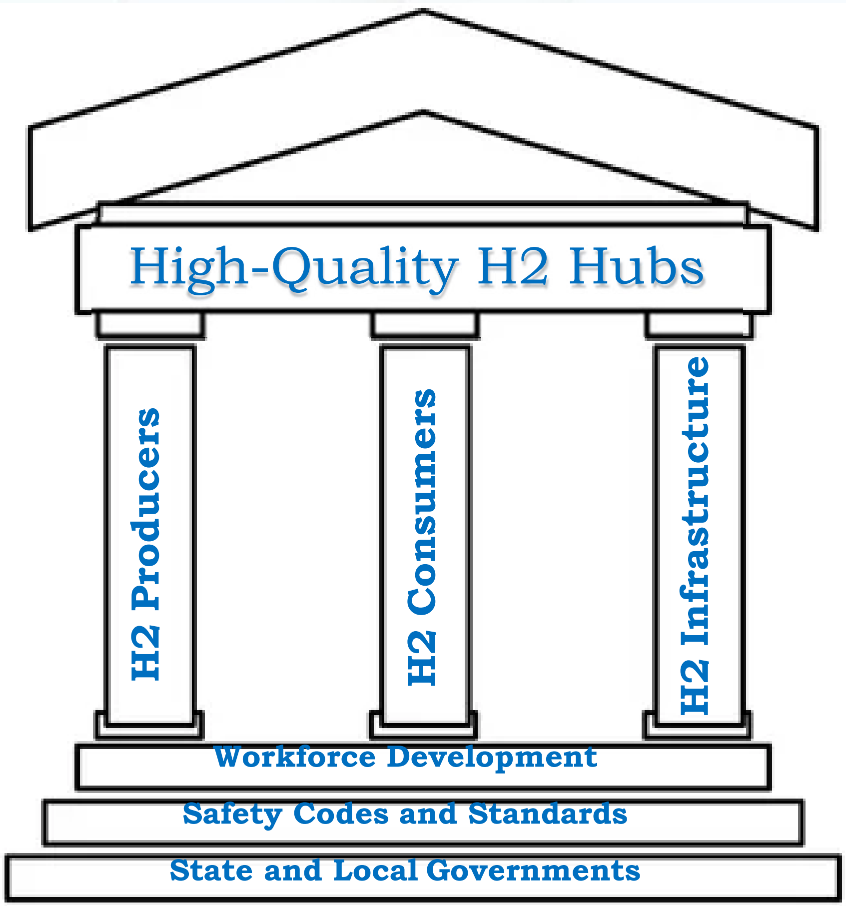
Microsoft, Intel leading tech company migration to clean hydrogen-powered fuel cells for power storage

The dawn of the H2 economy has arrived.

Ohio has the opportunity to lead, grow, and prosper…

Will we seize it, or be left standing by the side of the road as the zero-emission economy drives by?

Clean Hydrogen Hub Scope and Process



Example Stakeholders

H_2 Producers & Source

- Renewables
- Fossil Fuels (+CCS)
- Nuclear

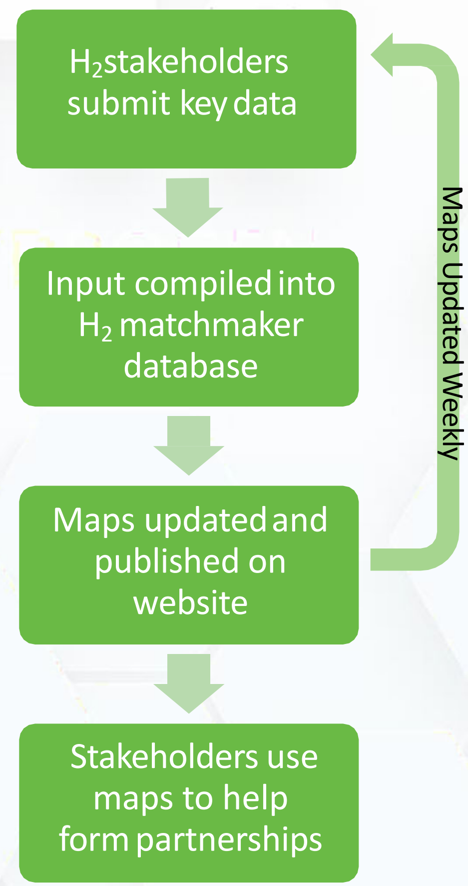
H_2 Consumers

- Electrical power production
- Industrial use
- Residential and commercial heating
- Transportation

H_2 Infrastructure Operators

- H_2 bulk storage
- H_2 compatible pipelines
- Fueling Stations
- H_2 delivery solutions

Matchmaker Process



Levin
Urban.csuohio.edu

The Ohio Clean Hydrogen Hub Alliance:
Decarbonizing Northern Appalachia and the Midwest


SARTA Fuel Cell Bus

Kirt Conrad
Chief Executive Officer
Stark Area Regional Transit Authority

Andrew R. Thomas
Mark Henning
Midwest Hydrogen Center of Excellence
Cleveland State University

MEC Conference
September 20, 2022

Levin
Urban.csuohio.edu

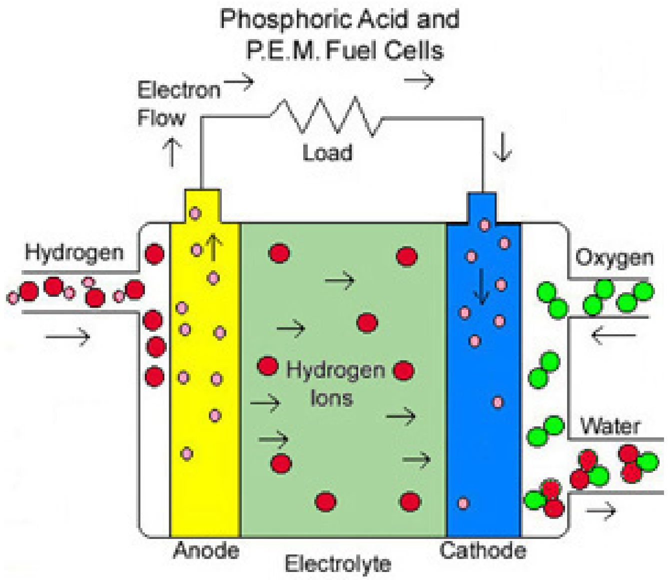
Midwest Hydrogen Center of Excellence

- Managed by:
  - Stark Area Regional Transit Authority
  - Cleveland State University
- Mission:
  - Enable adoption of H2 technology in Midwest
- Activities:
  - Education And Community Outreach
  - Commercialization research
  - Train drivers, mechanics, operators

H2 Refueling Station
Stark Area Regional Transit Authority
Canton, Ohio

Hydrogen Basics

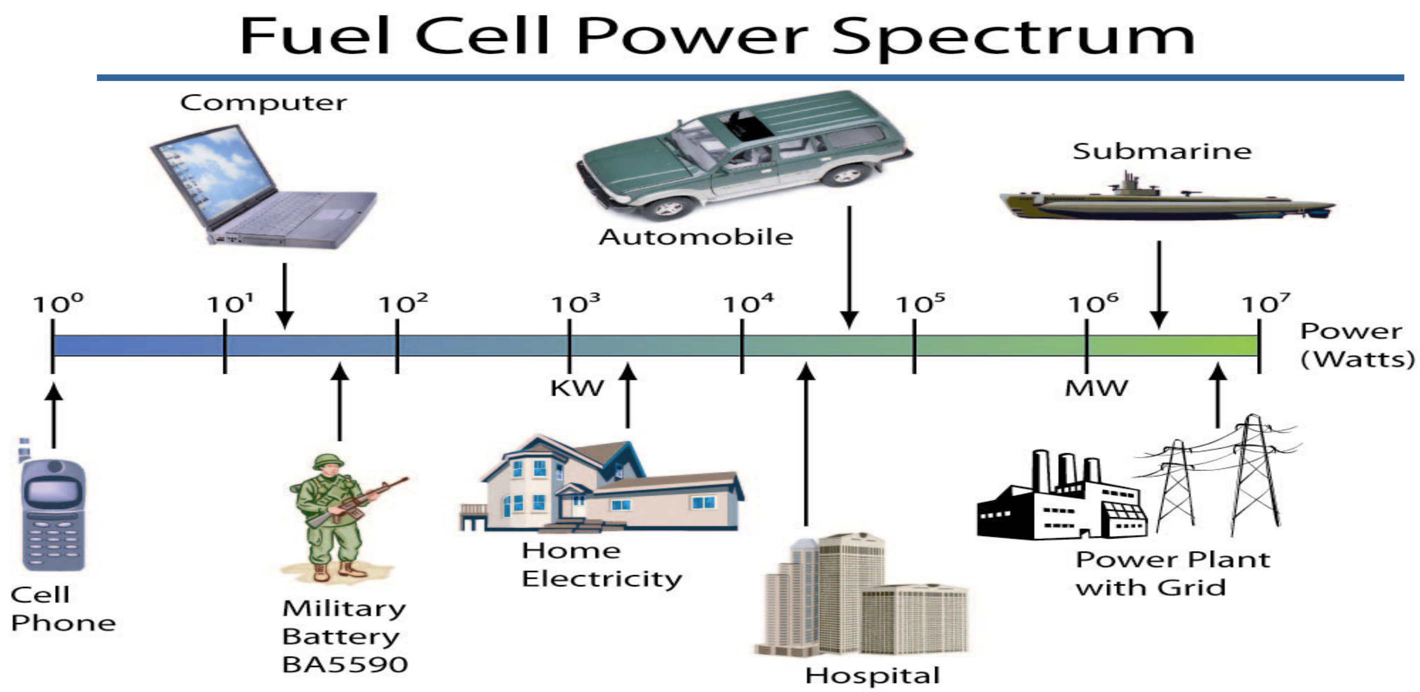
- Energy Carrier
  - Combined with oxygen creates H2O + energy
    - Creates heat if burned
    - Electricity if fuel cell
- Zero Emissions
  - Must capture carbon if made from natural gas
  - Must decarbonize transportation
- Uses
  - Electricity
  - Chemical feedstock
  - Thermal



Hydrogen fuel cell

Levin
Urban.csuohio.edu

Electricity Generation Range for Fuel Cells



Levin
Urban.csuohio.edu

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

Levin
Urban.csuohio.edu

Department of Energy Hydrogen Earth Shot

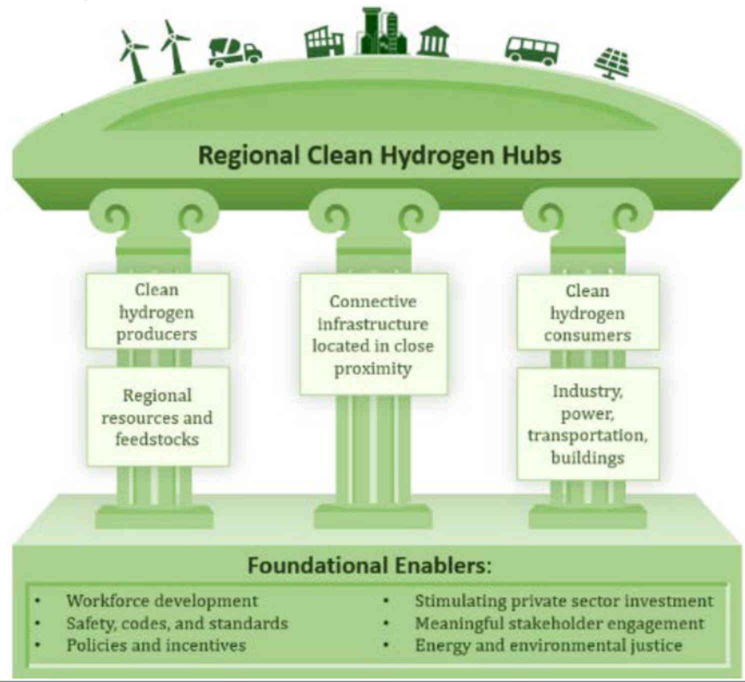
- First of several DoE Earth Shots aimed at decarbonization of:
  - Transportation
  - Electricity generation
  - Manufacturing
- Goal: $1.00/kg clean hydrogen by 2030
  - Gray hydrogen already under $1/kg
  - Green is $5-7/kg
  - Blue?
- But storage and distribution 2/3 of total cost at pump.
  - Currently $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)

Levin
Urban.csuohio.edu

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: at least 6 regional clean H_2 hubs

DOE's concept of a clean H_2 hub



Levin
Urban.csuohio.edu

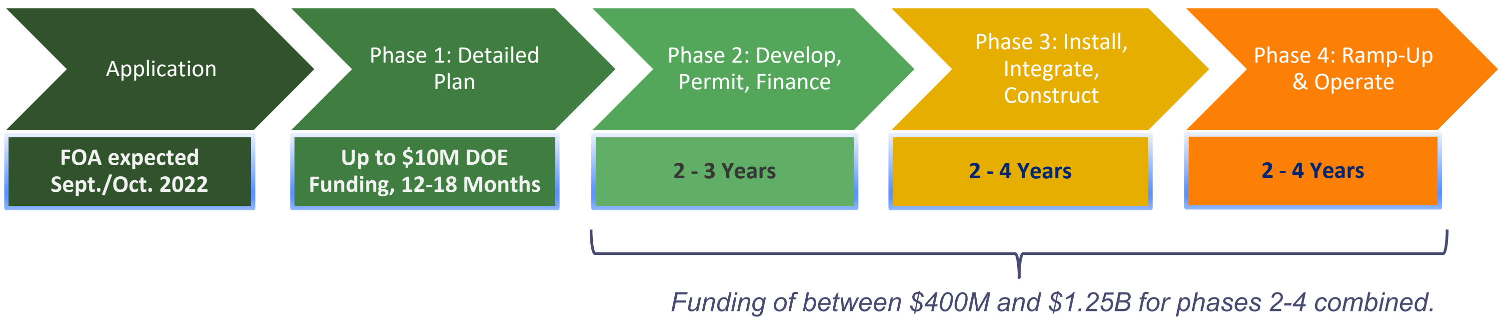
Infrastructure Law and Clean Hydrogen Hubs

- **Includes $8 billion for at least four regional clean hydrogen hubs**:
  - *Hubs:* network of clean hydrogen producers and consumers, plus connective infrastructure, located in close proximity.
  - *Clean hydrogen:* hydrogen produced with a carbon intensity less than or equal to 2 kg of CO_2 per kg of hydrogen produced.*
- **Law requires feedstock and end-use diversity:**
  - At least 1 hub for each hydrogen source: fossil fuels (w/carbon capture); renewable energy; nuclear energy.
  - At least 1 hub for each hydrogen use: electric power generation; transportation; industrial; residential and commercial heating.
- ***At least 2 hubs will be in regions with the greatest natural gas resources*.**

*1 kg of hydrogen = 1 gallon of gasoline in energy content

Levin
Urban.csuohio.edu

Regional Clean Hydrogen Hub Timeline



- **Objectives, Requirements, and Guiding Principles**
  - Feedstock, End-use, and Geographic Diversity
    - At least 2 hydrogen 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
  - Employment
    - Priority to hubs likelier to create long-term employment for greatest number of residents

- **22 prospective pre-application hubs announced as of August.**

Hydrogen Funding Opportunities

- **Inflation Reduction Act (IRA)**
  - 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

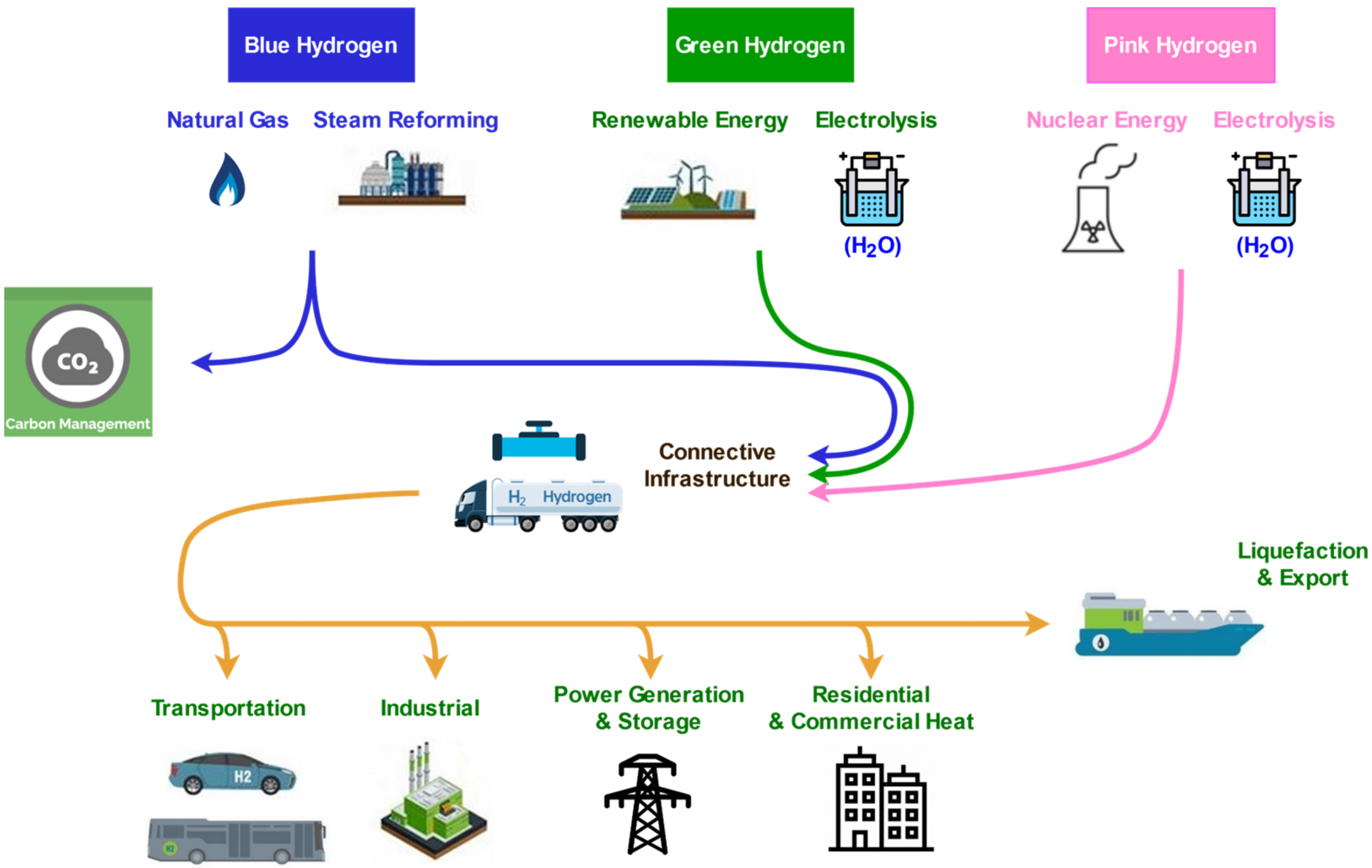
Sources of Hydrogen

- Steam Reforming of Natural Gas
  - Most cost- effective strategy
  - High temperature fuel cells have on-board refining
  - With carbon capture: **Blue**
- Electrolysis
  - Wind, Solar Energy: **Green**
  - Nuclear Power: **Pink**
  - Grid may not be clean
- Other
  - Biomass: **Green**

Steam Methane Reformer

Levin
Urban.csuohio.edu

Mapping a Clean Hydrogen Economy



Levin
Urban.csuohio.edu

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
- with EOR/ECOF	3.52	4.17
- with EOR/MCOF	3.47	4.40
- with RMC	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.**

Levin
Urban.csuohio.edu

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.

Levin
Urban.csuohio.edu

MIDWEST HYDROGEN CENTER OF EXCELLENCE
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.

MHCoE
Andrew R. Thomas
a.r.thomas99@csuohio.edu
Mark Henning
m.d.henning@csuohio.edu
216 687 9304
http://www.midwesthydrogen.org/mhcoe/
http://levin.urban.csuohio.edu/epc/

SARTA
Kirt Conrad, CEO
kconrad@sartaonline.com
https://www.sartaonline.com/

CHW Advisors
Matt Carle
matt@chwadvisors.com
https://chwadvisors.com/

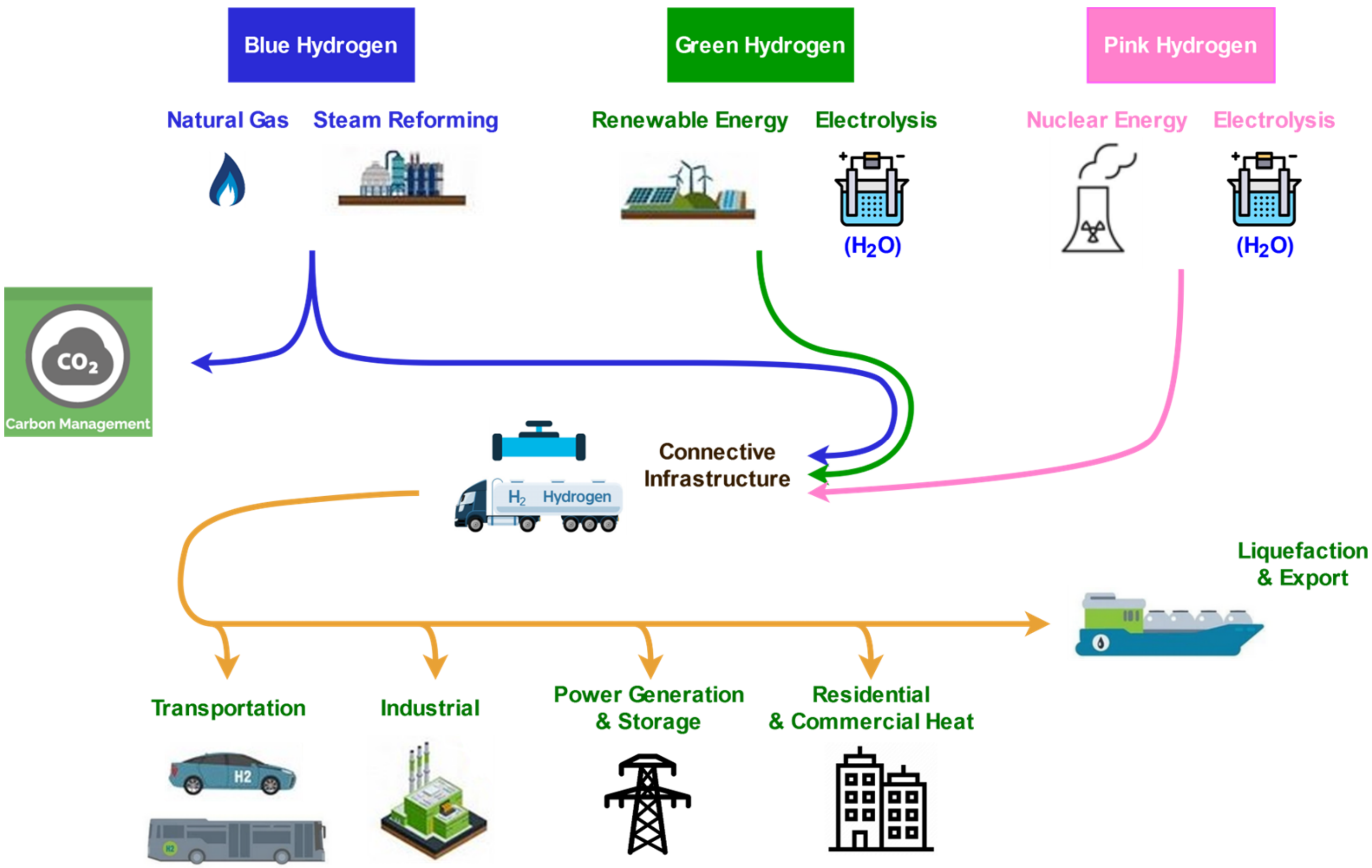
Mark Henning

Research Associate

Energy Policy Center/MHCoE

Cleveland State University

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.

(Canton)

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

(Monroe County)

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

(Toledo)

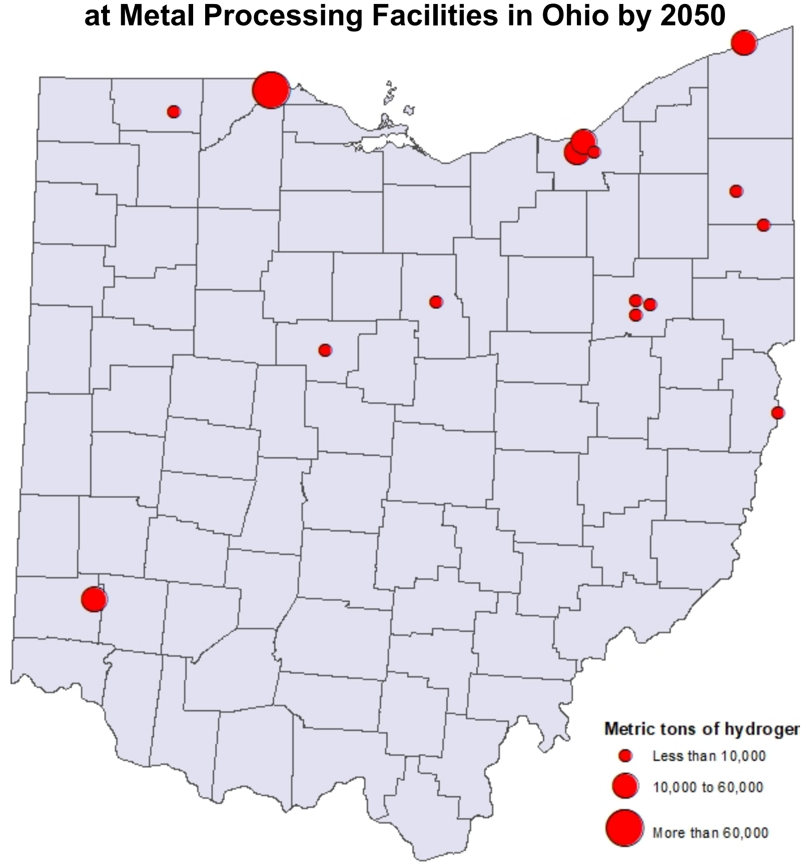
Sources: U.S. EPA (1), U.S. EPA (2), EIA, World Steel Association

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

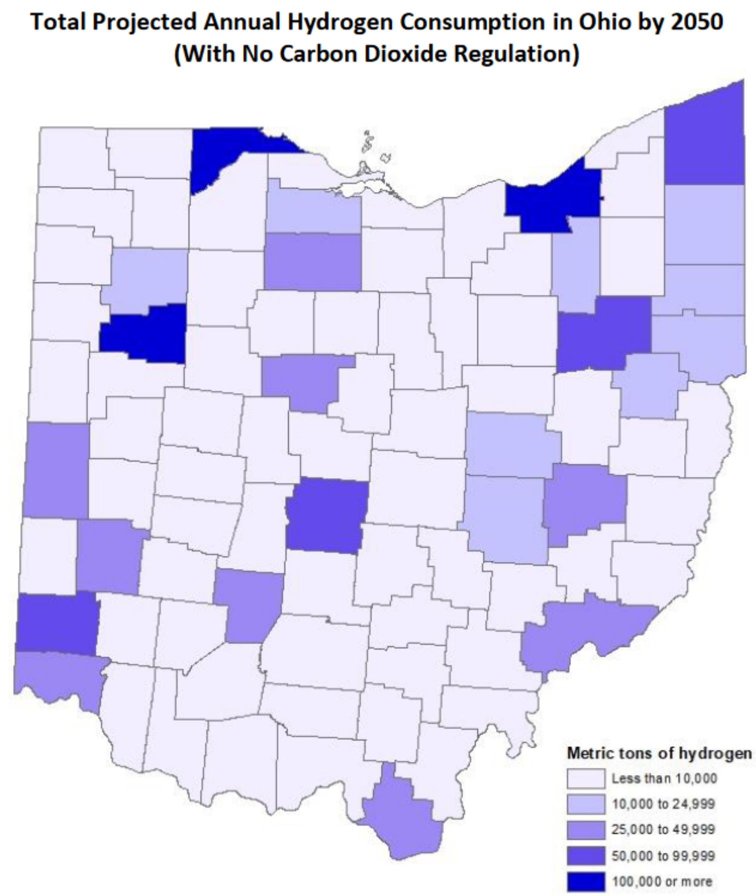
- World Steel Association describes hydrogen as a "breakthrough technology" for reducing emissions in metal refining.

- 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)



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.

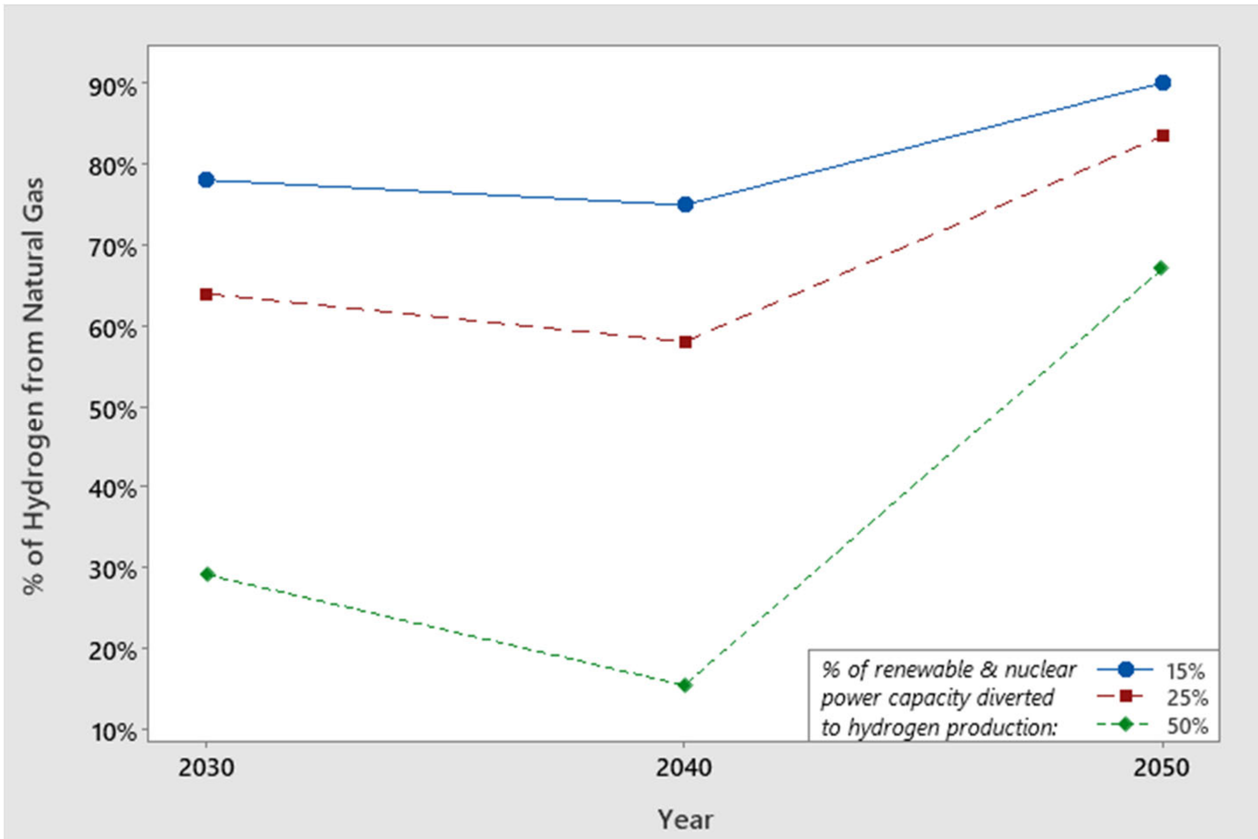
Projecting Supply for Hydrogen in Ohio by Source

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.

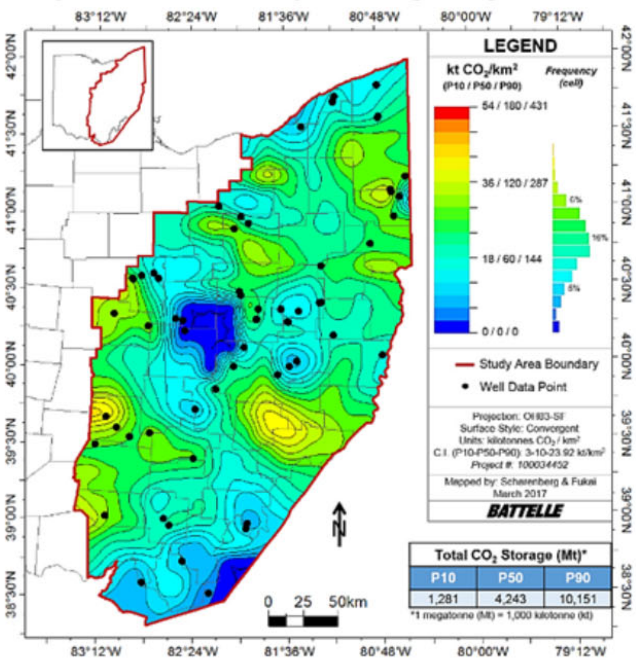
What if more nuclear/renewable power were diverted? How much natural gas would be needed then for hydrogen production?



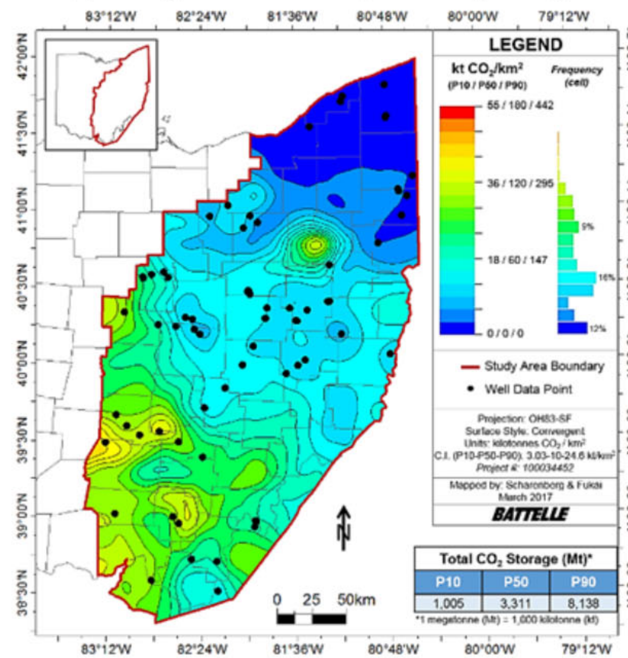
Carbon Management with Blue Hydrogen

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

Maryville Formation: Prospective CO_2 Storage Resource



Lower Copper Ridge Dolomite: Prospective CO_2 Storage Resource



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.

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.

Levin
Urban.csuohio.edu

MIDWEST HYDROGEN CENTER OF EXCELLENCE
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.

MHCoE
Andrew R. Thomas
a.r.thomas99@csuohio.edu
Mark Henning
m.d.henning@csuohio.edu
216 687 9304
http://www.midwesthydrogen.org/mhcoe/
http://levin.urban.csuohio.edu/epc/

SARTA
Kirt Conrad, CEO
kconrad@sartaonline.com
https://www.sartaonline.com/

CHW Advisors
Matt Carle
matt@chwadvisors.com
https://chwadvisors.com/

Biographical Information

Andrew R. Thomas
Energy Policy Center
College of Education and Public Affairs
Cleveland State University
216.687.9304 a.r.thomas99@csuohio.edu

Andrew Thomas directs the Energy Policy Center at the College of Education and Public Affairs at Cleveland State University, where for 13 years he has lead research on electricity regulation and markets, microgrids, transportation, energy storage, district energy, fuel cells and oil and gas development. He is also the director for the Renewable Hydrogen Fuel Cell Collaborative and the Midwest Hydrogen Center of Excellence. He received his J.D. from Loyola University of New Orleans, where he was a law review editor. He is chairman of the Ohio Oil and Gas Commission, which he has served on for six years.

Mark D. Henning, Research Associate, Energy Policy
Cleveland State University
216-875-9606 m.d.henning@csuohio.edu

Mark Henning is principal researcher with the Energy Policy Center at Cleveland State University, a role he also performs on behalf of the Midwest Hydrogen Center of Excellence, a regional initiative for the advancement of hydrogen-powered, zero-emissions vehicles in Midwestern public transit. His research focuses on the hydrogen economy, microgrids, energy storage, sustainable transportation, oil and gas investment and climate-related financial risk. His current projects include research on behalf of the Federal Transit Administration, Stark Area Regional Transit Authority, JobsOhio, and Cuyahoga County's Department of Sustainability. He holds a BA in Economics, a Master of Public Administration, and an MS in Statistics, all from Cleveland State University.