U.S. – INDIA ENERGY MONITOR

THE HYDROGEN ISSUE

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ORF AMERICA

The U.S.-India Energy Monitor is a quarterly snapshot of climate and energy in the United States and India: two of the world's largest economies, largest consumers of energy, and largest emitters of greenhouse gas emissions responsible for climate change. Each quarter, the monitor provides a roundup of energy and climate news, followed by a detailed analysis of a topic relevant to energy and climate in both countries. The monitor provides readers timely, policy-relevant analysis on issues affecting the trajectories of two countries who will shape the world's energy and climate future.

India announces its long-term decarbonization plan at COP 27

At COP 27, India submitted its Long-Term Low Emission Development Strategy detailing its plans to reduce emissions across its economy though greater electric vehicle (EV) penetration, investments in hydrogen, and increased carbon sequestration by forests.[1] The plan comes in the wake of India's August announcement that it would reduce the emissions intensity of its economy 45% by 2030 and achieve 50% non-fossil fuel electricity generation by the same year on the path to a net zero economy by 2070.[2] In negotiations, India was a strong force behind the establishment of a loss and damage fund and pushed hard for a phasedown of all fossil fuels as opposed to only a phasedown of coal.[3]

India's national carbon market legislation passes Parliament's upper house

India's cap and trade program is another step closer to taking effect after parliament approved the Energy Conservation (Amendment) Bill on December 12.[4] The legislation establishes a carbon market that is expected to launch in 2023.[5] The market will initially be voluntary with tentative plans for it to become mandatory in 2026 when it will cover 37% of India's total emissions, primarily in heavy-industry sectors including oil refining, steel, aluminum, and cement.[6] Emissions in India's manufacturing industry have doubled since 2007 and subjecting them to emissions trading will help India meet its international climate targets and align Indian climate policy more closely with the European Union (EU) as the bloc moves forward with carbon border adjustments, i.e. tariffs on carbon-intensive goods.[7]

Permitting reform moves into the next Congress, transmission backlog delays renewable energy projects

As part of the deal with Senator Joe Manchin (D-WV) to pass the Inflation Reduction Act (IRA), Democratic leadership in Congress promised to support and hold votes on separate legislation to accelerate and simplify the federal review process for a wide variety of energy and infrastructure projects. After a previous attempt to pass permitting reform in September, Senator Manchin led an unsuccessful effort to attach his legislation to the National Defense Authorization Act and the year-end government funding bill.[8] The future of permitting reform legislation in the next Congress will have major implications for a substantial backlog of renewable energy and storage projects. With an average wait time of four years, nearly 1,400 giga-watts of mostly renewable energy projects are in limbo, leading to cancellations on some projects.[9]

Tension with allies over Inflation Reduction Act provisions, other countries respond with similar policies

While celebrating American climate investments, U.S. allies and partners have raised concerns about North American content requirements and subsidies in the IRA.[10] For instance, Hyundai plans to have a new U.S. factory operating by 2025. In the meantime, the South Korean automaker fears losing market share with its not yet American made cars failing to qualify for the IRA's full EV tax credit.[11] Beyond making their concerns known, U.S. allies and partners have also responded with similar policies. Canada announced tax credits for net-zero technologies, battery storage, and clean hydrogen.[12] The EU is empowering member states to introduce subsidies to match those of non-EU states.[13]

The future of permitting reform legislation in the next Congress will have major implications for a substantial backlog of renewable energy and storage projects.

THE COLORS OF HYDROGEN: A TOOL FOR THE ENERGY TRANSITION

The focus of this issue of the U.S.-India Energy Monitor is hydrogen in the United States and India.[14] Hydrogen is a potential fuel for decarbonization and the energy transition. This report will evaluate current trends towards the diversification of the uses of hydrogen in both countries, as well as offer an outlook for the near- and long-term uses of hydrogen.

Despite its abundance on the planet, hydrogen does not exist freely on its own and must be separated from other compounds. Therefore, like electricity, hydrogen is an energy carrier, or a secondary source of energy. Hydrogen fuel is primarily created using fossil fuels or electricity with differing environmental impacts. It can be in gaseous form or cooled and liquefied for specific applications. Depending on how hydrogen is produced, it is sorted into three colors, namely, green, blue, and gray hydrogen (Figure 1).[15] Gray hydrogen is the most common form of hydrogen energy, and it is produced mostly from natural gas, but also other fossil fuels such as coal in some cases. This type of hydrogen production is the worst for the environment because its production emits carbon dioxide emissions that are not recaptured. Production of blue hydrogen goes a step further than gray hydrogen by using industrial carbon capture and storage to capture the carbon dioxide and store it underground. Globally, only about 1% of current hydrogen production is blue.[16] Green hydrogen is produced from renewable energy through the process of electrolysis where an electric current runs through water to split it into oxygen and hydrogen. Technology known as electrolyzers accomplish this splitting. Only 0.1% of hydrogen production globally is currently done through electrolysis, i.e., "green" hydrogen.[17] Regardless of how it is produced, when directly burned, hydrogen is a clean fuel with only water vapor as its product.[18] The demand for cleaner fuels will increase with the energy transition. **As such, green hydrogen is poised to play a role in reducing emissions in "hard-to-abate" sectors like heavy industry, steel, and chemicals where current renewable technologies are inadequate in providing inputs or required heat and power.**

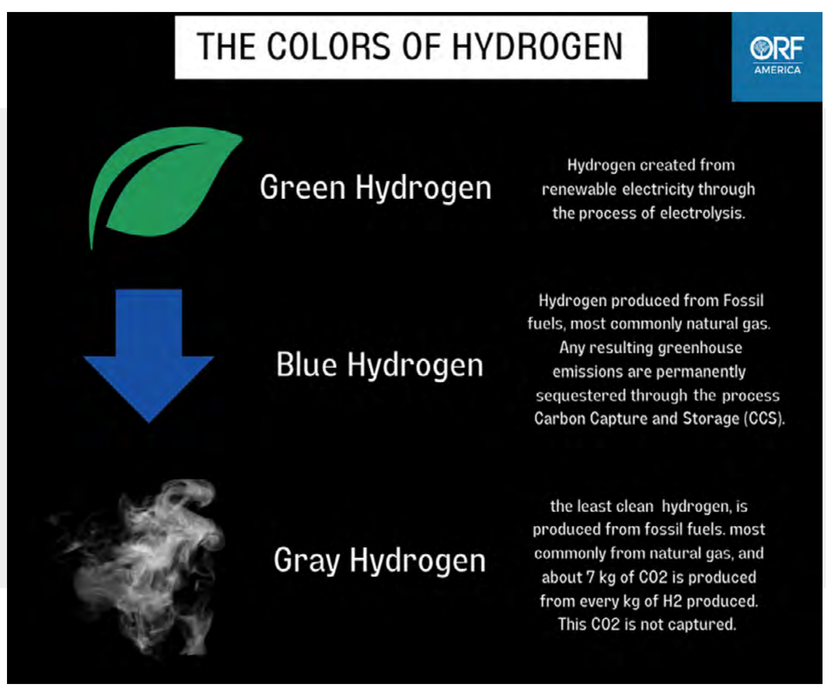


FIGURE 1.

The colors of hydrogen are categories based on source and environmental impact. Source: Adapted from Leachman (2015)[19]

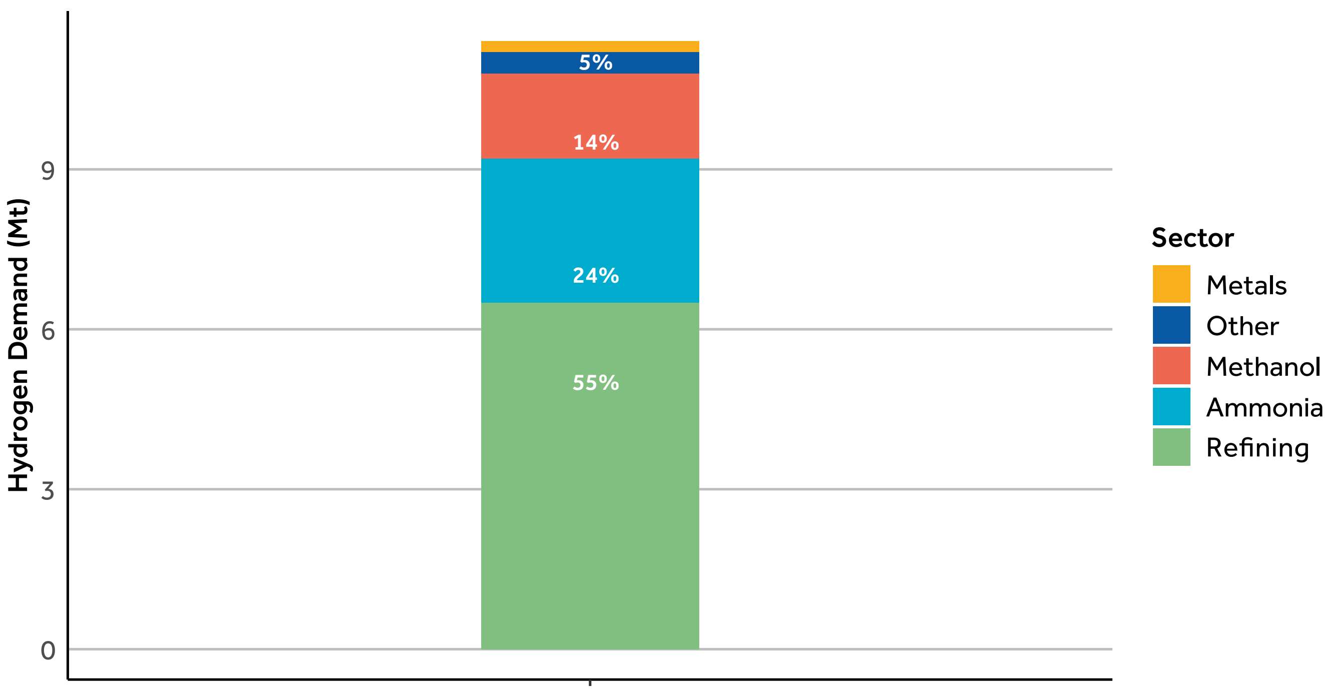
Leachman, Jacob. "The Colors of Hydrogen." Washington State University. 2015.

The U.S. produced approximately 10 million tons of hydrogen in 2020, about 10% of the global total and ranking second in the world after China.[20] Almost all (95%) of it was gray hydrogen from natural gas.[21] In the United States, more than 57% of gray hydrogen produced in 2020 went towards the refining sector, followed by chemical production of ammonia at 24%, methanol at 14%, and metals and other uses accounting for 5% (Figure 2). Notable niche uses include liquefaction for rocket fuel at NASA's Kennedy Space Center in Florida, the world's largest facility for hydrogen liquefaction.[22]

*The United States produced **approximately 10 million tons of hydrogen in 2020**, about 10% of the global total and ranking second in the world after China.*

FIGURE 2.

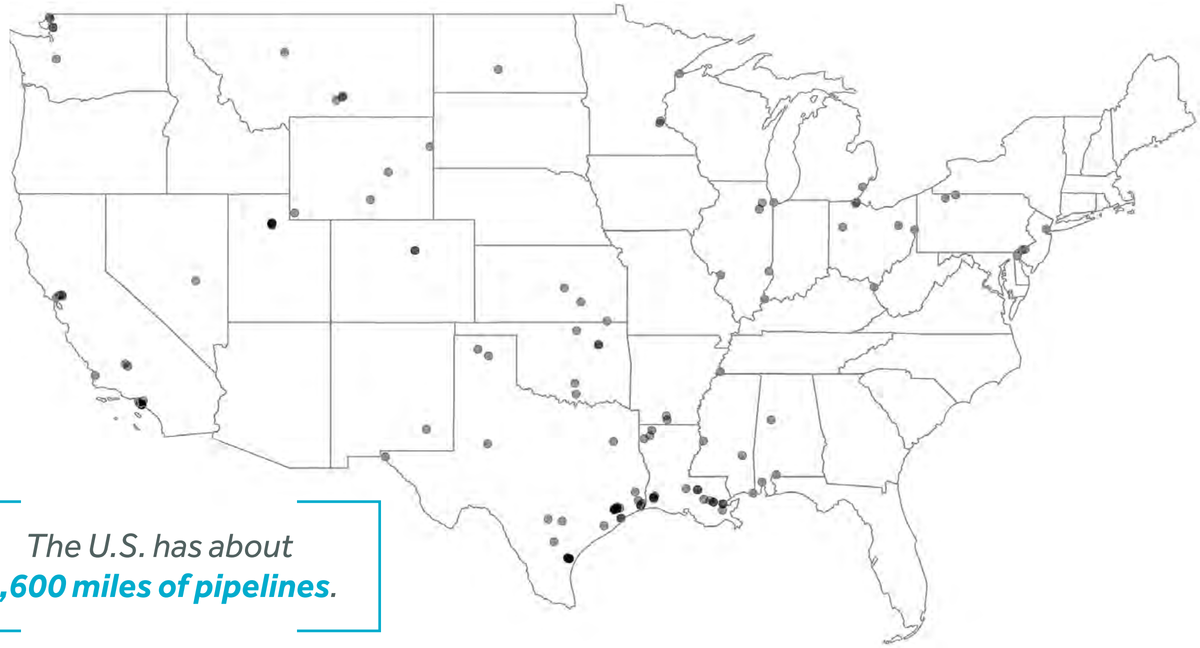
Hydrogen demand in United States in 2020 came mostly from refining, ammonia, and methanol sectors. Source: Fuel Cell and Hydrogen Cell Association (2021)[23]



The refining sector uses hydrogen to remove sulfur from fuels as mandated by regulations because when burned in fuels, sulfur produces air pollution. Refiners also use hydrogen to make heavier fuels into lighter fuels.[24] In the United States, refineries, where most hydrogen production currently occurs, are located throughout the country (Figure 3). Meanwhile, in the methanol and ammonia sectors, which rank second after the refining sector in the United States for hydrogen use, hydrogen serves as a chemical input. Methanol and ammonia are often sold as chemical products on their own or used as the building blocks for further products like fertilizer.[25]

FIGURE 3.

Most current fossil fuel-based hydrogen production the United States occurs at refineries located throughout the country, with each point representing a single refinery. Overlapping darker points show refineries located in close proximity. Source: U.S. Energy Information Administration (2019)[26]



The U.S. has about ***1,600 miles of pipelines.***

Currently, of the world's 2,900 miles of dedicated transport pipelines for hydrogen, the United States has about 1,600 miles of pipelines with much of the infrastructure along the Gulf Coast near refineries.[27] Other notable U.S. hydrogen infrastructure includes the world's largest storage facility in Texas where hydrogen is stored in underground salt caverns.[28]

There are analogues between natural gas and future potential hydrogen infrastructures. Examples include converting existing natural gas pipelines to transport hydrogen, storing hydrogen underground like natural gas, or liquefying hydrogen for transport by ship like liquefied natural gas. However, these efforts are at differing stages of deployment due to novelty, costs, and hydrogen's technical characteristics, the most important being that hydrogen is less dense than natural gas. The small size of the hydrogen molecule allows it to escape easily into the atmosphere. Because most hydrogen production and end use sites have been in close proximity, research has only looked at basic safety thresholds for transport. Consequently, further research on detection of leaks and related technology is needed, with implications for any future import and export of hydrogen.[29] Despite challenges of translating know-how and technology from natural gas to hydrogen, several ongoing and demonstration projects exist in the United States. For example, since the 1970s, Hawaii has blended up to 15% hydrogen with natural gas used in the state. Likewise, there are plans to use salt caverns along the Texas Gulf Coast to store green hydrogen (as opposed to current gray hydrogen) beginning in 2025.[30]

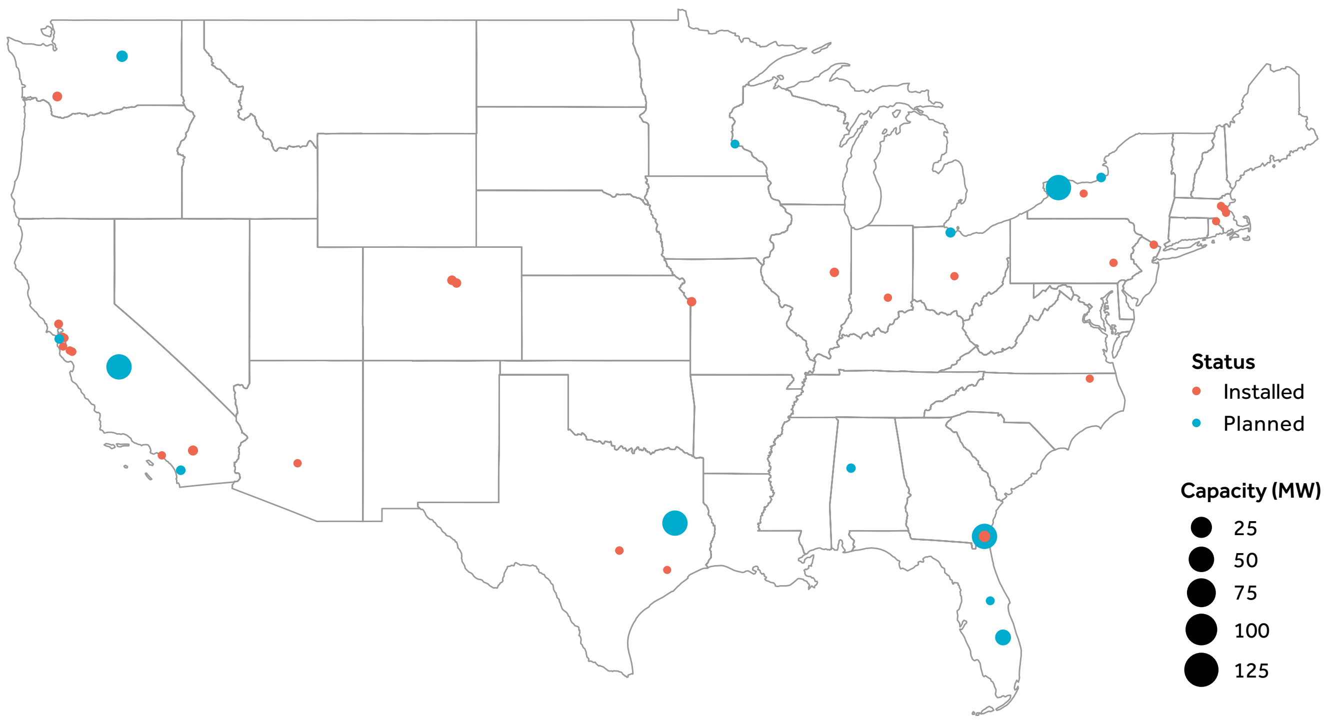
The United States Congress passed two major pieces of legislation in 2021 and 2022 that have expanded the scope of green hydrogen infrastructure and programs. **The Infrastructure Investment and Jobs Act of 2021 included $8 billion for Regional Clean Hydrogen Hubs to expand use of clean hydrogen in the industrial sector** as well as $1 billion for a Clean Hydrogen Electrolysis Program.[31] The selection process for the funding of these hubs is currently underway and is expected to conclude sometime in 2023.[32] The Inflation Reduction Act (IRA) of 2022 provides a 10-year production tax credit of 2.6 cents per kilowatt-hour and up to $3 per kilogram of hydrogen produced depending on emissions intensity. Furthermore, the IRA also expands loan and grant programs related to hydrogen.

The extended public support for cleaner hydrogen production has been apparent in the rapid scaling up of electrolyzers in the United States (Figure 4). Electrolyzers are sized by the amount of electricity they use similar to power plants. A 2021 estimate of electrolyzer capacity was 172 megawatts (MW), as compared to over 620 MW in 2022.[33] These installed and planned sites of cleaner hydrogen production are located throughout the country illustrating the future extent of any hydrogen-based economic activity.

> *An estimate of electrolyzer capacity was* ***172 megawatts in 2021****, compared to* ***620 megawatts in 2022****.*

FIGURE 4.

Installed and planned capacity of electrolyzers throughout the United States illustrate the future potential of a broad-based cleaner hydrogen sector. Source: U.S. Department of Energy (2022)[34]



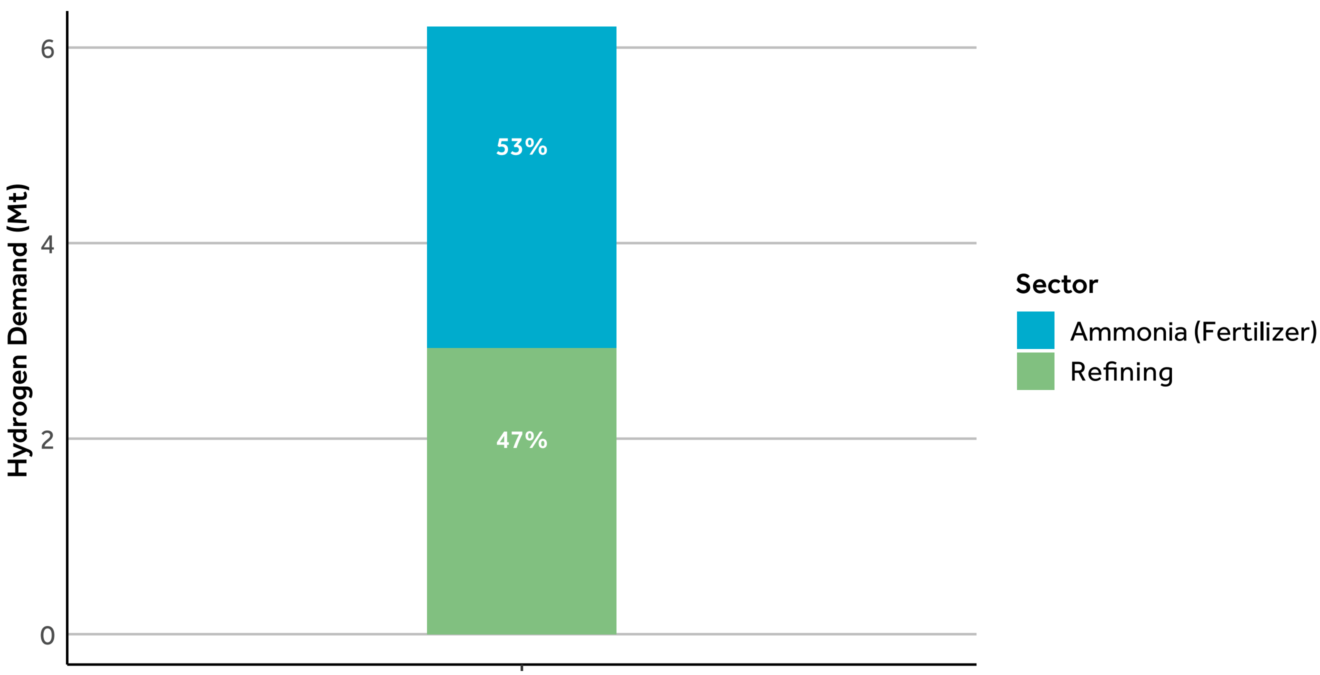
The U.S. Department of Energy has outlined a national strategy for a pathway to 10 million tons of clean hydrogen by 2030, 20 million tons by 2040, and 50 million annually by 2050. The legislation and accompanying financial incentives passed by Congress in 2021 and 2022 will help the United States realize this strategy by reducing costs and increasing research and development. Over the next 20-30 years, the department estimates hydrogen may play greater roles in sectors such as heavy-duty trucks and buses, biofuels, steel, ammonia production, and energy storage. For heavy duty vehicles and long-range applications where battery electric vehicles may not provide enough power, hydrogen may provide a cleaner alternative to current diesel. In energy storage, as the U.S. power grid increases its share of renewable energy, hydrogen produced during periods of excess renewable energy generation and used during limited generation periods, e.g., night, may provide a way to offset the intermittence of solar and wind electricity. Finally, to produce chemicals such as ammonia which already use hydrogen as an input, cleaner hydrogen may provide ways to reduce emissions from production.[35]

Demand for hydrogen in India was about six million tons in 2020, about 7% of the total global hydrogen demand.[36] This ranked fifth in the world after China, the United States, the Middle East, and Europe.[37] Most hydrogen consumed in India is gray produced from natural gas, a growing fraction of which is imported.[38] This demand was approximately equally split between the fertilizer and refinery sectors with a negligible amount going to methanol production (Figure 6).[39] The transportation of hydrogen in India via pipeline or truck is likely negligible given hydrogen's intermediary status. Globally, over 85% of hydrogen is produced for onsite use.[40]

*In terms of global hydrogen demand, **India ranks fifth in the world** after China, the United States, the Middle East, and Europe.*

FIGURE 5.

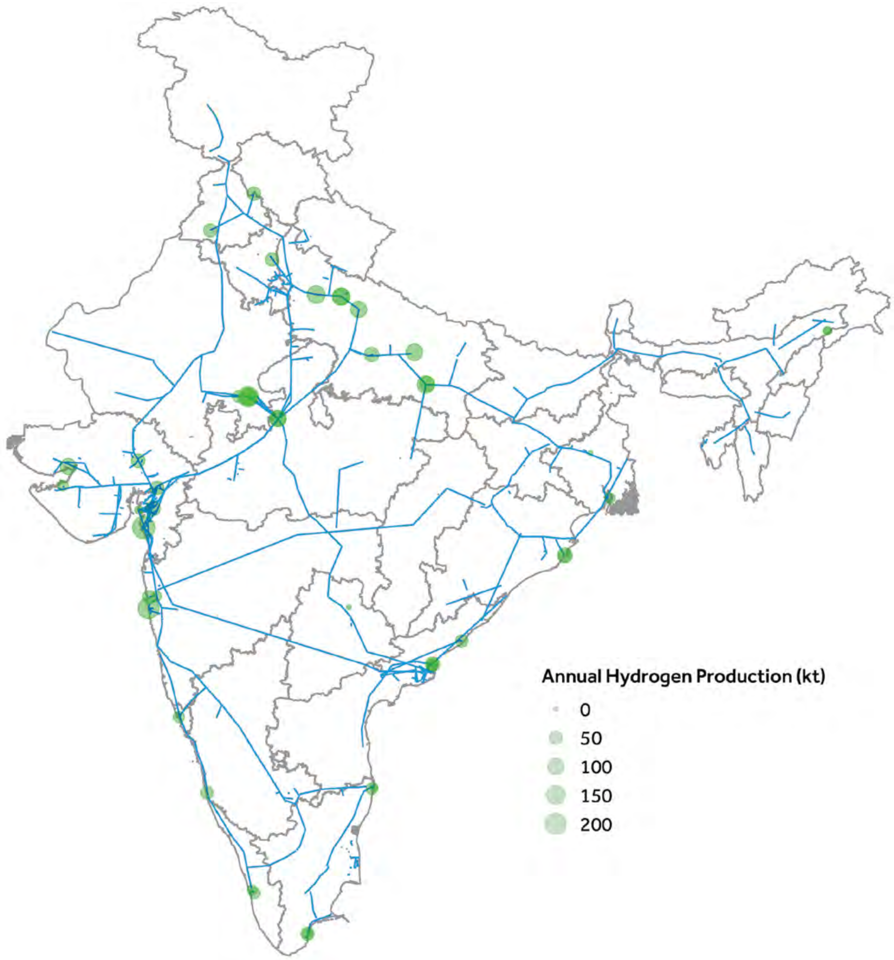
Hydrogen demand in India in 2020 was roughly split between fertilizer and refining sectors. Source: Hall et al. (2020)[41]



In the fertilizer sector, hydrogen serves as a feedstock for the chemical ammonia which is turned into finished fertilizers.[42] India produces most of the fertilizer it consumes. However, it is also dependent on imports of both finished fertilizers as well as fertilizer inputs such as natural gas.[43] Currently, since natural gas is an input, hydrogen production at fertilizer plants is largely concentrated around natural gas pipelines in India (Figure 6).

FIGURE 6.

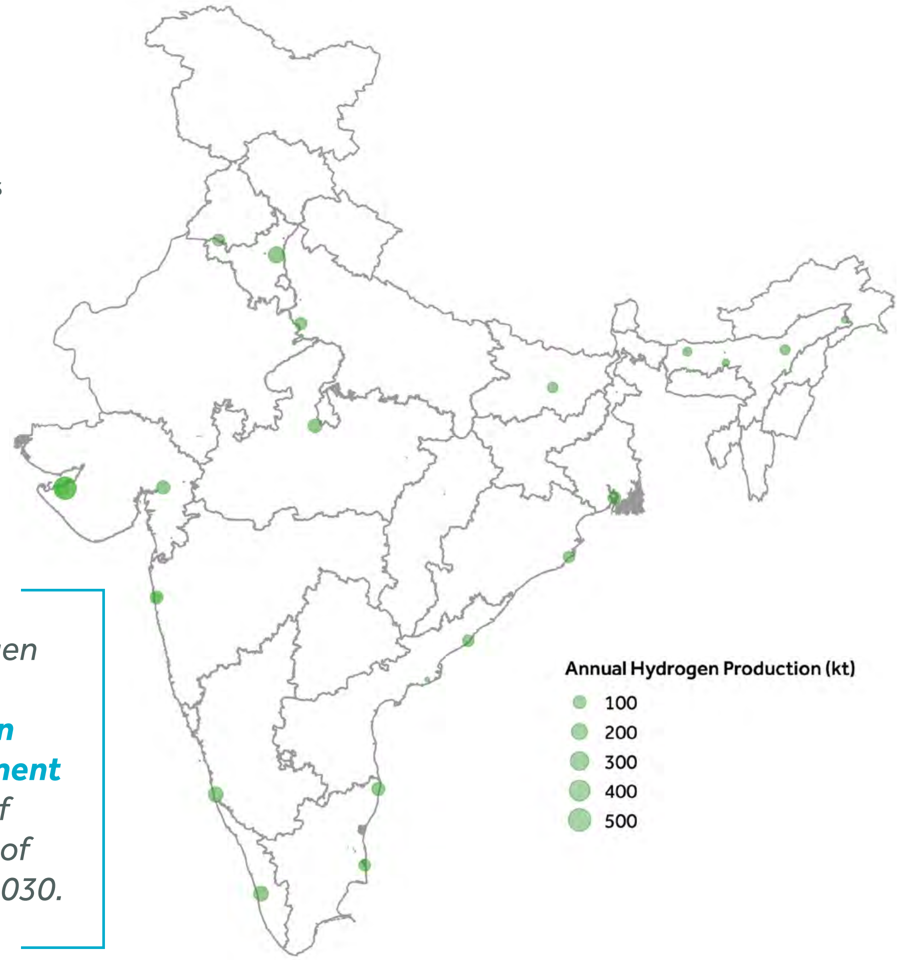
Hydrogen production at fertilizer plants in India is largely concentrated along natural gas pipelines. Source: Author analysis based on Hall et al. (2020)[44] and Government of India[45]



In the refining sector, hydrogen in India is produced directly from either: a) natural gas or a mixture of hydrocarbons called naphtha as an input or b) as a byproduct to make products such as gasoline, diesel, jet fuel, and various petrochemicals. As in the United States, one of the chief uses for hydrogen is to remove sulfur when refining diesel and other fuels. Indian refineries must meet increasingly stringent regulations for sulfur content in the fuels they produce.[46] Most refining capacity and, consequently, hydrogen production, is in coastal India to take advantage of both domestically produced offshore oil and imported oil (Figure 7).

FIGURE 7.

Most hydrogen production at refineries in India is along the coasts to take advantage of offshore oil production and imported oil. Source: Manna et al. (2021)[47]



*The National Green Hydrogen Mission appropriates approximately **$2 billion in public subsidies and investment incentives** in the hopes of producing five million tons of green hydrogen annually by 2030.*

The Government of India's National Green Hydrogen Mission has framed a bullish outlook for green hydrogen in India's future energy mix, with likely roles in the refining, fertilizer, and steel sectors.[48] The National Green Hydrogen Mission appropriates approximately $2 billion in public subsidies and investment incentives in the hopes of producing five million tons of green hydrogen annually by 2030. It also aims to subsidize electrolyzer manufacturing to kickstart the export of green hydrogen and its derivative products.[49]

In the fertilizer sector, green hydrogen produced from locally sited renewable energy provides opportunities for India to reduces its reliance on imported natural gas, ammonia, and fertilizer.[50] Under business-as-usual scenarios, fertilizer ammonia produced from green hydrogen may meet about a third of ammonia demand in India by 2050.[51]

The future of refining in India will depend on the country's demand for oil, which could grow more than sixfold despite shifts away from transportation fuels due to increasing electrification.[52] Consequently, in the refining sector, green hydrogen offers opportunities to replace current gray hydrogen used to remove sulfur in transportation fuels. Green hydrogen could likewise account for a third of total hydrogen demand from the refining sector.[53]

Lastly, compared to replacing existing uses of hydrogen in fertilizer and refining sectors, green hydrogen presents the newest opportunity to reduce emissions from future expanded steel production in India.[54] Green hydrogen-based steel production in India is at cost parity with imported natural gas-based steel production. However, coal-based steel production remains the cheapest option. To be competitive with coal-based steel production, green hydrogen-based production would need reductions in the cost of green hydrogen from adequate supporting policies like subsidies, procurement, and mandates.[55]

SYNTHESIS

The United States and India rank among the top current consumers of hydrogen, mainly gray hydrogen in the refining and chemical sectors. **Both countries also see hydrogen playing a critical role in their future energy mixes, especially green hydrogen to decarbonize difficult, hard-to-abate sectors like steel and chemicals.** Thus, they have outlined aggressive targets to achieve reductions in cost and increases in production of green hydrogen by 2030. To reach these targets, governments in both countries have offered financial incentives through production credits, i.e., subsidies, to spur green hydrogen production. These subsidies are commensurate with each country's respective economic and fiscal capacity. While there are significant efforts to increase deployment of green hydrogen, there is also significant uncertainty in the future of green hydrogen. Much of the sector is currently fossil fuel based and the technology for and production of green hydrogen must scale dramatically from current levels at lower costs to reach policy targets. Consequently, hydrogen will likely play a role in the energy transition for both the United States and India, but it will not be a silver bullet solution capable of replacing fossil fuels in every sector.

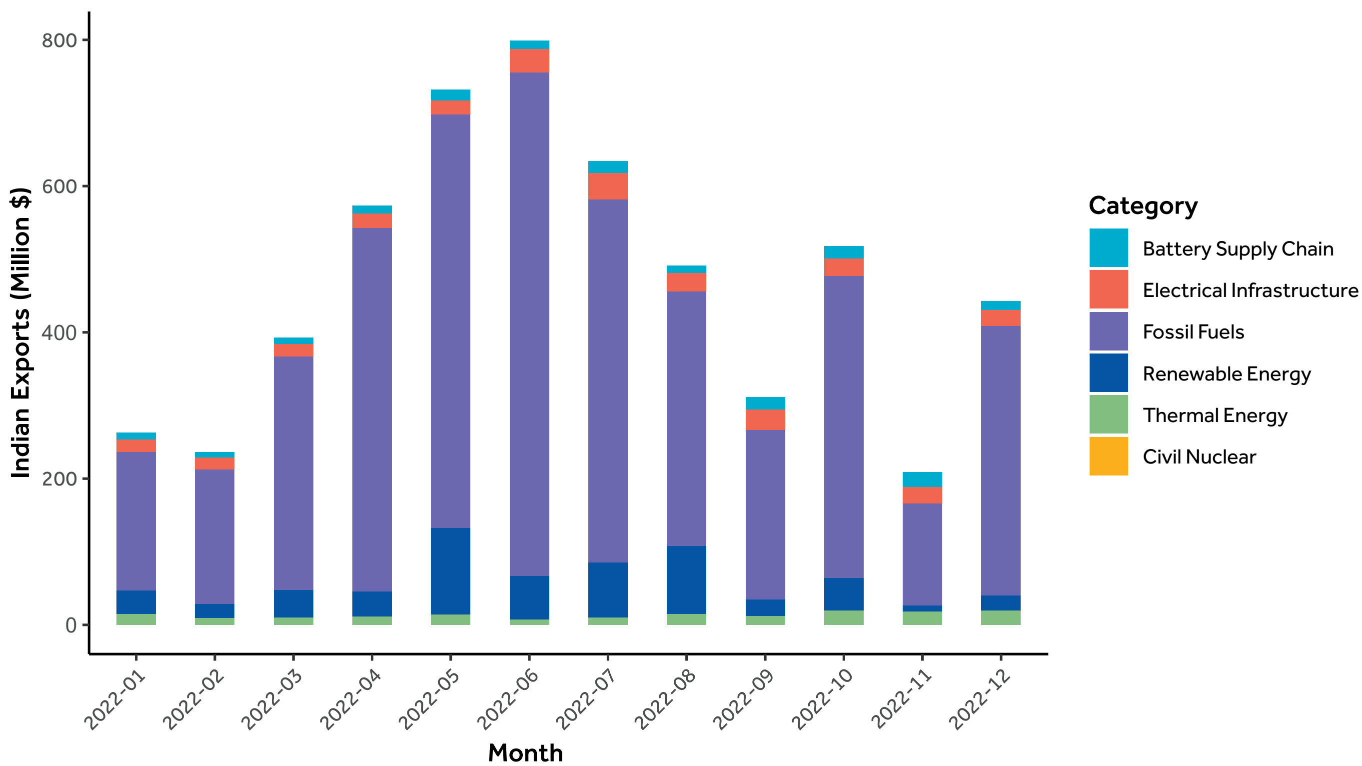
The United States and India must target green hydrogen toward sectors where current alternatives to fossil fuels do not exist or electrification is not an option. Current projections of green hydrogen demand point to these sectors but are highly uncertain. Policy must be responsive and learn from the deployment of the financial incentives in the IRA and the National Green Hydrogen Mission. Learning from these efforts will reduce uncertainty about the demand for green hydrogen over time and help to target assistance effectively. Here there is also the potential for private sector investment in green hydrogen to flow towards the United States at the expense of India in the short term because the former provides higher levels of support. To sustain broad-based green hydrogen development and direct it to toward targeted sectors, the United States and India should cooperate to harmonize green hydrogen policies. Forums such as the U.S.-India Hydrogen Task Force provide avenues for cooperation.[56]

> ***Hydrogen will likely play a role*** *in the energy transition for both the United States and India, but it* ***will not be a silver bullet solution*** *capable of replacing fossil fuels in every sector.*

INDIA-U.S. ENERGY TRADE

INDIAN EXPORTS TO THE U.S. (MILLION $)

CATEGORY	OCTOBER 2022	NOVEMBER 2022	DECEMBER 2022
Fossil Energy	412	140	368
Renewable Energy	45	8	21
Electrical Infrastructure	24	22	22
Thermal Power	19	18	19
Battery Supply Chain	17	21	13
Civil Nuclear	-	-	-

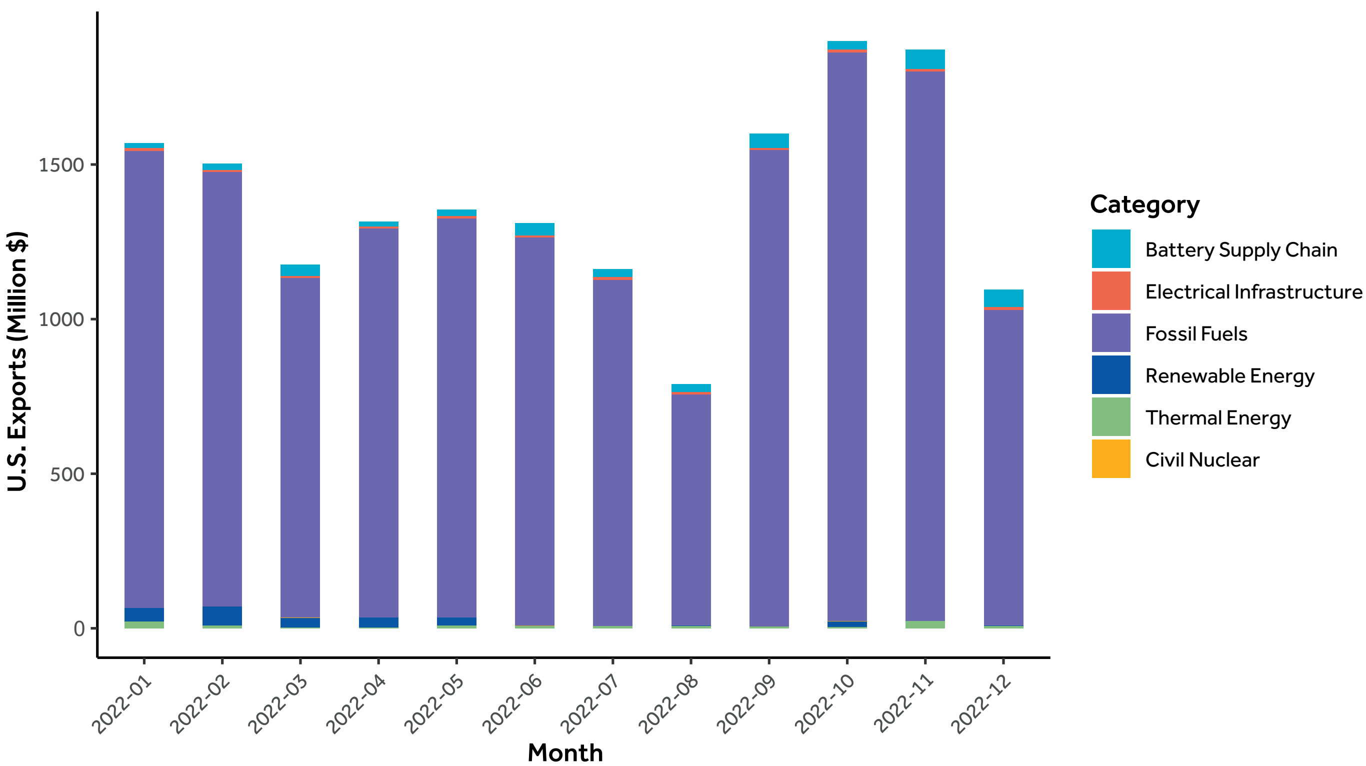


Source: U.S. Census Bureau[57], U.S. International Trade Administration[58]

U.S.-INDIA ENERGY TRADE

U.S. EXPORTS TO INDIA (MILLION $)

CATEGORY	OCTOBER 2022	NOVEMBER 2022	DECEMBER 2022
Fossil Energy	1,840	1,778	1,022
Renewable Energy	17	0	0.07
Electrical Infrastructure	9	8	10
Thermal Power	5	23	8
Battery Supply Chain	29	62	57
Civil Nuclear	0.09	0.06	0.004



Source: U.S. Census Bureau[59], U.S. International Trade Administration[60]

ENDNOTES

[1] Dickie, "COP27."
PIB Delhi, "India Submits Its Long-Term Low Emission Development Strategy to UNFCCC."

[2] Nandi, "India Updates Its NDC to Tackle Climate Crisis."

[3] Dickie, "COP27."

[4] "Parliament Passes Bill to Promote Non-Fossil Energy Sources and Carbon Credit Trading."

[5] Baruah, "Voluntary Carbon Trades to Start in 2023."

[6] Singh and Narayan, "India to Bolster Carbon Trading Market with Stabilisation Fund."

[7] Del Bello, "India Gets Ready to Launch a National Carbon Market," October 18, 2022.

[8] Del Bello, "India Gets Ready to Launch a National Carbon Market," October 18, 2022; Emma and Adragna, "What's in and What's out of Congress' $1.7T Spending Bill."

[9] Pontecorvo, "Renewables Are Growing — but a Backlog of Projects Is Holding up a Greener Grid."

[10] Cooban, "'Not How You Treat Friends.' Biden's Climate Plan Strains Trade Ties with Europe."

[11] Ha, "IRA and the EV Tax Credits."

[12] Fischer, "Canada Introduces Major Investment Tax Credits for Clean Energy."

[13] Van Gaal, "Will a Green Industrial Arms Race with the US Spur EU's Energy Transition?"
Radowitz, "EU to Ease State Aid Rules for Green Energy as US IRA 'Could Lead to Unfair Competition.'"

[14] Hall et al., "The Potential Role of Hydrogen in India."

[15] Leachman, "The Colors of Hydrogen."

[16] Zapantis, "Blue Hydrogen."

[17] "The Future of Hydrogen."

[18] "Hydrogen Basics."

[19] Leachman, "The Colors of Hydrogen."

[20] "Global Hydrogen Review 2022."

[21] U.S. Department of Energy, "Hydrogen Production: Natural Gas Reforming."

[22] "Global Hydrogen Review 2022."

[23] Fuel Cell and Hydrogen Association, "Roadmap to a U.S. Hydrogen Economy."

[24] "Global Hydrogen Review 2022."

[25] "Global Hydrogen Review 2022."

[26] U.S. Energy Information Administration, "Petroleum Refineries."

[27] "Global Hydrogen Review 2022"; U.S. Department of Energy, "Hydrogen Pipelines."

[28] "Global Hydrogen Review 2022."

[29] Hamburg and Ocko, "For Hydrogen to Be a Climate Solution, Leaks Must Be Tackled."

[30] "Global Hydrogen Review 2022."

[31] Department of Energy, "DOE Establishes Bipartisan Infrastructure Law's $9.5 Billion Clean Hydrogen Initiatives."

[32] Offutt, "Hydrogen Hubs and Demonstrating the Hydrogen Energy Value Chain."

[33] Satyapal, "2022 AMR Plenary Session"; Arjona, "PEM Electrolyzer Capacity Installations in the United States."

[34] Arjona, "PEM Electrolyzer Capacity Installations in the United States."

[35] U.S. Department of Energy, "DOE National Clean Hydrogen Strategy and Roadmap."

[36] "Hydrogen."

[37] "Global Hydrogen Review 2022."

[38] Petroleum Planning & Analysis Cell, "Natural Gas Consumption."

[39] Hall et al., "The Potential Role of Hydrogen in India."

[40] "The Future of Hydrogen."

[41] Hall et al., "The Potential Role of Hydrogen in India."

[42] Hall et al.

[43] Hall et al.; Petroleum Planning & Analysis Cell, "Natural Gas Consumption."

[44] Hall et al., "The Potential Role of Hydrogen in India."

[45] Department of Fertilizers, "Annual Report 2020-2021"; "Energy Map of India."

[46] Hall et al., "The Potential Role of Hydrogen in India."

[47] Manna et al., "Opportunities for Green Hydrogen Production in Petroleum Refining and Ammonia Synthesis Industries in India."

[48] "National Green Hydrogen Mission."

[49] "National Green Hydrogen Mission."

[50] Raj, Lakhina, and Stranger, "Harnessing Green Hydrogen: Opportunities for Deep Decarbonisation in India."

[51] Hall et al., "The Potential Role of Hydrogen in India."

[52] Hall et al.

[53] Hall et al.

[54] Raj, Lakhina, and Stranger, "Harnessing Green Hydrogen: Opportunities for Deep Decarbonisation in India."

[55] Hall et al., "The Potential Role of Hydrogen in India."

[56] "U.S.-India Hydrogen Task Force."

[57] "International Trade (Annual 2005 - Present, Monthly 2013-Present)."

[58] "U.S. Energy Trade Dashboard."

[59] "International Trade (Annual 2005 - Present, Monthly 2013-Present)."

[60] "U.S. Energy Trade Dashboard."

REFERENCES

Arjona, Vanessa. "PEM Electrolyzer Capacity Installations in the United States." U.S. Department of Energy, June 6, 2022. https://www.hydrogen.energy.gov/pdfs/22001-electrolyzers-installed-in-united-states.pdf.

Baruah, Rituraj. "Voluntary Carbon Trades to Start in 2023." Mint, January 24, 2023. https://www.livemint.com/news/india/voluntary-carbon-trades-to-start-in-2023-11674498997601.html.

Cooban, Anna. "'Not How You Treat Friends.' Biden's Climate Plan Strains Trade Ties with Europe." CNN, December 6, 2022. https://www.cnn.com/2022/12/06/business/eu-us-trade-tensions-ira/index.html.

Del Bello, Lou. "India Gets Ready to Launch a National Carbon Market." Energy Monitor, October 18, 2022. https://www.energymonitor.ai/policy/carbon-markets/india-gets-ready-to-launch-a-national-carbon-market/.

Department of Energy. "DOE Establishes Bipartisan Infrastructure Law's $9.5 Billion Clean Hydrogen Initiatives," February 15, 2022. https://www.energy.gov/articles/doe-establishes-bipartisan-infrastructure-laws-95-billion-clean-hydrogen-initiatives.

Department of Fertilizers. "Annual Report 2020-2021." New Delhi: Ministry of Chemicals and Fertilizers, Government of India, 2021. https://www.fert.nic.in/sites/default/files/2020-082022-08/Annual%20report%20of%20Department%20of%20Fertilizer%202020-2021.pdf.

Dickie, Gloria. "COP27: India Lays out Plan for Long-Term Decarbonization." Reuters, November 14, 2022, sec. COP27. https://www.reuters.com/business/cop/cop27-india-lays-out-plan-long-term-decarbonization-2022-11-14/.

Emma, Caitlin, and Anthony Adragna. "What's in and What's out of Congress' $1.7T Spending Bill." POLITICO, December 20, 2022. https://www.politico.com/news/2022/12/20/spending-bill-omnibus-shutdown-tiktok-00074788.

"Energy Map of India." NITI Aayog and Indian Space Research Organisation, 2020. https://vedas.sac.gov.in/energymap/.

Fischer, Anne. "Canada Introduces Major Investment Tax Credits for Clean Energy." Pv Magazine, November 7, 2022. https://pv-magazine-usa.com/2022/11/07/canada-introduces-major-investment-tax-credits-for-clean-energy/.

Fuel Cell and Hydrogen Association. "Roadmap to a U.S. Hydrogen Economy." Washington, DC, 2021. https://www.fchea.org/us-hydrogen-study.

"Global Hydrogen Review 2022." Paris: International Energy Agency, September 2022. https://www.iea.org/reports/global-hydrogen-review-2022.

Ha, So Jung. "IRA and the EV Tax Credits: Disruption or Expansion of Trade Alliance? | New Perspectives on Asia | CSIS." CSIS (blog). Accessed February 1, 2023. https://www.csis.org/blogs/new-perspectives-asia/ira-and-ev-tax-credits-disruption-or-expansion-trade-alliance.

Hall, Will, Thomas Spencer, G Renjith, and Shruti Dayal. "The Potential Role of Hydrogen in India." New Delhi: The Energy and Resources Institute, 2020.

Hamburg, Steven and Lissa Ocko. "For Hydrogen to Be a Climate Solution, Leaks Must Be Tackled." EDF Voices (blog), 2022. https://www.edf.org/blog/2022/03/07/hydrogen-climate-solution-leaks-must-be-tackled.

"Hydrogen." Paris: International Energy Agency, 2022. https://www.iea.org/reports/hydrogen.

"Hydrogen Pipelines," 2022. https://www.energy.gov/eere/fuelcells/hydrogen-pipelines.

"Hydrogen Production: Natural Gas Reforming," 2022. https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming.

"India Gets Ready to Launch a National Carbon Market." Energy Monitor, October 18, 2022. https://www.energymonitor.ai/policy/carbon-markets/india-gets-ready-to-launch-a-national-carbon-market.

"International Trade (Annual 2005 - Present, Monthly 2013-Present)." U.S. Census Bureau, May 4, 2022. https://www.census.gov/data/developers/data-sets/international-trade.html.

Leachman, Jacob. "The Colors of Hydrogen." Hydrogen Properties for Energy Research (blog), December 22, 2015. https://hydrogen.wsu.edu/2015/12/22/the-colors-of-hydrogen/.

Manna, Joydev, Prakash Jha, Rudranath Sarkhel, Chandan Banerjee, A.K. Tripathi, and M.R. Nouni. "Opportunities for Green Hydrogen Production in Petroleum Refining and Ammonia Synthesis Industries in India." International Journal of Hydrogen Energy 46, no. 77 (November 2021): 38212–31. https://doi.org/10.1016/j.ijhydene.2021.09.064.

Nandi, Jayashree. "India Updates Its NDC to Tackle Climate Crisis." Hindustan Times, August 26, 2022. https://www.hindustantimes.com/india-news/india-updates-its-ndc-to-tackle-climate-crisis-101661537644696.html.

"National Green Hydrogen Mission." New Delhi: Ministry of New and Renewable Energy, Government of India, January 2023.

National Renewable Energy Laboratory. "Hydrogen Basics." US Government. Accessed February 2, 2023. https://www.nrel.gov/research/eds-hydrogen.html.

Offutt, Martin C. "Hydrogen Hubs and Demonstrating the Hydrogen Energy Value Chain." Congressional Research Service, August 24, 2022. https://crsreports.congress.gov/product/pdf/R/R47289.

Petroleum Planning & Analysis Cell. "Natural Gas Consumption." Ministry of Petroleum & Natural Gas, Government of India, April 11, 2022. https://www.ppac.gov.in/content/152_1_Consumption.aspx.

REFERENCES

PIB Delhi. "India Submits Its Long-Term Low Emission Development Strategy to UNFCCC." Accessed February 1, 2023. https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1875816.

Pontecorvo, Emily. "Renewables Are Growing — but a Backlog of Projects Is Holding up a Greener Grid." Grist, April 20, 2022. https://grist.org/energy/renewables-are-growing-but-a-backlog-of-projects-is-holding-up-a-greener-grid/.

Radowitz, Bernd. "EU to Ease State Aid Rules for Green Energy as US IRA 'Could Lead to Unfair Competition.'" RECHARGE, December 15, 2022. https://www.rechargenews.com/energy-transition/eu-to-ease-state-aid-rules-for-green-energy-as-us-ira-could-lead-to-unfair-competition/2-1-1374453.

Raj, Kowtham, Pranav Lakhina, and Clay Stranger. "Harnessing Green Hydrogen: Opportunities for Deep Decarbonisation in India." New Delhi: NITI Aayog and RMI, June 2022. https://rmi.org/insight/harnessing-green-hydrogen/.

Satyapal, Sunita. "2022 AMR Plenary Session." Energy Market and Policy Context. Department of Energy, June 6, 2022. https://www.hydrogen.energy.gov/pdfs/review22/plenary4_satyapal_2022_o.pdf.

Singh, Sarita Chaganti, and Mohi Narayan. "India to Bolster Carbon Trading Market with Stabilisation Fund." Reuters, December 22, 2022, sec. Sustainable Business. https://www.reuters.com/business/sustainable-business/india-bolster-carbon-trading-market-with-stabilisation-fund-2022-12-21/.

"The Future of Hydrogen." Paris: International Energy Agency, June 2019. https://www.iea.org/reports/the-future-of-hydrogen.

The Times of India. "Parliament Passes Bill to Promote Non-Fossil Energy Sources and Carbon Credit Trading," December 12, 2022. https://timesofindia.indiatimes.com/india/parliament-passes-bill-to-promote-non-fossil-energy-sources-and-carbon-credit-trading/articleshow/96175637.cms.

U.S. Department of Energy. "DOE National Clean Hydrogen Strategy and Roadmap." Department of Energy, September 2022. https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf.

U.S. Energy Information Administration. "Petroleum Refineries," October 4, 2019. https://atlas.eia.gov/datasets/eia::petroleum-refineries.

"U.S. Energy Trade Dashboard." U.S. International Trade Administration, 2022. https://www.trade.gov/data-visualization/us-energy-trade-dashboard.

U.S.-India Strategic Partnership Forum. "U.S.-India Hydrogen Task Force," 2021. https://usispf.org/us-india-hydrogen-task-force/.

Van Gaal, Wester. "Will a Green Industrial Arms Race with the US Spur EU's Energy Transition?" EUobserver, December 30, 2022. https://euobserver.com/green-economy/156575.

Zapantis, Alex. "Blue Hydrogen." Melbourne: Global CCS Institute, April 2021. https://www.globalccsinstitute.com/wp-content/uploads/2021/04/Circular-Carbon-Economy-series-Blue-Hydrogen.pdf.

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