MI Hydrogen Initiative Overview

Todd Allen and Greg Keoleian co-directors

MAGMA, December 12, 2025

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Primary energy sources and carriers are important components of an energy system

Primary Energy Sources

- Non-Renewable
  - Fossil Fuels - coal, oil, natural gas
  - Nuclear – uranium fission
- Renewable
  - Wind – onshore, offshore
  - Solar – photovoltaic, thermal
  - Water - hydropower, tidal
  - Geothermal – steam, hot water
  - Biomass and Waste - agricultural crops and waste, wood and processing waste, animal waste, solid waste, algae

Energy Carriers[1]

- Electricity
- Hydrogen[2] and derivatives

Notes
1 - fossil fuels are energy carriers as well as sources
2 - naturally-occurring hydrogen is an insignificant energy source today

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Hydrogen Ecosystem

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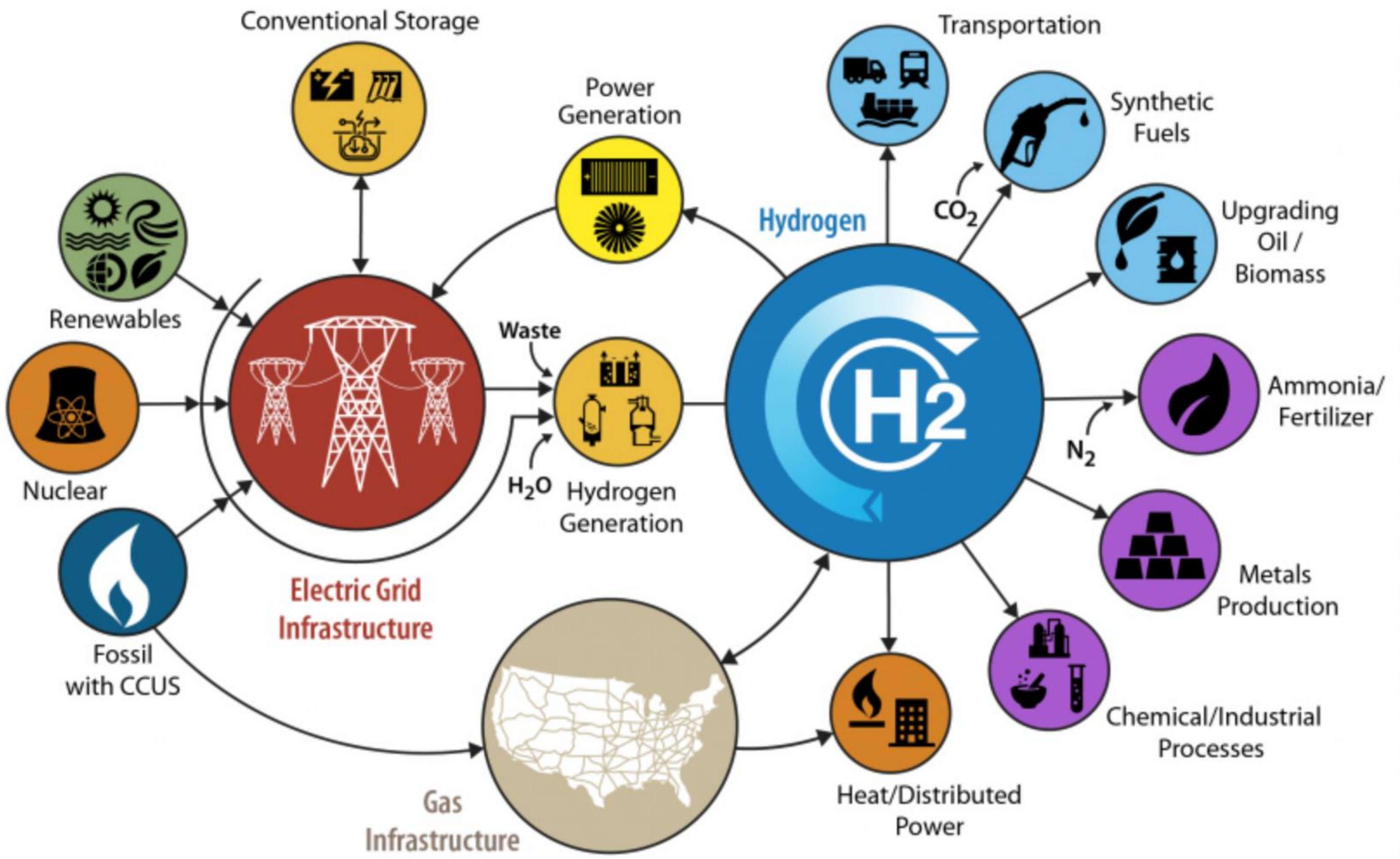

CCUS: Carbon Capture, Utilization, and Storage

DOE hydrogen ecosystem diagram (from U.S. DOE, Office of Energy Efficiency & Renewable Energy, H2@Scale. https://www.energy.gov/eere/fuelcells/h2scale)

Hydrogen as a Fuel

1 kg of hydrogen ≈ $1\ gallon\ of\ gasoline$

MI Hydrogen

- *Integrate UM research expertise to create hydrogen solutions that accelerate clean and just energy transitions*
  - **Hydrogen has the potential to decarbonize industrial, transportation and other sectors** where electrification is problematic
  - Integration across **technology, energy systems analysis, policy and social sciences** will be emphasized in research and engagement activities.

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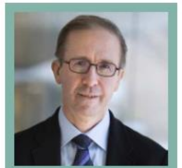
Faculty Expertise


Alauddin Ahmed
Mechanical Engineering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Nuclear Engineering and Radiological Sciences


Andre Boehman
Mechanical Engineering


Rohini Bala Chandran
Mechanical Engineering


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Naval Architecture and Marine Engineering


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Mechanical Engineering


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Royan D'Mello
Aerospace Engineering


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Mechanical Engineering


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Mechanical Engineering


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Mechanical Engineering; Materials Science and Engineering


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Timothy Wallington
Climate and Space Sciences and Engineering


Margaret Wooldridge
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Engaged Organizations

Noble GAS SYSTEMS

BONTAZ Bennett

ONTARIO CANADA

PLASTIC OMNIUM

Walbridge

BOSCH

MITSUBISHI POWER

EATON

FMG Fortescue

FORTESCUE FUTURE INDUSTRIES

NEL HYDROGEN

gm

CITY OF DETROIT

DTE Energy

TENNECO

MICHIGAN ECONOMIC DEVELOPMENT CORPORATION

MICHIGAN INFRASTRUCTURE OFFICE

INL Idaho National Laboratory

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

American Center for Mobility

CMS ENERGY

EPRI GRIDED The Center for Grid Engineering Education

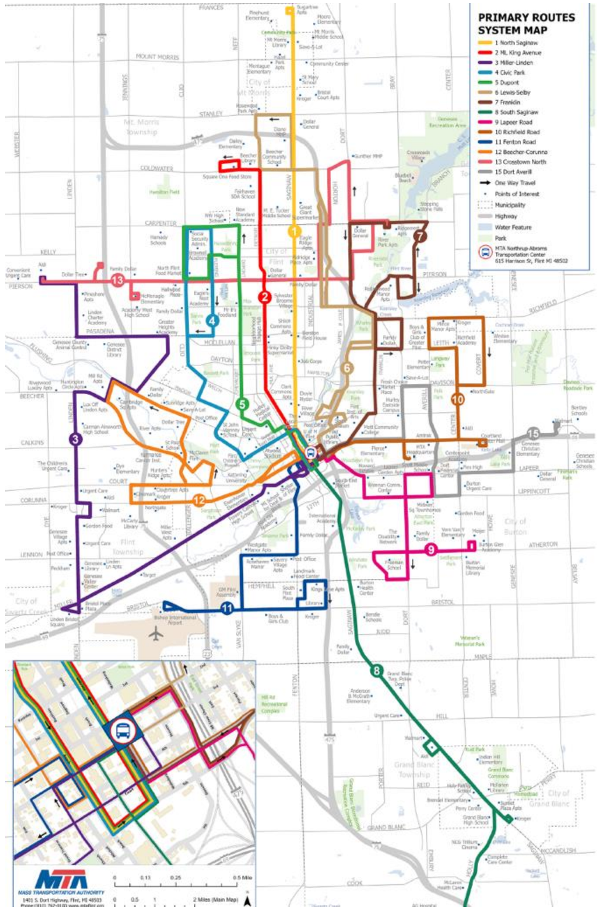
H_2EDGE Hydrogen Education for a Decarbonized Global Economy

NextHydrogen

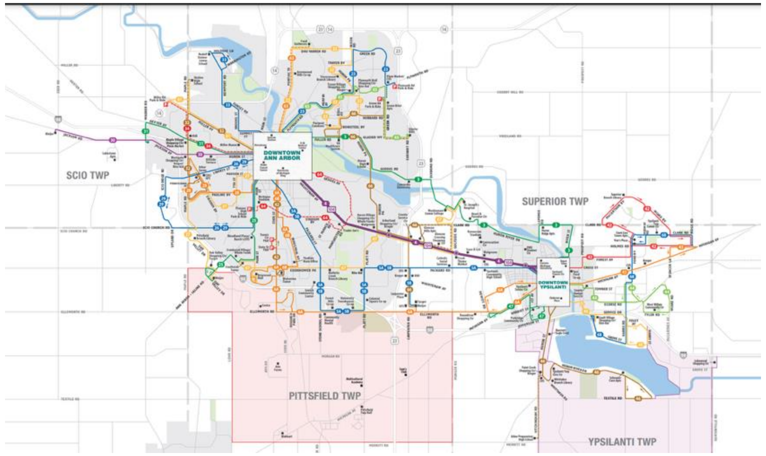
Selected Regional Clean Hydrogen Hubs

OCED
Office of Clean Energy Demonstrations

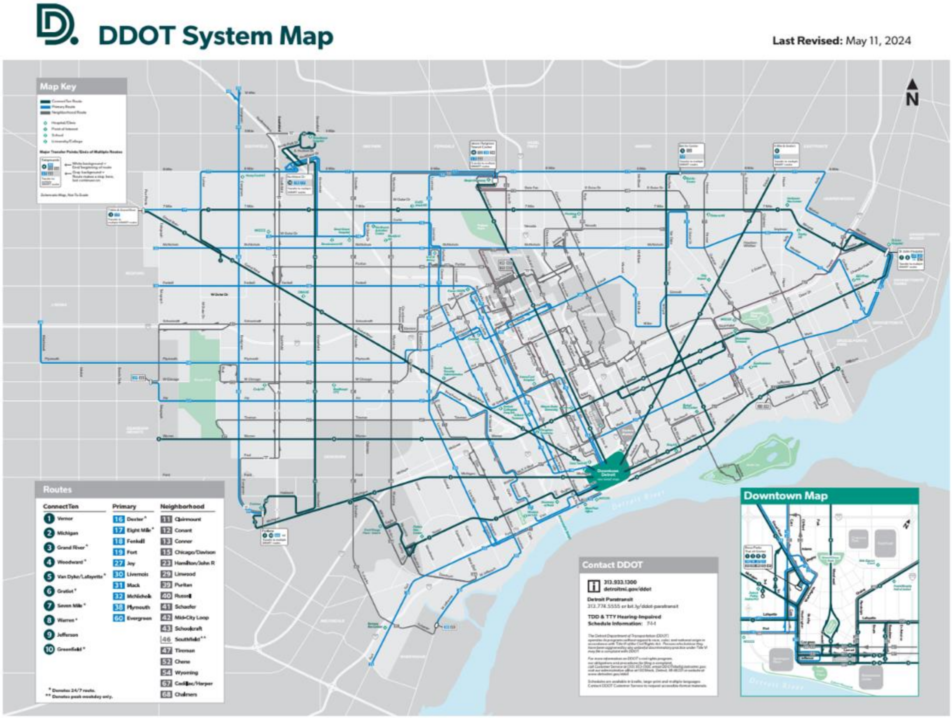
Hydrogen Bus Initiatives



Flint MTA



Ann Arbor AAATA



Detroit DDOT

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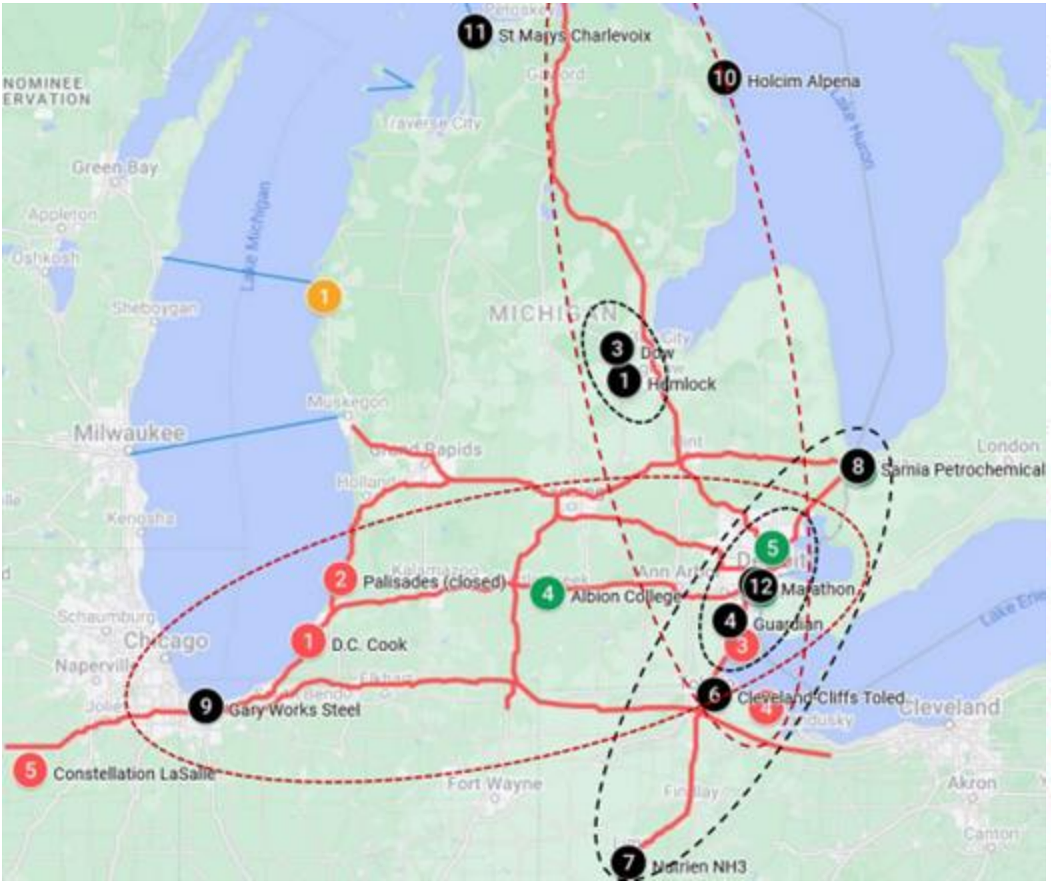
2022 MI Hydrogen Roadmap identified Clusters along Transportation Corridors



Nuclear plant

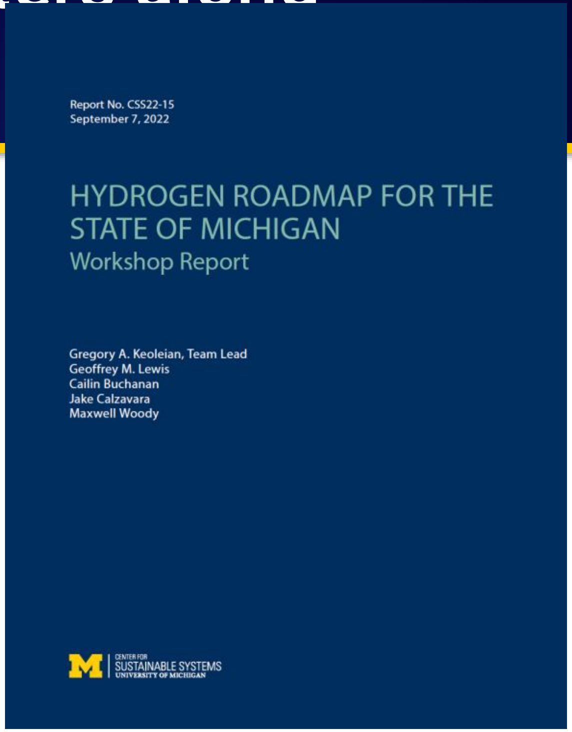
1. D.C. Cook
2. Palisades (closed)
3. Fermi
4. Davis-Besse
5. Constellation LaSalle

H2 production

1. Air Products
2. Air Products
3. Praxair
4. Albion College
5. Detroit Arsenal
6. Air Products Sarnia
7. Praxair Sarnia

Industry

1. Hemlock Semiconductor
2. Marathon Refinery
3. Midland chemical complex
4. Guardian Glass
5. Cleveland Cliffs Rouge Steel
6. Cleveland-Cliffs Toledo DR
7. Nutrien NH3
8. Sarnia petrochemical complex
9. Gary Works Steel
10. Holcim Cement
11. St Marys Cement
12. St Marys Cement


Report No. CSS22-15
September 7, 2022

HYDROGEN ROADMAP FOR THE STATE OF MICHIGAN
Workshop Report

Gregory A. Keoleian, Team Lead
Geoffrey M. Lewis
Cailin Buchanan
Jake Calzavara
Maxwell Woody

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- **GHG reduction potential** – contribution to state and national targets, other environmental impacts
- **Technology** – readiness, constraints, competition (with other carriers, technologies))
- **Scale** – capacity and potential for hydrogen production, delivery, storage, and end use applications
- **Spatial mapping and analysis** – of hydrogen supply chain (potential hub(s) and spokes) including: production sites, routing network, industrial sites, fueling stations, etc.
- **Regional linkages** – extending beyond Michigan
- **Time horizon** – near term (to 2030) and longer term (2030 to 2050)
- **Socio-economic impacts** – jobs, justice, and equity issues

MI Hydrogen Projects

Project 1 - Hydrogen Demand Analysis for the State of Michigan

Project 2 - Critical Review: **Role for Hydrogen in Sustainable Transportation**

Project 3 - Critical Review: **Role for Hydrogen in Decarbonizing the Industrial Sector**

***Project 4 - Planning a Hydrogen Ecosystem**

(Production, Delivery, Storage and End-Use Applications): **Michigan/Great Lakes Region** Case Analysis.

Other MI Hydrogen Activities

- **DOE Hydrogen Hub Mach H2 Award**
- **FRA Hydrogen Locomotive Award**

MIDWEST ALLIANCE FOR CLEAN HYDROGEN

- **Seminar series** two per semester
- **Workshops**
  - Hydrogen Roadmap for the State of Michigan (May 20, 2022)
  - State of Michigan Workshop: Building Foundations for the Hydrogen Economy (May 13, 2024)
  - Near-Term H_2 Ecosystem Planning Workshop (May 13, 2025)
  - Geologic Hydrogen in Michigan (tentative May 2026)
- **Prize Competitions – Hydrogen Grand Challenge, Middle School Grand Prix**
- **Building hydrogen curriculum: EPRI – H2 EDGE**

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Michigan Hydrogen Horizon 3.0

Hydrogen Grand Challenge

FIRST CHALLENGE SECO
RESOURCES NEWS

Workshop Schedule

Register for Workshops

Workshops take place from 5–7pm.

- **Preview Event:** H2 Edge Introduction To Hydrogen And Competition Announcement (October 9, Phoenix 2000A)
- **Workshop #1:** Prize Competition Kickoff (November 5, Phoenix 2000A **OR** November 6, Lane Hall 2239)
- **Workshop #2:** Understanding a Problem (December 3, Phoenix 2000A)
- **Workshop #3:** Identifying Viable Opportunities (January 15, Lane Hall 2239)
- **Workshop #4:** Presenting Your Draft Business Case (January 28, Phoenix 2000A)
- **Workshop #5:** Team Report Out (February 12, Lane Hall 2239)

Third Challenge

The third edition of the Hydrogen Grand Challenge will once again ask University of Michigan students to develop innovative business cases for Michigan-centered, regional deployment of hydrogen technology in key sectors such as transportation and industrial applications. **Questions? Contact Yugo Ashida.**

Competition Structure

Teams will compete for a share of the $5,000 prize pool, with the first-place team receiving $2,500, the first runner-up awarded $1,500, and the second runner-up receiving $1,000.

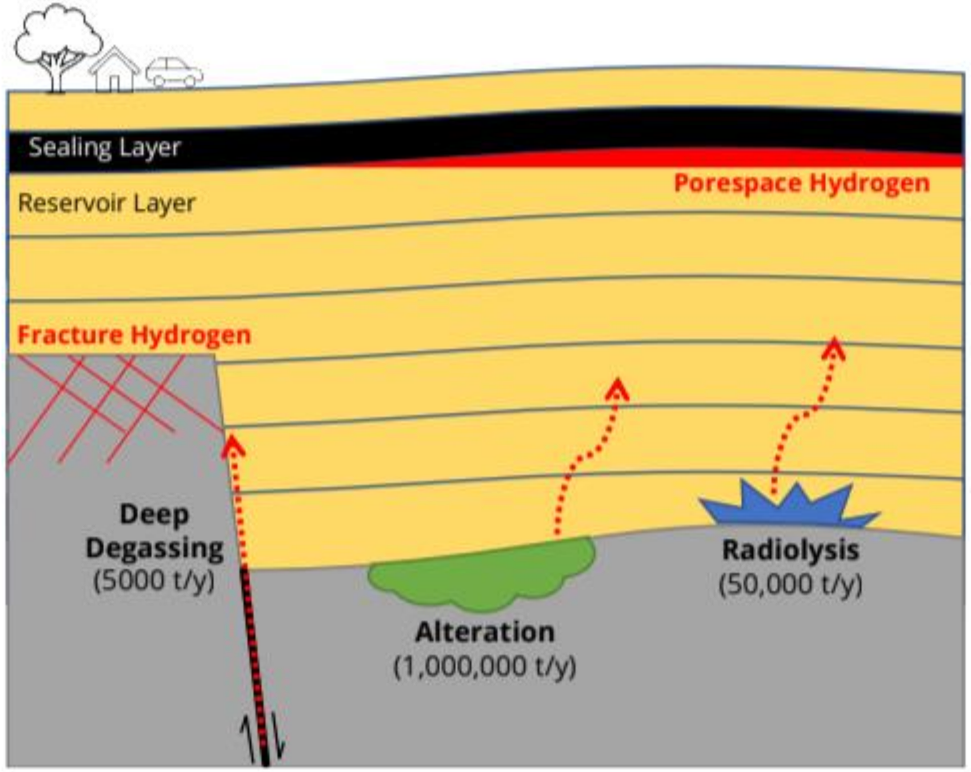
https://hydrogenprize.engin.umich.edu/third-challenge/

H2 GRAND PRIX SERIES

- 27 eighth graders from Henderson Academy in Detroit built and raced model hydrogen cars at the Michigan Engineering Zone.

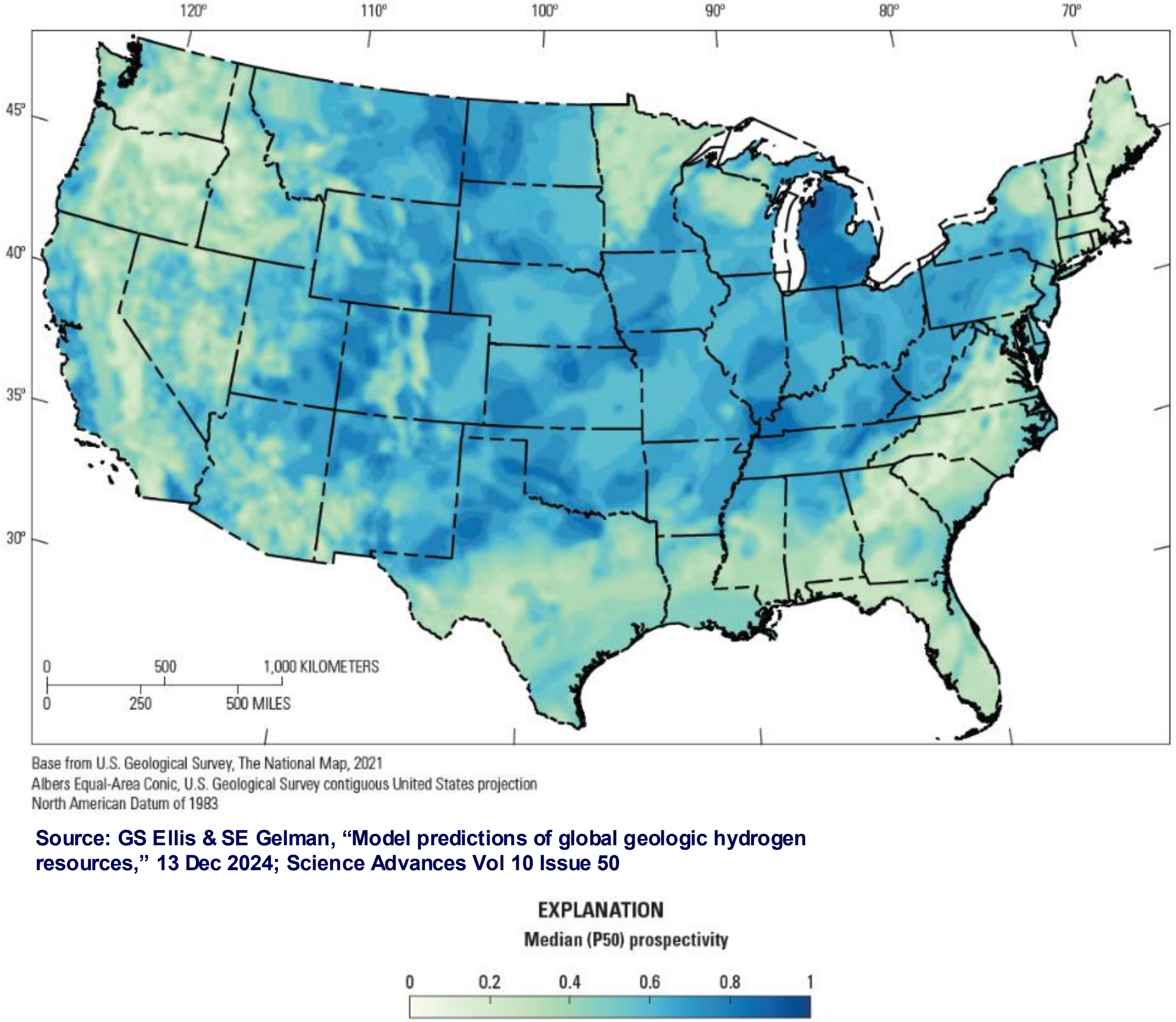
- The students used electrolyzers to produce hydrogen gas from water and power miniature fuel cell cars.

The question of the **amount and feasibility** of extraction of **Geologic “Natural” H_2** remains a question



After Klein et al, 2020 *Elements*

Source: Adapted from Franek Hasiuk Slides (MI Hydrogen Seminar 02-28-2025)



Base from U.S. Geological Survey, The National Map, 2021
Albers Equal-Area Conic, U.S. Geological Survey contiguous United States projection
North American Datum of 1983

Source: GS Ellis & SE Gelman, “Model predictions of global geologic hydrogen resources,” 13 Dec 2024; Science Advances Vol 10 Issue 50

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Reference Material

Hydrogen Factsheet

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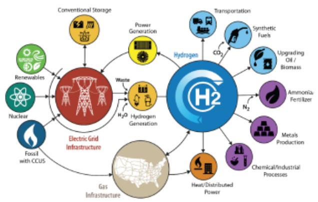
factsheets
Energy

Hydrogen

Hydrogen Economy

Hydrogen is a feedstock and energy carrier used in multiple sectors of our economy. Globally 90 million metric tons (Mt) of hydrogen were produced and used in 2020, with U.S. production being approximately 10 Mt. Hydrogen is the most abundant element in the universe, but is present in limited amounts in elemental form on Earth. The primary method of producing hydrogen globally and in the U.S. is steam methane reforming (SMR) of natural gas. SMR results in CO_2 emissions, which is problematic from a climate change perspective. Electrolysis is a hydrogen production process that uses electricity to split water into hydrogen and oxygen. This production process can provide a pathway for decarbonizing some sectors of the economy if the electricity is generated from zero- or low-carbon sources such as renewables and nuclear power. Hydrogen can play a key role in decarbonizing end-use applications where other alternatives such as electrification are problematic.[1]

H2@Scale Diagram[2]



- Global demand for hydrogen could reach 150 Mt by 2030.[3]
- Hydrogen has a very low volumetric energy density and is stored as either a high-pressure gas, or low-temperature liquid.[4]

Hydrogen Technologies and Impacts

Production

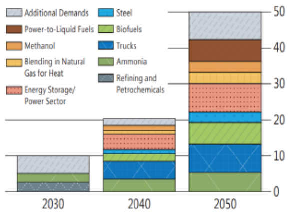
- Hydrogen can be produced via several pathways including SMR, electrolysis of water, and gasification of coal or biomass.[5]
- Color codes have been used to describe hydrogen production pathways. Commonly used colors include grey for SMR, blue for SMR with carbon capture and sequestration (CCS), and green for electrolysis using renewable electricity.[6]
- In SMR, natural gas is reacted with high temperature steam to produce hydrogen. The resulting synthesis gas also contains CO and CO_2. Using the "water-gas shift reaction" the CO and steam are reacted together over a catalyst producing more hydrogen and CO_2.[7]
- SMR is the least expensive ($1-2/$kgH_2$) and widely used method of producing hydrogen.[5,8] Currently about 95% of hydrogen in the U.S. is produced using SMR at large central plants.[7] Hydrogen produced with SMR emits about 7-10 $kgCO_2/kgH_2$.[9]
- The 2020 production cost for green hydrogen is about $7.5/$kgH_2$. The U.S. Department of Energy (DOE) targets are to lower this to $2/$kgH_2$ by 2026 and $1/$kgH_2$ by 2031.[2]
- Alkaline and proton exchange membrane (PEM) electrolyzers are commercially available, while solid oxide electrolyzer cell (SOEC) and anion exchange membrane (AEM) electrolyzers are maturing.[10] In 2019, electrolyzers had a baseline higher heating value conversion efficiency of 71%.[11]
- The current grid mix is not ideal for electrolysis as around 60% of U.S. electricity is still produced using fossil fuels.[12] The CO_2 intensity of hydrogen produced by electrolysis is approximately 20-25 $kgCO_2/kgH_2$ in the U.S.[2]

Distribution and Storage

- Hydrogen in the U.S. is produced at, or near, where it will be used, reflecting difficulties with transportation.[5]
- Hydrogen can be transported to point of use via pipeline, or over the road using liquid tanker, or tube trailer trucks.[13]
- Pipelines are the least expensive way to deliver hydrogen at a cost $0.2-0.5/$kgH_2$. There are approximately 1600 miles of pipeline in the U.S.[5,14]
- Tube trailers can transport compressed hydrogen, typically used over distances of 200 miles or less, but are expensive at $0.9-1.9/$kgH_2$.[5,14]
- Liquid tankers are better suited than tube trailers for transporting larger amounts of hydrogen over longer distances, but are more expensive at $2.7-3.2/$kgH_2$ due to the energy and equipment requirements for the liquefaction process.[5,14]
- Hydrogen has the highest energy per mass of any fuel at 120 MJ/kgH_2 on a lower heating value basis, but a low volumetric energy density of 8 MJ/l for liquid hydrogen, compared to a volumetric energy density of 32 MJ/l for gasoline.[4]
- At 1 bar and 25°C, the volumetric energy density of hydrogen is lower than those of gasoline, diesel, jet fuel, and marine bunker fuel by factors of approximately 3200, 3700, 3600, and 4000, respectively.[1]
- Even as a compressed gas at 700 bar or as a liquid at -253°C the volumetric energy density of hydrogen is 7-8 and 4-5 times lower, respectively, than conventional liquid hydrocarbon fuels at ambient conditions.[1]
- Using compression or liquefaction, hydrogen can be stored in its pure form as a compressed gas or cryogenic liquid. Liquefaction can achieve greater densities than compressed gas, but is more energy intensive and requires specialized equipment.[15]
- Hydrogen gas is typically stored at 350 or 700 bar while liquid storage requires cryogenic temperatures since its boiling point is −253°C.
- Underground hydrogen storage may be possible, conventional options include using salt caverns, while proposed methods include abandoned coal mines and refrigerated mined caverns.[16]

End-Uses

Projected Growth in Hydrogen End-Uses in U.S.[17]
(million metric tons H_2 per year)



- Petroleum refineries are the largest consumers of hydrogen in the U.S. using about 5.5 Mt annually in 2021. Second to refineries, U.S. ammonia synthesis consumed around 3.5 Mt of hydrogen in 2021.[2] Other uses of hydrogen include the production of methanol used in industrial applications and chemical manufacturing, and the reduction of iron ore through direct reduction.
- A variety of hydrocarbon synfuels can be produced by reacting hydrogen with CO_2, making production of synfuels a potential demand for hydrogen. When CO_2 is captured from the atmosphere and used for hydrocarbon synfuel production the carbon in the fuel can be considered net zero in terms of emissions, though there are potentially emissions associated with the CO_2 capture process.[18]
- Blending hydrogen with natural gas could result in rapid demand increase.[18] Preliminary estimates say hydrogen can be injected into natural gas pipelines up to concentrations of 20% by volume, but co-firing with natural gas reduces greenhouse gas emissions only 6-7%.[18,19]
- Direct reduction of iron (DRI) using hydrogen has potential to replace blast furnace steel production - 47-68 kgH_2/tDRI is estimated to be required in this process.[8]
- Hydrogen burners are currently under development to replace natural gas and other fossil fuels in high-temperature heat applications. These applications include cement clinker kilns, glass furnaces, aluminum remelting furnaces, metal rolling and heat treatment furnaces.
- Hydrogen can be used in residential buildings to power fuel cell combined heat and power (CHP) systems, direct flame combustion boilers, catalytic boilers, and gas powered heat pumps. Larger district heat and CHP devices using NG could be redesigned for hydrogen.[20]
- Hydrogen can be used directly or indirectly in conventional and synfuels, in all forms of transportation (road, rail, water, air). Global petroleum refining used 40 Mt H_2 in 2021, which was more than 1000 times the direct use of hydrogen as a transportation fuel. Clean hydrogen is expected to play an important role in decarbonizing heavy-duty transport (road, marine fuels, aviation fuels) by 2050.
- Direct use of electricity in light-duty vehicles is about 3 times more energy efficient than conversion into hydrogen and use in fuel cell vehicles.
- Hydrogen is not well suited for use in light-duty cars and trucks, but may find use in medium- and heavy-duty vehicles that need to store large amounts of energy and refuel rapidly, both of which are challenging for electric vehicles.

Environmental Impacts

- Global hydrogen production currently accounts for approximately 1 Gt of CO_2 emissions.
- Electrolysis represents less than 5% of worldwide hydrogen production now, but is a pathway to zero-carbon emissions.[20]
- On a stoichiometric basis the water consumption required for electrolysis is 9 kgH_2O/kgH_2.[22] When accounting for electricity generation, water consumption increases to 15-20 kgH_2O/kgH_2.[23]
- The water required to produce 800 Mt of hydrogen for a net zero economy in 2050 is much less than what is needed for the extraction and processing of fossil fuels today.[23]
- Hydrogen production on this scale would account for 0.7% of global freshwater use. Desalination would add approximately $0.02/kg to the price of hydrogen.[23]

U.S. Hydrogen Strategy and Policy

To bolster development of the hydrogen economy the U.S. the Infrastructure, Investment, and Jobs Act (IIJA) contains $9.5 billion of funding for hydrogen. The Inflation Reduction Act (IRA) contains two provisions that will subsidize clean hydrogen production.[24] The U.S. National Clean Hydrogen Strategy and Roadmap from the DOE explores pathways for clean hydrogen to aid in decarbonization goals across the economy.[2] The U.S. Department of Transportation Federal Highway Administration designated a national network of electric vehicle charging and hydrogen, propane, and natural gas fueling infrastructure along national highway system corridors.[25]

Hydrogen Hubs

- The U.S. DOE aims to establish 6-10 regional clean hydrogen hubs across the U.S. through a Regional Clean Hydrogen Hubs Program (H2Hubs). H2Hubs has a $7 billion budget and is part of the larger hydrogen hub program funded by the IIJA with the goal of creating networks of hydrogen producers, consumers, and local connective infrastructure.[26]

Tax Credits Promoting Hydrogen

- The value of the IRA tax credits (IRC Sec 45V) are determined based on life cycle CO_2e emissions per kg of hydrogen produced. The IRA also increases the rate of an existing tax credit for carbon sequestration (IRC Sec 45Q) that cannot be combined with 45V.[24]

IRA Hydrogen Investment Tax Credit and Production Tax Credit[24]

Life Cycle Emissions ($kgCO_2e/kgH_2$)	Investment Tax Credit (%)	Production Tax Credit (2022$/$kgH_2$)
2.5-4	6%	0.60
1.5-2.5	7.5%	0.75
0.45-1.5	10%	1.00
0-0.45	30%	3.00

1. Center for Sustainable Systems (CSS) (2022) MI Hydrogen Roadmap Workshop Report.
2. U.S. Department of Energy (DOE) U.S. National Clean Energy Strategy and Roadmap.
3. International Energy Agency (IEA) (2023) Hydrogen.
4. U.S. DOE Hydrogen Storage.
5. U.S. DOE Hydrogen Production and Distribution.
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Links

- Hydrogen Roadmap for State of Michigan Workshop Report
  - report link
  - Workshop participants p. 93 – 95.
- DOE Clean Hydrogen Hubs
  - program announcement
- Hydrogen Grand Challenge
  - First prize competition: Michigan Hydrogen Horizon
- Hydrogen Factsheet
  - Center for Sustainable Systems Sustainability Factsheet Collection
  - Hydrogen Factsheet

Backup Slides

Project 1: State of Michigan Hydrogen Demand Analysis

Brooke Alsterlind, M.S.
Chemical Lead
Glass Secondary
Cement Secondary

Shagun Parekh, M.S./M.S.E.
Glass Lead
Cement Lead
Petroleum Refining Secondary

Patrick Killian, M.S./M.S.I.
Transportation Co-Lead
Semiconductor Secondary

Stephen Lipshaw, M.S./M.Eng
Transportation Co-Lead
Steel Secondary

Sara Murphy, M.S./M.Eng
Petroleum Refining Lead
Semiconductor Lead
Pulp & Paper Lead
Chemical Secondary

Yaqi Zhang, M.S./M.S.E.
Steel Lead
Pulp & Paper Secondary
Transportation Secondary

Current demand
Future demand

Project 2: Role for Hydrogen in Sustainable Transportation (ground, air, marine)

Eytan Adler

Aerospace Engineering

Matt Collette

Naval Architecture & Marine Engineering

Greg Keoleian

SEAS/ Environmental Engineering

Geoff Lewis

SEAS

Joaquim Martins

Aerospace Engineering

Tim Wallington

SEAS

Max Woody

SEAS/ Mechanical Engineering

Project 3: Role of Hydrogen in Decarbonizing the Industrial Sector

Daniel R. Cooper and Yongxian Zhu
(Mechanical Engineering)

a comprehensive review of over 200 academic and grey literature sources to characterize each hydrogen industry application, compare hydrogen demand projections, identify implementation drivers and challenges, and assess the decarbonization potential of each application.

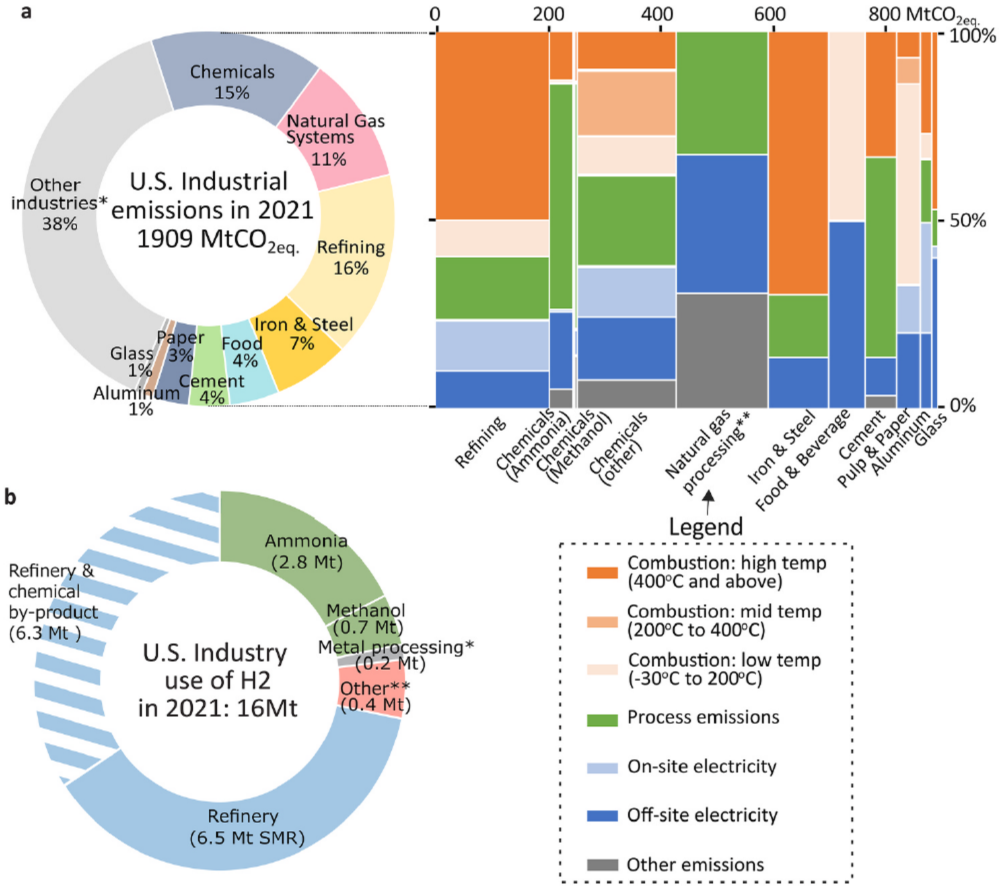
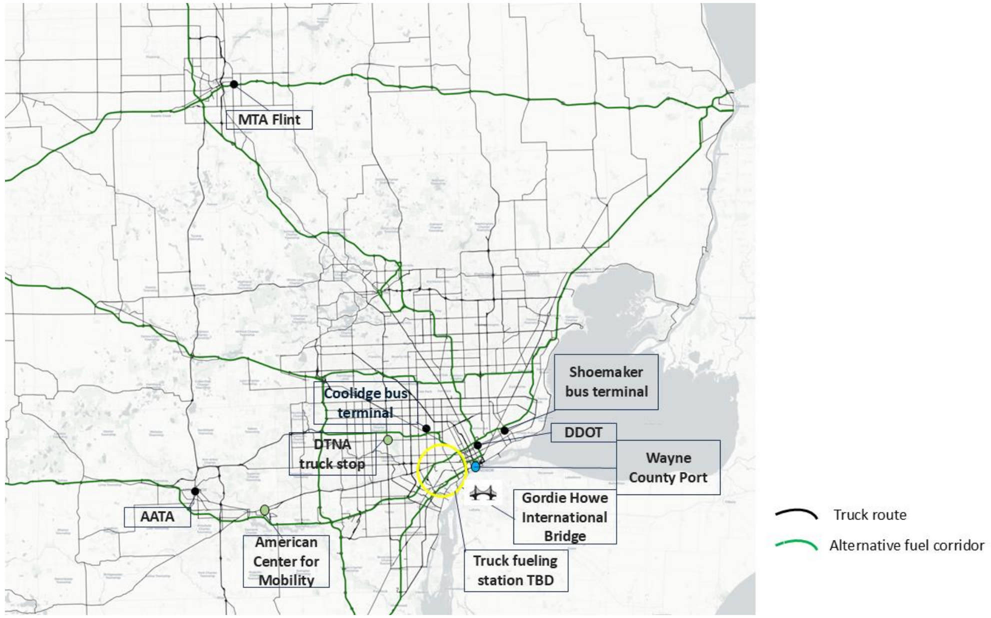


Fig. 1. (a) U.S. industry GHG emissions in 2021 derived using data on electricity and combustion-related emissions from EIA (2022), process emissions from EPA (2023), and the industry breakdown from Refs. [12–14] (S1). *Other industries include machinery, computers and electronics, transportation equipment, wood products, and mining. **Natural gas processing is often included as part of the refining and chemical industry [13] (b) U.S. industry hydrogen consumption in 2021 (S2). *Glass production and metal processing; **Chemicals (polymers, other petrochemicals), float glass, rocket fuel, electronics (semiconductors), hydrogenation of liquid fuels.

Project 4: Hydrogen Ecosystem Planning Scope

- **Near term** –> 2050
- **SE Michigan** –> Great Lakes Region –> beyond
- **Hydrogen transportation** –> industry, power generation sectors
- **Technology, policy, economics, and environmental impact**

Detroit-Windsor border is one of the busiest international border crossings in North America. Over 40,000 commuters, tourists and **truck drivers carrying $323 million worth of goods across the Detroit-Windsor border each day.** This traffic is even expected to grow when the new Gordie Howe International Bridge is completed in 2025, more than doubling our border capacity.



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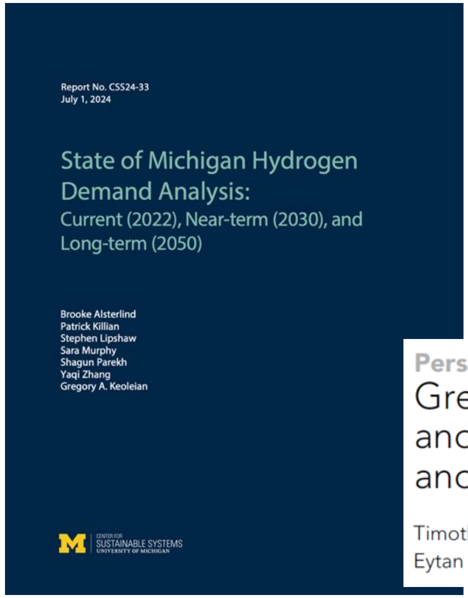
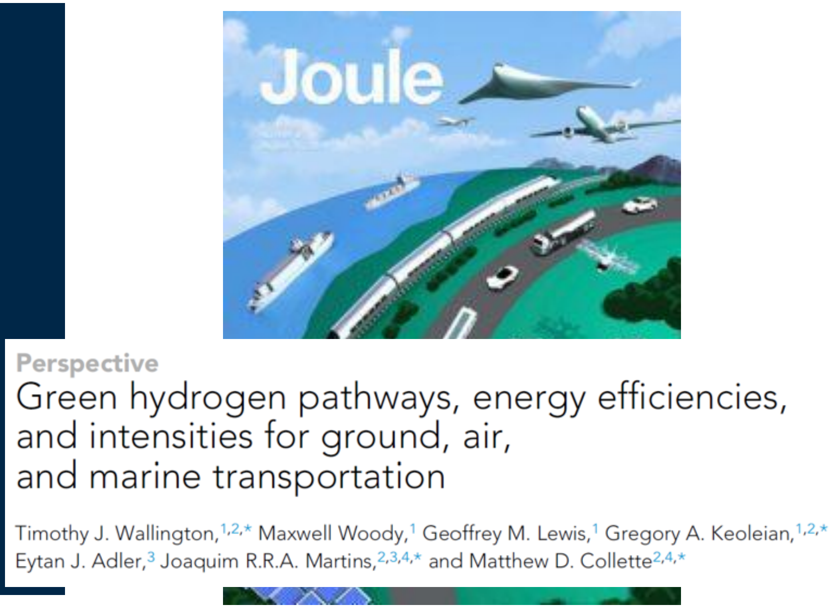
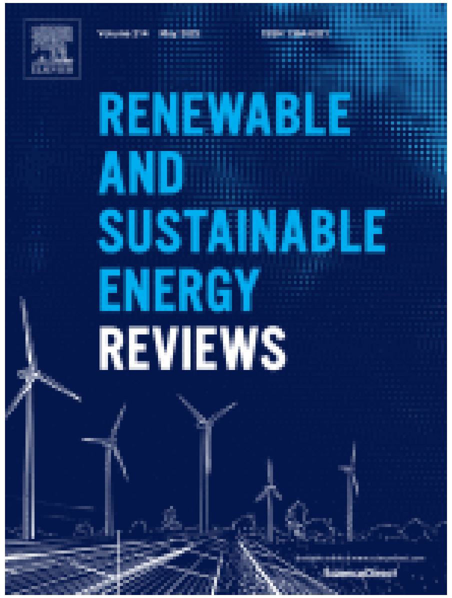
Report and Journal Publications (Projects 1 – 3)







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Hydrogen as a sustainable transportation fuel

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A B S T R A C T

This review examines the potential direct and indirect (synthetic fuels) uses of hydrogen in road, rail, air, and marine transportation. Key physical properties of hydrogen (e.g., energy density) are presented and contrasted against conventional fuels. The costs and emissions of current and future hydrogen production methods are characterized, and the challenges of transporting, storing, distributing, and dispensing hydrogen are highlighted. The sustainability of hydrogen use is evaluated in terms of CO_2 and other air pollutant emissions, energy efficiency and intensity, critical material use, and water consumption.

Electrification is much more energy efficient than using hydrogen in transportation. Hydrogen should be used strategically where electrification is impractical due to range, refueling times, or energy storage requirements. Electrification is already well advanced, making hydrogen unlikely to play a significant role in the light-duty road sector. Hydrogen can play a role in long-distance rail and heavy-duty road transportation, where electrification is problematic. Electrification is impractical for deep ocean shipping and aviation due to volume and weight constraints (except for ranges below approximately 200 miles). Hydrogen can be used, either directly or indirectly (in e-fuels), to fully decarbonize these sectors. Currently, the high costs of clean hydrogen production, storage, and distribution make it prohibitive for transportation. Major reductions in these hydrogen infrastructure costs, the cost of e-fuel synthesis, or both are needed to make hydrogen competitive with other fuel options. Strong policy measures such as the Bipartisan Infrastructure Law and the Inflation Reduction Act are funding R&D and technology demonstration to support this goal.

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