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Update on Ohio Hydrogen Hub Strategy
February 2024

SARTA Hydrogen Fuel Cell Bus
Refueling Station
Canton, Ohio

American Institute of Chemical Engineers
February 15, 2024

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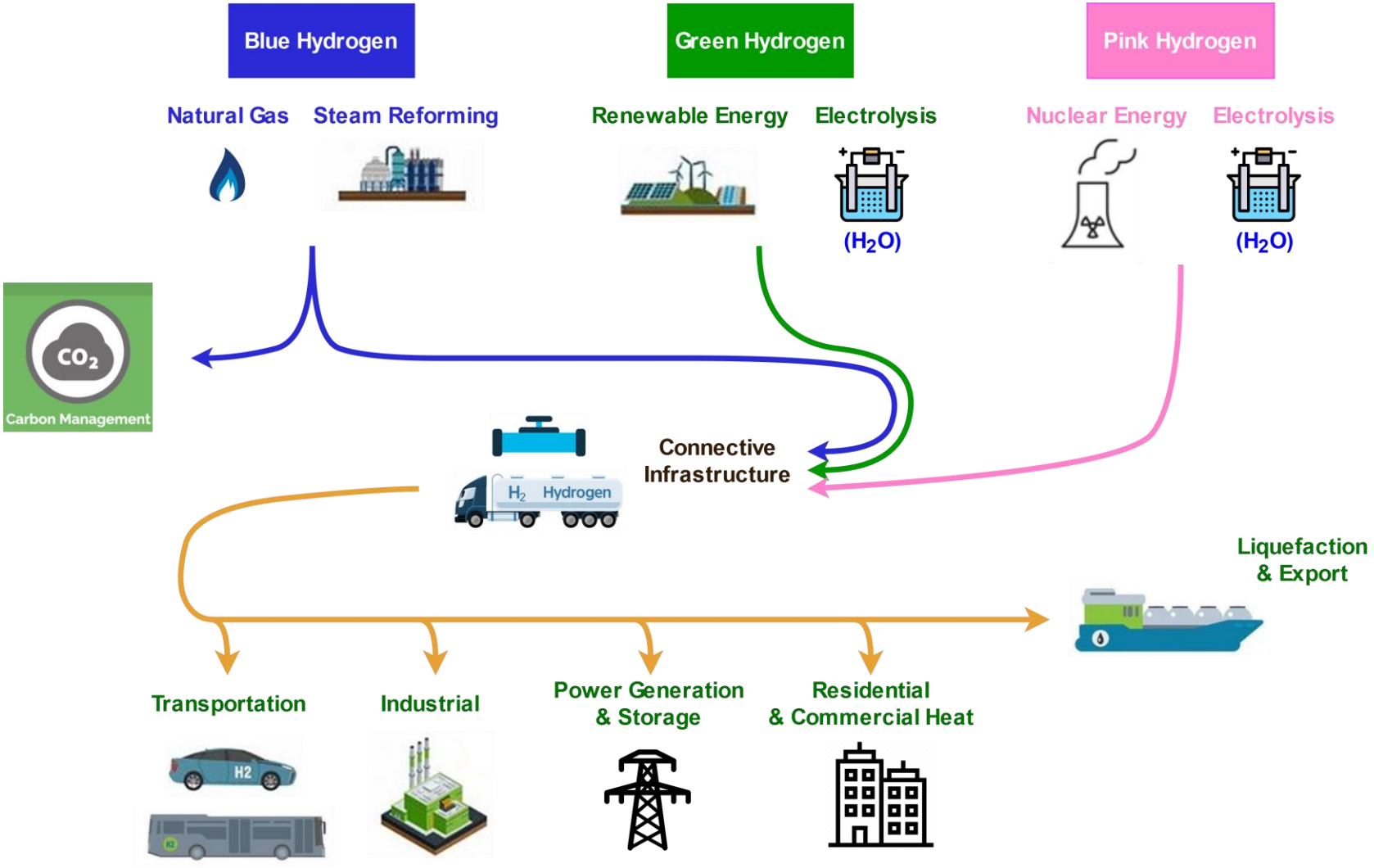
Mapping a Clean Hydrogen Economy



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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.

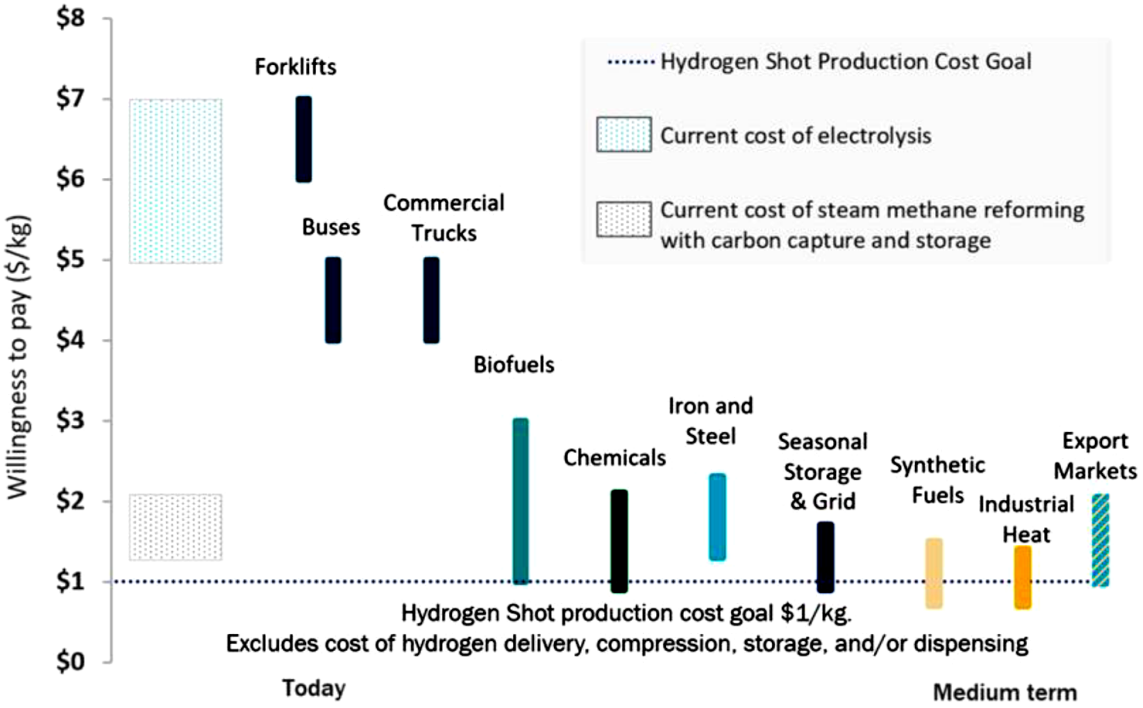
- Electrolytic production limited to 15% of power generation capacity.
- Hydrogen from natural gas is what must be supplied to meet demand after accounting for pink and green hydrogen.
- 1.8 million metric tons of hydrogen supplied via SMR would require around 280 bcf of natural gas.
  - 280 bcf ≈12.5%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

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)

Willingness To Pay

Willingness to pay, or threshold price, for clean hydrogen in several current and emerging sectors (including production, delivery, and conditioning onsite, such as additional compression, storage, cooling, and/or dispensing). Current costs of hydrogen production depicted do not include impacts of regulatory incentives, such as those in IRA.



Source: U.S. Department of Energy 2023

Comparison of Cost and Carbon Intensity for Various Small-Scale Hydrogen Production Options.

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.**

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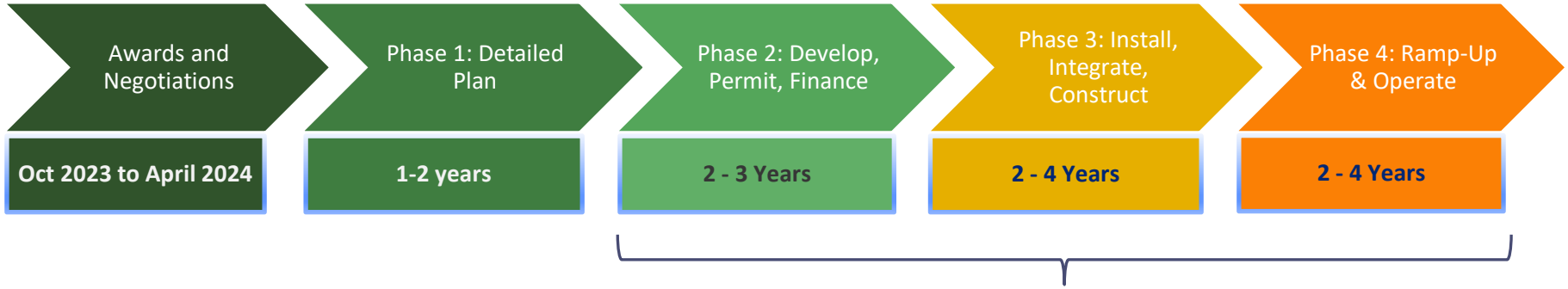
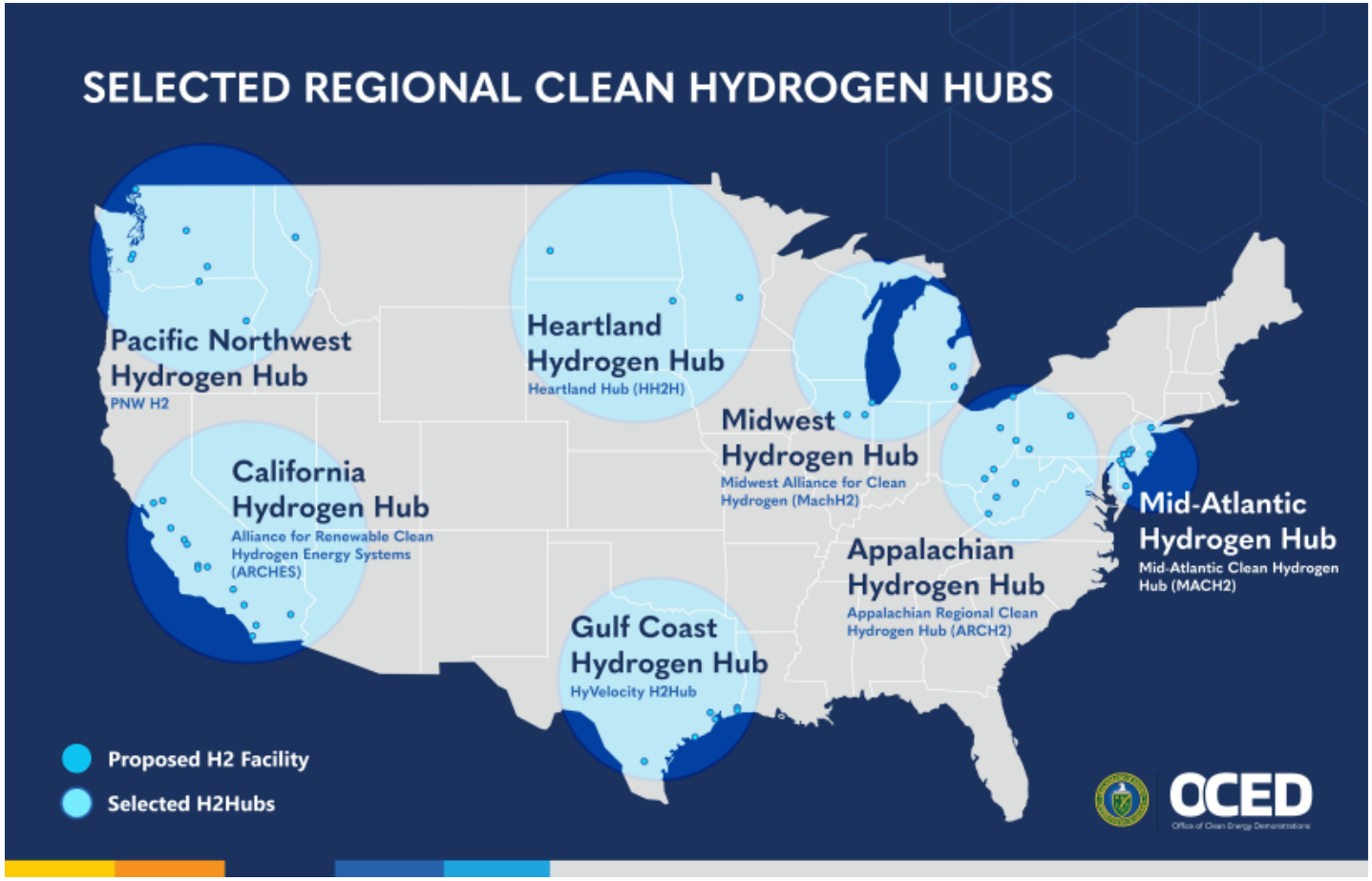
Federal Investment Into Clean Energy

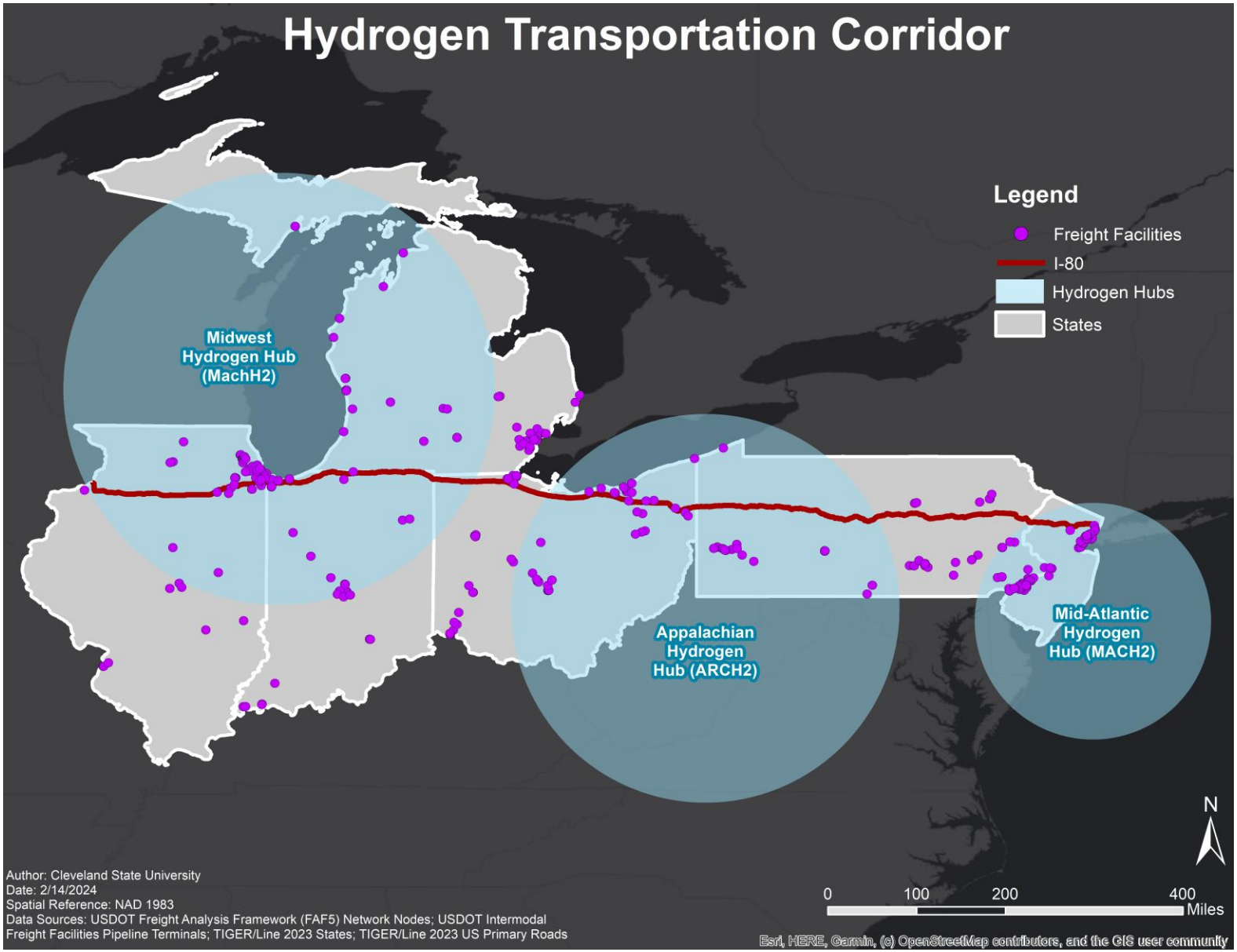
- **Bipartisan Infrastructure Bill**
  - $73 billion over 5 years on grid infrastructure
  - $50 billion over 5 years for weatherization
  - ***$8 billion for clean hydrogen infrastructure***
  - ***$1.5 billion for hydrogen research***
  - ***$12 billion for carbon capture and sequestration***
- **Inflation Reduction Act**
  - No Cap – federal tax credits that can be converted to cash – 30-50% of project cost
  - Covers renewable power, geothermal, microgrids, H2
  - McKinsey estimates credits at over $400 B over ten years – without H2
    - ***With H2, estimated at $1 trillion***

Dept of Energy Clean Hydrogen Hub Timeline



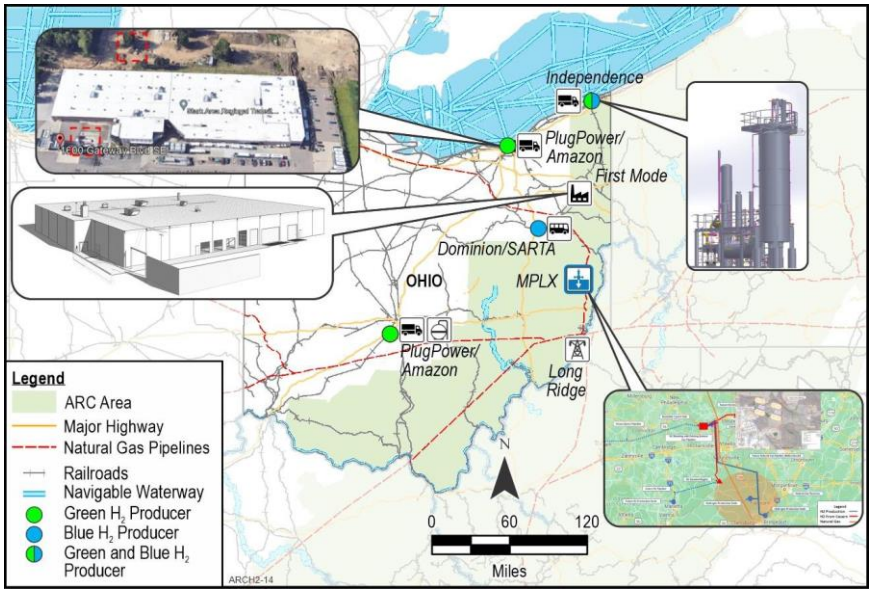
- **$7 Billion in Awards Made in October 2023 for Clean H2 Generation**
  - 7 of 33 finalists awarded hubs
    - **ARCH2 -- $925 mm (led by Battelle)**
      - Ohio, West Virginia, Pennsylvania, Kentucky
    - Other Winners: California, Gulf Coast, Heartland (Minn), Mid-Atlantic, Midwest (Ill), Pacific NW
  - $1 Billion more coming for market development programs
    - Notice of Intent summer 2023 for clean hydrogen off takers
- **Requirements**
  - Production capacity of at least 50 to 100 metric tons/day
  - 50% non-federal cost share
  - Clean H2 defined as less than 4 kg CO2e/kg H2 for lifecycle emissions


SELECTED REGIONAL CLEAN HYDROGEN HUBS
Pacific Northwest Hydrogen Hub
PNW H2
Heartland Hydrogen Hub
Heartland Hub (HH2H)
Midwest Hydrogen Hub
Midwest Alliance for Clean Hydrogen (MachH2)
California Hydrogen Hub
Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES)
Appalachian Hydrogen Hub
Appalachian Regional Clean Hydrogen Hub (ARCH2)
Mid-Atlantic Hydrogen Hub
Mid-Atlantic Clean Hydrogen Hub (MACH2)
Gulf Coast Hydrogen Hub
HyVelocity H2Hub
Proposed H2 Facility
Selected H2Hubs
OCED


Hydrogen Transportation Corridor
Legend
Freight Facilities
I-80
Hydrogen Hubs
States
Midwest Hydrogen Hub (MachH2)
Appalachian Hydrogen Hub (ARCH2)
Mid-Atlantic Hydrogen Hub (MACH2)
N
0
100
200
400
Miles
Author: Cleveland State University
Date: 2/14/2024
Spatial Reference: NAD 1983
Data Sources: USDOT Freight Analysis Framework (FAF5) Network Nodes; USDOT Intermodal Freight Facilities Pipeline Terminals; TIGER/Line 2023 States; TIGER/Line 2023 US Primary Roads
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

ARCH2 Project Summaries

- **MPLX:** H_2 storage facility development with connective infrastructure to support ARCH2 producers, storage, and end-users
- **Dominion Energy Ohio**: H2 production with CO_2 capture to supply H_2 to regional transit (e.g., SARTA)
- **Plug Power/ Amazon:** One distribution center with H_2 fueling MHE; fueling station FCEV delivery trucks.
- **First Mode:** H_2 end-user: Manufacturing facility for retrofitting mining trucks with H_2 fuel cell power system.
- **Independence Hydrogen:** H2 production facility using industrial off-gas as feedstock in Ashtabula, Ohio to provide clean hydrogen for material handling equipment at distribution centers.



Note: Proposed project locations based on preliminary siting are subject to change during the detailed planning phase (phase 1).

Source: Battelle Memorial Institute 2023

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
- **IRS rule 45V development – Guidance issued in December 2023.**
  - ***Taking comments until Feb 26, 2024***
  - ***Additionality, Locality, Timing requirements***
- IRA Investment Tax Credits
  - 30% cost of refueling stations, 15% of the cost of commercial fuel cell vehicles
  - 30% of cost of hydrogen storage equipment

Why Do We Need Geologic Storage?

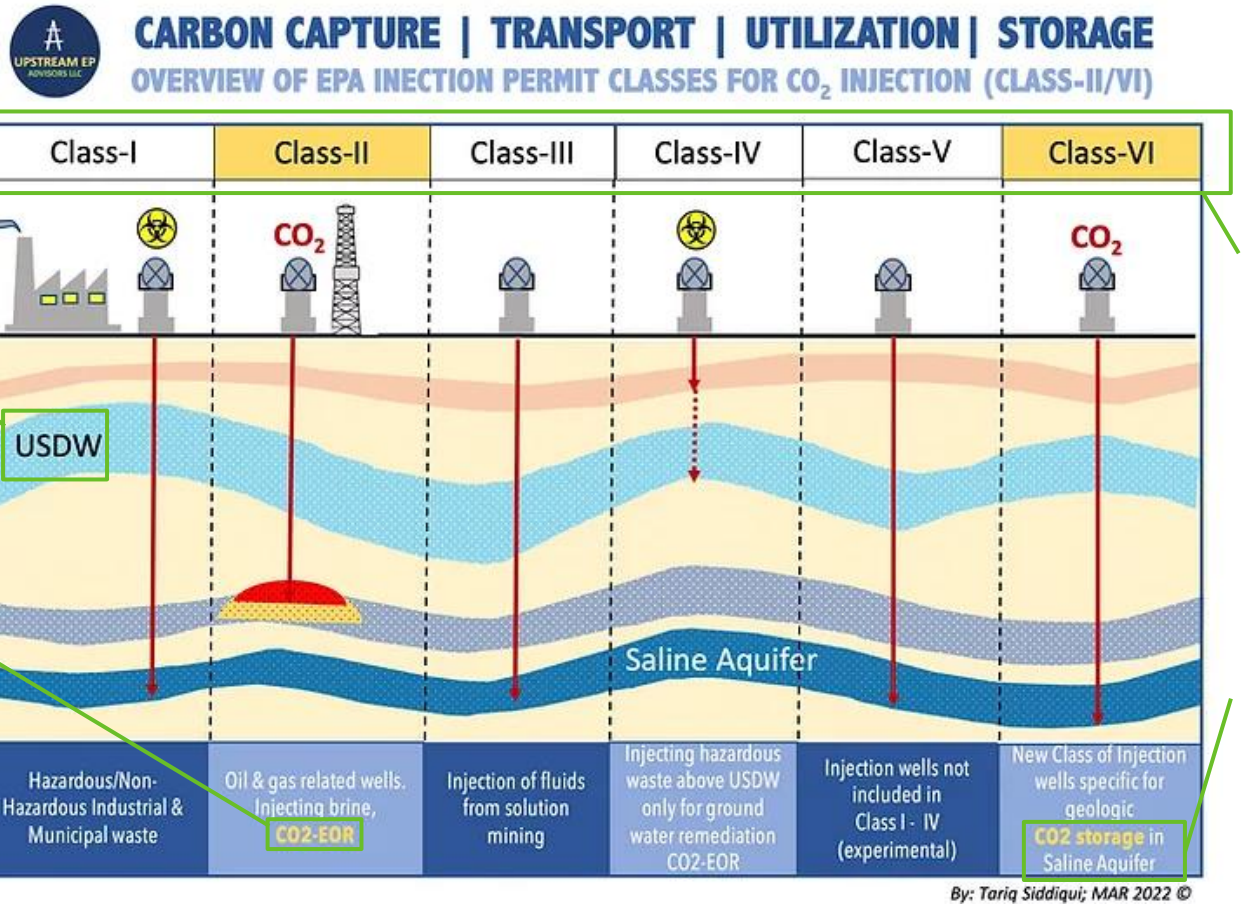
Total Great Lakes Region Carbon Sink Potential 2022-2050

Potential Carbon Dioxide Sinks	Cumulative CO2 Removal Capacity (gigatons)
Reforestation	2.2
Aggregates for Construction and Concrete	0.79
Geologic Storage Deep saline aquifers Depleted oil and gas reservoirs	 14-51 1.8-5.3

Great Lakes Region CO2 Emissions: 1.5 Gigatons/yr

(1 gigaton = 1 billion metric tons)

Source: "Capturing the Economic Opportunity of Carbon"
Global CO2 Initiative, University of Michigan 2022



"Underground Sources of Drinking Water"

"Enhanced Oil Recovery"

Classifications based on type of injection, depth of injection, and impact on USDW

Primary Targets:

- Deep saline aquifers
- Depleted oil & gas fields
- Unmineable coal seams

(Source: Upstream EP Advisors, 2022; Zhang & Song, 2014)

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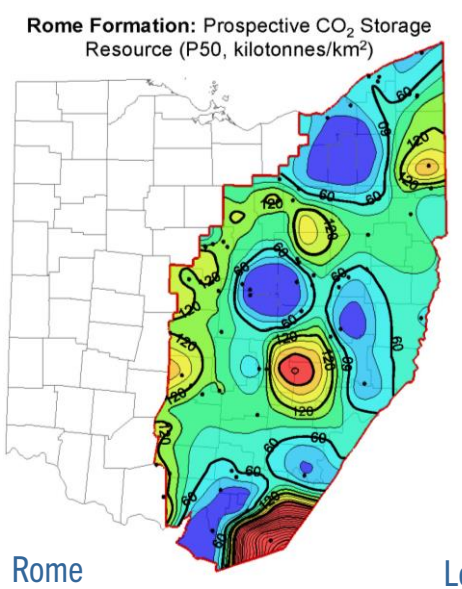
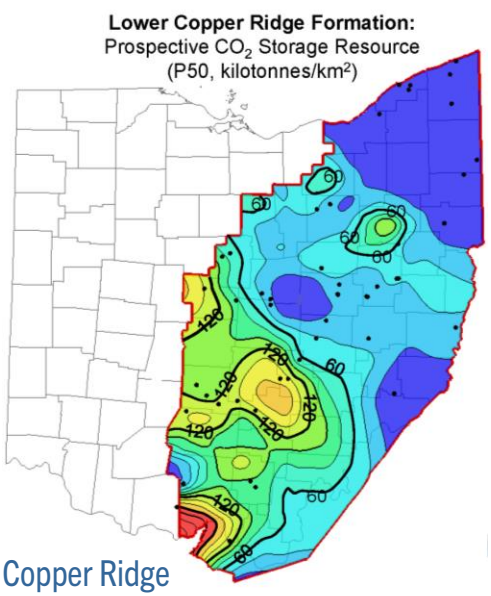
CCS Geology in Ohio

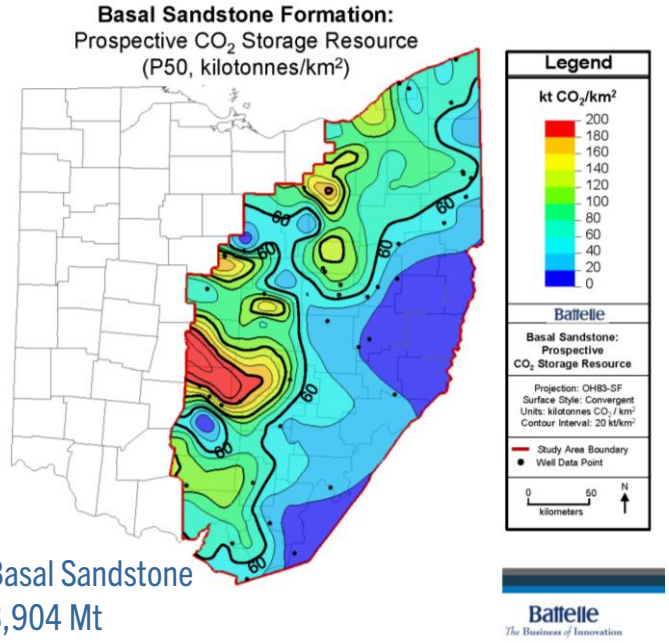
Total Prospective Storage by Formation



Rome
5,556 Mt



Lower Copper Ridge
3,561 Mt



Basal Sandstone
3,904 Mt

Battelle
The Business of Innovation

Mt = megatonnes, kt = kilotonnes

Source: Battelle Memorial Institute (2023)

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Ohio's Class VI Primacy Strategy

- Ohio must demonstrate that its statutes and regulations meet US EPA requirements for effectively preventing endangerment of underground sources of drinking water (USDW).
  - North Dakota, Wyoming and Louisiana only states with primacy
- Ohio General Assembly passed (governor signed) HB 175, effective July 2022, directing ODNR to begin Class VI well primacy application process.
  - ODNR has engaged US EPA on crosswalk process to map state regulations to federal requirements.
    - Permitting, well constructure, operations, post-injection monitoring, decommissioning
  - Members of state legislature have been engaged and presented with model enabling statutes that meet federal requirements.
    - Legislative Service Commission has prepared draft of ORC.
  - Ohio's 2-for-1 regulatory requirement. Could impede primacy application process.
    - Other issues: pore space ownership, unitization

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