South Asia Scan

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December 2022

Emerging Markets and Opportunities from India's Clean Energy Initiatives

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Introduction

India is today among the world's largest energy consumers and will continue growing its energy demand for at least the next two decades. The steady economic growth and development is supported primarily by imported energy in the form of crude oil, coal and natural gas. As of FY2019-20, 85 per cent of crude oil, 53 per cent of natural gas and 25 per cent of coal are imported.[1] The import share is expected to increase as domestic supply cannot match the demand growth. India's imported goods and services were worth 21 per cent of the country's total gross domestic product (GDP) in 2019.[2]

The country is under increased pressure to switch to cleaner fuels – in 2021, 35 of the top 50 most polluted cities in the world were in India.[3] The need for emissions reduction to counteract global warming is also increasingly dire. Indian power sector and industry are heavily reliant on coal and oil products for energy, being among the most emissions-intensive in the world. Upcoming carbon border pricing mechanisms, such as the European Union's Carbon Border Adjustment Mechanism, could, therefore, reduce the competitiveness of Indian exports.

India has, however, seen rapid progress in the deployment of clean energy sources, primarily solar power which has grown from 2.6 gigawatts (GW) of installed capacity in 2014 to 54 GW in 2022.[4] Successes from the solar power story are seen as an indicator of the opportunities available in the green energy space, where India can take the lead in technology development, manufacturing and deployment. The COVID-19 pandemic has enabled the Indian government to make drastic financial allocations for economic growth and green energy development is seen as one attractive sector for driving growth.

1 Ministry of Petroleum and Natural Gas [MoPNG]. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf; and Ministry of Coal. 2022. Production and Supplies, https://coal.nic.in/en/major-statistics/production-and-supplies.

2 The World Bank. 2019. *Imports of goods and services (% of GDP) – India*, https://data.worldbank.org/indicator/NE.IMP.GNFS.ZS?locations=IN.

3 IQAir. 2022. *World's most polluted cities (historical data 2017-2021)*, https://www.iqair.com/us/world-most-polluted-cities.

4 Ministry of New and Renewable Energy [MNRE]. 2021a. *Solar Energy*, https://mnre.gov.in/solar/current-status/; and Ministry of Power. 2022. *Power sector at a glance*, https://powermin.gov.in/en/content/power-sector-glance-all-india.

Significant Potential for Green Energy in India

Moving forward, India has ample potential to look inward for its energy needs. The country has vast resources for renewable energy; the following are some approximate potentials:

i. Solar and wind energy = 748 GW and 696 GW (as per Ministry of New and Renewable Energy [MNRE]);[5] and 4,000 GW (as per NREL).[6]
ii. Biomass and waste = 48 GW (as per MNRE).[7]
iii. Small hydro = 21 GW (as per MNRE).[8]

India already has the fourth largest installed capacity of renewable energy in the world, with much of the growth happening in the last decade.[9] Renewable power produced from solar and wind resources is already cost-competitive with conventional energy sources. Distributed renewable energy systems are already powering livelihoods where conventional grids are unavailable or unreliable. Purchase-linked incentives introduced by the government for solar energy are encouraging the domestic manufacturing industry to manufacture all components of the PV systems. Such schemes will provide the right environment for green hydrogen to proliferate. Also, there are cross-linkages between green hydrogen and biomass utilisation for the production of green fuels (biomass providing the carbon along with the green hydrogen for producing synthetic hydrocarbons).

Political Will to Accelerate the Energy Transition

The Indian government is keen on accelerating the pace of the energy transition of the Indian economy through various policy interventions.

5 MoPNG. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, op. cit.; and MNRE. 2021b. Wind Energy, https://mnre.gov.in/wind/current-status/.
6 Rose, Amy, Ilya Chernyakhovskiy, David Palchak, Sam Koebrich, and Mohit Joshi. 2020. *Least-Cost Pathways for India's Electric Power Sector*. National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy20osti/76153.pdf.
7 MNRE. 2021c. *Bioenergy*, https://mnre.gov.in/bio-energy/current-status; and MNRE. 2021d. *Waste to Energy*, https://mnre.gov.in/waste-to-energy/current-status.
8 MNRE. 2022. *Small hydro energy*, https://mnre.gov.in/small-hydro/current-status.
9 IRENA. 2021. *Renewable Capacity Statistics 2021*, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_RE_Capacity_Statistics_2021.pdf.

The economy has started to transform to low-carbon energy sources and is firmly on the pathway to decoupling its GDP from emissions.

In 2015, India was the first country to announce a 100 GW installed capacity target for renewable energy systems (which was achieved in 2021). The International Solar Alliance was established in 2015 by the Indian government to bring multinational, multi-stakeholder partnerships in developing solar energy across the world. The government proposed the Electricity Amendment Bill in 2021 to delicence the power sector, thus allowing freer participation of private power producers and distributors to access the market. This will be an enabler for the green hydrogen developers. To reduce inefficiencies and losses in the power distribution system, the government is also looking to privatise state-owned distribution companies. Creating jobs in the rural sector has become a priority and certain green energy solutions in the bioenergy space provide the required support. The government's flagship initiative – 'Make in India' – is being utilised to support the development of entire ecosystems in several industrial sectors, including the green energy business. This initiative gives a sense of direction and expectation from various arms of government.

In 2021, the Indian government announced a target of achieving net-zero GHG emissions by 2070, supplemented by the five targets[10] of

i. 500 GW of non-fossil power capacity by 2030;
ii. 50 per cent of electricity from renewable sources by 2030;
iii. 1 billion tCO2 reductions from the baseline scenario by 2030;
iv. 45 per cent reduction in the carbon intensity of GDP by 2030; and
v. Net zero GHG emissions by 2030.

The following are some key schemes government ministries have introduced for the energy sector reforms:

i. MNRE – National Hydrogen Energy Mission;
ii. Solar Energy Corporation of India – National Solar Mission; and

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10 Press Information Bureau [PIB]. 2021. "*National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow*", https://pib.gov.in/PressReleasePage.aspx?PRID=1768712.

iii. Ministry of Petroleum and Natural Gas – Sustainable Alternative Towards Affordable Transportation (SATAT).

Several governmental institutions and public sector undertakings are involved in the research and development of new technologies for energy transition, such as:

i. National Chemicals Laboratory;
ii. Bhabha Atomic Research Centre;
iii. Indian Space Research Organisation;
iv. Indian Oil Corporation Limited;
v. National Thermal Power Corporation; and
vi. Steel Research and Technology Mission of India.

Geopolitical and Multilateral Landscapes

There has been a restructuring of global value chains amid India's rising economic and geopolitical prominence. Looking specifically at South East Asia, India's 'Look East' policy, renamed in 2014 as the 'Act East' policy, has seen trade rise to over US$80 billion (S$110 billion) with the member states of the Association of Southeast Asian Nations (ASEAN) in 2019-20,[11] although it is still much lower than the US$200 billion (S$275 billion) targetted for 2020.[12] Considering the global geopolitical situation and rising influence of China, India is seen as an important partner in bilateral (such as with the US) and multilateral initiatives (such as the Quad) and resilient supply chain initiatives (such as the Supply Chain Resilience Initiative between Australia, India and Japan)[13] among nations with shared interests.

India-Singapore relations have historically been strong due to the longstanding cultural and economic links between the two regions. In 2005, the two countries signed the Comprehensive Economic

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11 Department of Commerce. 2022. *Foreign Trade (ASEAN)*. Ministry of Commerce and Industry, https://commerce.gov.in/about-us/divisions/foreign-trade-territorial-division/foreign-trade-asean/.

12 Kesavan, K.V. 2020. *India's 'Act East' policy and regional cooperation*. Observer Research Foundation. https://www.orfonline.org/expert-speak/indias-act-east-policy-and-regional-cooperation-61375/.

13 PIB. 2021. "*Australia-India-Japan Trade Ministers' Joint Statement on Launch of Supply Chain Resilience initiative*." Delhi: Ministry of Commerce & Industry, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1714362.

Cooperation Agreement (CECA) to strengthen bilateral trade by simplifying collaboration, finance flows and mutual economic development.[14] India and Singapore are also part of the ASEAN-India Free Trade Area. In 2019, India was the 10th largest export market for Singapore,[15] and Singapore was the 5th largest export market for India.[16] The main traded goods were oil products. Singapore is a top source of foreign direct investment (FDI) into India, investing more than US$16 billion (S$22 billion) in FY2020-21.

This edition of the South Asia Scan looks into four key sectors in India's energy transition – renewable power, natural gas, bioenergy and green hydrogen. The current status and potential for growth in each sector are explored, along with initiatives taken by the Indian government and the private sector to stimulate development. We also study the potential for foreign investment and collaboration in each sector. The overall challenges and risks the country faces during the energy transition are also explored.

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14 Department of Commerce. 2022. *Comprehensive Economic Cooperation Agreement between The Republic of India and the Republic of Singapore*, https://commerce.gov.in/international-trade/trade-agreements/comprehensive-economic-cooperation-agreement-between-the-republic-of-india-and-the-republic-of-singapore/.

15 World Integrated Trade Solution [WITS]. 2019. *Singapore trade balance, exports and imports by country 2019*. The World Bank, https://wits.worldbank.org/CountryProfile/en/Country/SGP/Year/2019/TradeFlow/EXPIMP/Partner/by-country.

16 World Integrated Trade Solution [WITS]. 2019. *India trade balance, exports and imports by country 2019*. The World Bank, https://wits.worldbank.org/CountryProfile/en/Country/IND/Year/2019/TradeFlow/EXPIMP/Partner/by-country.

Renewable Power

Background

Renewable energy has been part of India's climate change and energy security strategy since the late 1980s. Initial support mechanisms like accelerated depreciation and technology collaborations expanded wind capacity. The Jawaharlal Nehru National Solar Mission (NSM), notified in January 2010, targetted reducing investor risk through auctions by state backed intermediaries. Auctions by entities like Solar Energy Corporation of India Limited (SECI), which later also conducted auctions for wind, have led to exponential growth in solar and wind capacity in the utility scale. From approximately 21 GW of utility-scale solar and wind capacity at the end of FY2012 (1 GW solar and 20 GW wind), India now has 82 GW capacity by 31 January 2022 (42 GW ground-mounted solar and 40 GW wind).[17] Other supportive policies like must-run status for renewable energy and waiver of inter-state transmission charges have also increased attractiveness of investment in renewable energy.

In the rooftop sector, the Union Government also provides financial incentives in the residential sector and incentives to distribution utilities to support expansion of rooftop solar projects. Additionally, certain states provide net-metering to distributed solar plants that help lower electricity input costs to commercial and industrial consumers. Net-metering provides consumers with rooftop solar systems to feed power back to the grid; their monthly consumption will be billed for the net amount of electricity consumed (total consumption minus supply to the grid). About 7.7 GW of rooftop projects are in operation as of December 2021.[18]

Status Quo

Driven by the supportive government policies and interest from private players, India's total renewable energy capacity (excluding

17 MNRE. 2022. *Physical Progress Achievements*, https://mnre.gov.in/the-ministry/physical-progress.
18 Bridge to India. 2022. *India RE Navigator*, https://india-re-navigator.com/rooftop.

large hydro) stands at 105 GW[19] and represents 26.8 per cent of the electricity generation mix[20] as of January 2022. In order to efficiently utilise the power infrastructure and land resources and reduce the intermittency of renewable energy, the Indian government is promoting hybrid projects (solar-wind and renewable energy-storage). There's also a focus on strengthening domestic manufacturing of various renewable energy technologies like solar PV modules[21] and batteries.[22]

Potential

India is a signatory of the Paris Agreement, which was adopted by 196 parties in 2015. The Agreement's goal is to limit global warming to well below 2 °C, preferably to 1.5 °C, compared to pre-industrial levels.[23] As part of its increased commitments under the Paris Agreement, India has pledged to increase its non-fossil electricity generation capacity to 500 GW by 2030, of which 280 GW would come from solar. India's renewable energy ambitions are one of the largest expansion plans in the world. It has also committed to net-zero greenhouse gas emissions by 2070. A major part of the net-zero commitments is planned to be driven by electrification of the economy and use of renewable energy to produce electricity.[24]

Government Initiatives

Sale to Distribution Utilities through Competitive Bidding

Distribution utilities are the major purchasers of renewable energy in India. They have renewable purchase obligations (RPOs) wherein a fixed percentage of their purchases must be renewable energy.

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19 MNRE. 2022. *Physical Progress Achievements*, https://mnre.gov.in/the-ministry/physical-progress.

20 MoP. 2022. *Power Sector at a Glance All India*, https://powermin.gov.in/en/content/power-sector-glance-all-india.

21 PIB. 2021. "*Steps to enhance domestic manufacturing of solar PV cells and modules*.", https://pib.gov.in/PressReleasePage.aspx?PRID=1742795.

22 PIB. 2021. "*Production Linked incentive Scheme For Manufacturing of Advance Chemistry Cell To Reduce Import Dependence on ACC Battery*.", https://pib.gov.in/PressReleasePage.aspx?PRID=1744879.

23 UNFCCC. 2022. *The Paris Agreement*, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

24 Chaturvedi, Vaibhav, and Ankur Malyan. 2021. "*Implications of a Net-Zero Target for India's Sectoral Energy Transitions and Climate Policy." New Delhi: Council for Energy*, Environment and Water.

All distribution utilities are required by law to purchase power only through competitive bidding. Competitive bidding can be conducted by individual utilities or by power trading intermediaries like the Solar Energy Corporation of India Limited (SECI). These trading intermediaries then on-sale the power to individual utilities. The lowest bidders will enter into a power purchase agreement (PPA) with either the utility directly or with the intermediaries, depending on who conducts the auction. Renewable energy PPAs with the utilities are typically for 25 years. Discovered tariffs for solar are currently in the range of ₹2.14 to ₹2.69 per kWh (S$0.038 to S$0.048); and for wind in the range of ₹2.69 to ₹3.43 per kWh (S$0.048 to S$0.061).[25]

Tender designs are evolving with round-the-clock tenders or with tenders coupling renewable energy generation with energy storage.

Direct Sale to Consumers through Open Access

Indian electricity law ensures open access for end-users to the transmission and distribution network. Hence, renewable energy project developers can set up power plants, up to any capacity, for direct sale through open access to third-party consumers through mutually negotiated PPAs. However, open-access consumers are required to pay cross subsidy surcharges and additional surcharges to the distribution utilities to compensate for loss of revenue from commercial and industrial consumers and towards the fixed cost of developing distribution infrastructure.

Open access projects may also sell in the open market in power exchanges. India has two power exchanges with term-ahead (up to 11 days), day-ahead, and real-time markets. Renewable energy has a separate market platform called the Green-term ahead market where renewable energy is bought and sold exclusively. A separate segment for longer duration contracts is under development.

25 CEEW-CEF. 2022. "*Market Handbook Q3 2021–22*." New Delhi: CEEW, https://cef.ceew.in/system/market_handbooks/handbook_pdfs/000/000/008/original/CEEW-CEF-Market-Handbook-Q3-2021-22-10Feb22.pdf?1644478731.

Many large corporations have committed to decarbonising and moving towards net-zero in line with national objectives.[26] These commitments create demand for green energy purchases whether through open-access or through market platforms.

Sale to Consumers through Captive Power Plants

Project developers may also set up captive power plants for single or group of consumers. Consumers need to make up to 26 per cent equity investment to qualify as captive projects. Captive power plants are exempt from payment of cross subsidy surcharges.

Private Sector Initiatives

Foreign direct investment up to 100 per cent is allowed under the automatic route in renewable energy generation. Equity investment in the renewable energy sector continues to be robust. A total investment worth more than US$5.9 billion (S$8.2 billion) was made in the last quarter of 2021.[27] Sustainability linked bonds and green bonds issuances are on the rise. Offshore bonds issued by renewable energy developers raised more than US$3.1 billion (S$4.3 billion) in the last three quarters of 2021.

Investment Potential

There is a large investment opportunity in solar manufacturing. The Indian government has introduced a production linked incentives scheme to support domestic manufacturing of solar cells and modules. Other opportunities lie in the solar and wind parks, distributed renewables in the form of rooftop solar, mini and microgrids. A recent study by the Council on Energy, Environment and Water (CEEW) and the International Energy Agency indicates that the accommodative monetary policy, participation of public and

26 Kabeer, Nitin. 2019. "*Toyota Motor's 87% of Power Needs at Karnataka Facility Sourced from Renewable Sources." Mercom India (blog)*, 27 March 2019, https://mercomindia.com/toyota-motors-karnataka-facility-renewable-sources/.

27 JMK Research and Analytics. 2022. "*2021 RE Update*.", https://jmkresearch.com/q4-2021-india-re-update/.

private sector enterprises, and participation of new independent power producers in the tenders has brought down the debt financing costs for large scale solar and wind projects.[28] Of late, distributed and offshore wind is also gaining traction in India.

Potential for Collaboration

Unlike India, Singapore doesn't have favourable geography to harness various types of renewable energy sources. The country faces land scarcity, making large scale ground-mounted solar unviable. The wind speeds are low ruling out wind energy deployment. The seafronts are also occupied by ports, so ocean energy is also not a preferred choice. Hence, Singapore focuses on harnessing its solar potential through distributed systems like rooftop and floating solar.[29] They are also focusing on scaling energy storage systems to maximise the utilisation of installed solar capacity.

India and Singapore can collaborate on deploying urban solar solutions. Both countries have growing urban energy needs that should be met through clean energy solutions to achieve the national climate change mitigation commitments. Demand aggregation programmes, building-integrated photovoltaic solar, urban microgrids are some potential collaboration areas. The two countries can also collaborate to deploy floating solar solutions. India recently achieved the lowest floating solar project costs globally. Singapore can leverage the learnings from India to accelerate the capacity deployment of floating solar.

The two countries can also collaborate to work on designing futuristic electricity markets reflective of a dynamic electricity mix and consumer needs.

28 Dutt, Arjun, Pablo Gonzalez, Nikhil Sharma, Lucila Arboleya, and Ruchita Shah. 2021. *Clean Energy investment Trends: Mapping Project-Level Financial Performance Expectations in India*. New Delhi, Paris: Council on Energy, Environment and Water; International Energy Agency.

29 NCCS. n.d. *Renewable Energy*, https://www.nccs.gov.sg/faqs/renewable-energy/.

Natural Gas

Background

Natural gas is widely considered to be a 'transition' fuel from coal and oil to cleaner fuels such as bioenergy and green hydrogen. Globally, around 23 per cent of the total energy supplied is from natural gas, with a significant percentage going into gas-based power generation.[30] Compared to the global scenario, natural gas accounts for only 6.6 per cent of the total energy supply in India, with the power sector in particular having a much smaller share of demand. However, absolute gas demand continues to grow, with the five-year period between FY2015 and FY2020 registering a compound annual growth rate of 3.7 per cent.

Status Quo

Supply

India produces natural gas domestically to meet only 49 per cent of its demand.[31] A majority of domestic gas (~57 per cent) is produced in offshore fields in the West off the coast of Maharashtra.[32] Discoveries in the East coast (KG Basin) have severely underperformed, although production has recently picked up. While an output of 80 million standard cubic metres per day (scmd) was expected, the fields produced only 8-10 million scmd in 2019-20.[33]

The remaining 51 per cent is imported as liquified natural gas (LNG), primarily through long-term contracts with suppliers in Qatar (41 per cent), the United Arab Emirates (12 per cent), Nigeria (12 per cent), Angola (11 per cent), etc.[34] The average import price of natural gas varied from US$5.60 (S$7.90)/MMBtu (UAE) and US$8.5 (S$12.00)/ MMBtu (Egypt), with a weighted average of US$7.40 (S$10.40)/ MMBtu for 2019-20.

30 IEA. 2019. "*Data and statistics*", https://www.iea.org/data-and-statistics/data browser?country=WORLD&fuel=Energy%20supply&indicator=TESbySource.

31 MoPNG. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf.

32 Ibid.

33 The Economic Times. 2009. "*RIL KG-basin to produce 80-mmscmd gas by December: Pandey*". Mumbai, http://www.ecoti.in/Z-ow-b; and Ministry of Petroleum and Natural Gas [MoPNG]. 2022. op.cit.

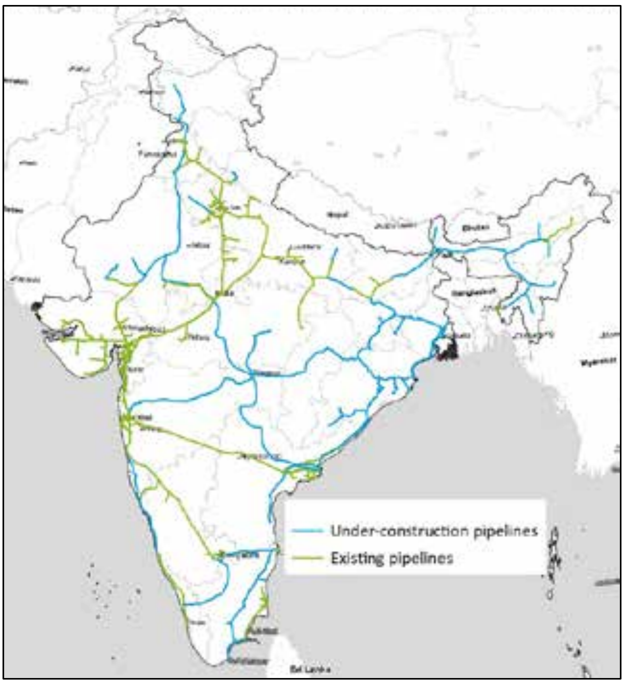
34 Ministry of Commerce. 2022. *Export-import database*, https://tradestat.commerce.gov.in/eidb/Icomcntq.asp.

There are six active LNG terminals in the country – five in the West coast and one in the East. Eight more terminals are planned or are under construction.

Transmission and Distribution

India is investing heavily into building up a national gas transmission and distribution pipeline network. The country has nearly 20,000 kilometres of operational gas pipelines which primarily cover the Western and Northern regions. An additional 15,000 kilometres of pipelines are planned or are under construction, which will improve connectivity in the Southern and Eastern parts of the country.[35]

Figure 1: Map of Existing and Upcoming Pipelines in India



Source: Authors' illustration using data from Ministry of Petroleum and Natural Gas [MoPNG]. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf; Ministry of Coal. 2022. Production and Supplies, https://coal.nic.in/en/major-statistics/production-and-supplies.*and PNGRB. 2021; and Gas Infrastructure of India – 2021, https://pngrb.gov.in/pdf/GAS_INFRASTRUCTURE_MOI_26102021.pdf.*

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35 MoPNG. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf.

Demand

Natural gas in India is consumed primarily by the fertiliser industry (28.5 per cent) as a feedstock for the manufacture of urea-based fertilisers.[36] The power sector consumes less than 20 per cent of the total gas demand; this share is expected to further reduce.[37] Gas-based power plants in India operate at very low capacity utilisation factors due to the limited availability of cost-subsidised domestic natural gas.[38] With imported gas (as LNG), the economics of gas power are unfavourable. Therefore, gas demand in the power sector is not expected to register any significant growth. Refineries and petrochemical plants also consume significant volumes (13.8 and 6.3 per cent respectively) of gas as feedstock.[39]

The primary driver for gas demand growth comes from the city gas distribution (CGD) sector, which serves residential, commercial and small industrial consumers in urban regions, along with urban transport through compressed natural gas stations. Demand from other sectors such as iron and steel, ceramics and glass exist, but these are marginal volumes and the outlook of gas uptake in these sectors is not strong. Existing consumption in these sectors was largely driven by court-mandated fuel switching to reduce local impacts of air pollution.[40]

Pricing

Domestically produced natural gas is price controlled and subsidised by the government, as it is allocated on priority to certain sensitive sectors such as fertiliser, power, residential and compressed natural gas (CNG) for vehicles.[41] The prices are calculated based on indexing

36 MoPNG. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf.

37 MoPNG. 2022. op. cit.

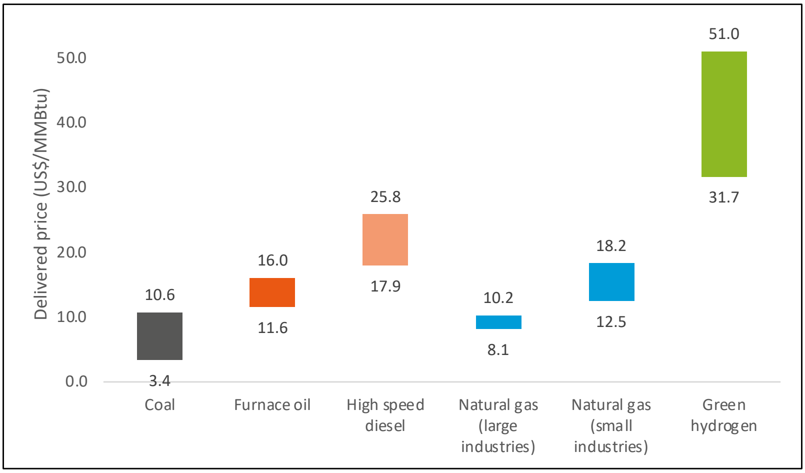
38 Central Electricity Authority. 2021. *Annual Report on Fuel Supply/Consumption for Gas Based Power Stations for the Year 2020-21*, https://cea.nic.in/wp content/uploads/fuel_consumption/2020/Annual_Gas_Report_2020_21.pdf.

39 MoPNG. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf.

40 Mint. 2020. "*Delhi: Industries to switch over to PNG by 31 Jan, orders Air Quality Commission*", https://www.livemint.com/news/india/delhi-air-quality-commission-directs-switching-over-of-all-industries-to-png-11608626505713.html; and The Times of India. 2019. "*Gujarat: After NGT crackdown, 450 ceramic units prepare to switch to gas*", https://timesofindia.indiatimes.com/city/ahmedabad/after-ngt-crackdown-450-ceramic-units-prepare-to-switch-to-gas/articleshow/68365929.cms.

41 Press Information Bureau. 2019. "*Demand and supply of natural gas*", https://pib.gov.in/Pressreleaseshare.aspx?PRID=1558885.

Figure 2: Natural Gas is More Cost-competitive with Liquid Fuels



Source: Authors' analysis using data from Ministry of Statistics and Programme Implementation [MoSPI]. 2019. Annual Survey of Industries, http://www.csoisw.gov.in/CMS/cms/Home.aspx.

of gas prices to the indices of Henry Hub, Alberta Gas Reference Price, NBP, and Federal Tariff Service of Russia.[42] Ultra-deepwater and high temperature wells (which are considered difficult wells) have pricing freedom subject to a price ceiling, calculated using a different mechanism.[43] Gas from these wells is sold through bilateral contracts. Due to the limited availability of domestic gas, no sector fulfils its entire demand at the subsidised price. With gas demand growing faster than domestic production, the share of imports is expected to rise, consequently increasing the average delivered price of gas. Uptake of natural gas in industries not coming under the purview of domestic gas allocation is limited due to the reliance on higher-priced imported gas. The delivered price of imported gas is uncompetitive with coal, which is the predominant fuel used by industry. Natural gas is typically price competitive with naphtha, furnace oil, diesel, kerosene and LPG. It is the demand base for these fuels which can switch to natural gas.

42 MoPNG. 2014. *New Domestic Natural Gas Pricing Guidelines, 2014*, http://petroleum.nic.in/sites/default/files/1NewNaturalGasPricingGuidelines.pdf; and MoPNG. 2014. *Sources of data considered for determination of domestic natural gas price as per the New Domestic Natural Gas Pricing Guidelines, 2014, http://petroleum.nic.in/sites/default/files/ngsourcedata.pdf.*

43 MoPNG. 2016. *Marketing including pricing freedom for the gas to be produced from Discoveries in Deepwater, Ultra Deepwater and High Pressure-High Temperature areas*, http://petroleum.nic.in/sites/default/files/mkt_freedom.pdf.

Potential

The CGD sector has seen a compound annual growth rate of nearly 11 per cent from FY2014 to FY2020. The sector is expected to grow with rapid expansion of gas networks in areas recently allocated for CGD development. After the 11th round of bidding for CGD licences, 98 per cent of the population is expected to be covered by the city gas networks once the distribution networks are constructed.[44] We estimate that it could take a decade or more for all the new CGD networks to be fully operational.

CNG is significantly cheaper than petrol and diesel. Demand for CNG is likely to continue growing for the next decade (especially in the 4-wheeler segment) after which electric vehicles could become cheaper on a total cost of operation (TCO) basis. 3-wheeler EVs are already cheaper in terms of TCO than CNG options. Long-distance heavy-duty vehicles are expected to start switching to LNG engines. The government is encouraging the construction of LNG refuelling stations along major highways in the country.[45]

Pipeline access issues and exorbitant delivered prices, especially for industrial consumers, has limited the offtake of natural gas by small and medium-sized industries. However, natural gas delivered as small-scale LNG can overcome these issues and is a promising alternative. All existing LNG terminals have truck-loading facilities to enable small-scale LNG supply. Several defunct fertiliser plants are set to be returned to operation after refitting and renovations. These plants will likely switch to natural gas from the earlier naphtha-based production systems.[46] Consumption of natural gas in refineries and petrochemical plants is also expected to register minimal growth, since the demand for oil and oil products is yet to peak in India.

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44 PIB. 2022. "*PNGRB has authorized of Intent for 289 Geographical Area after 11th CGD Bidding Round*". Delhi, 31 March 2022, https://pib.gov.in/PressReleasePage.aspx?PRID=1811907.

45 PIB. 2020. "*Petroleum Minister lays foundation stone for the first 50 LNG fueling stations, says 1000 LNG stations will be set up in next three years*". Delhi, 19 November 2020, https://pib.gov.in/PressReleasePage.aspx?PRID=1673998.

46 Department of Fertilizers. 2022a. *Hindustan Urvarak & Rasayan LTD*. (HURL)., https://fert.nic.in/fertilizer-projects/hindustan-urvarak-rasayan-ltd-hurl; and Department of Fertilizers. 2022b. *Ramagundam Fertilizers and Chemicals Limited. (RFCL*), https://fert.nic.in/fertilizer-projects/ramagundam-fertilizers-and-chemicals-limited-rfcl; and Department of Fertilizers. 2022c. *Talcher Fertilizer LTD. (TFL)*, https://fert.nic.in/fertilizer-projects/talcher-fertilizer-ltd-tfl.

Natural gas can be pyrolysed to produce 'turquoise' hydrogen and solid carbon. Pyrolysis plants can allow seamless blending of hydrogen with natural gas in the pipeline system; blending targets for hydrogen are expected to be part of the National Hydrogen Energy Mission (NHEM). The solid carbon produced from the pyrolysis process can be integrated into carbon value chains such as for tyre manufacturing, activated carbon and steelmaking.

Government Initiatives

The MoPNG has set a target of 15 per cent share of natural gas in the total energy supply by 2030, up from the current 6.6 per cent. Considering the demand profile and delivered price of natural gas, it is unlikely that the target will be achieved. However, it does signal a strong political intent to develop India's gas economy. The government's domestic gas pricing mechanism and domestic gas priority allocation policy have somewhat driven price sensitive sectors to switch over to natural gas from other fuels.

Most of the natural gas transmission infrastructure is owned and operated by government-owned public sector undertakings (mainly GAIL India Ltd and Indian Oil Corporation Ltd). The government plans to set up a transmission system operator[47] to separate the role of the pipeline owner/operator from the entity responsible for allocating pipeline capacity to different consumers. This will enable better price discovery for the delivered gas price regardless of the consumer category. Development of policy for LNG refuelling stations has been taken up by the government to promote the use of LNG as a fuel for heavy-duty transport.[48] Fertiliser plants are mostly public sector units – fuel switching to natural gas was a government decision.

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47 MoPNG. 2021. *Draft Petroleum and Natural Gas Regulatory Board (Matters Related to Natural Gas Sector Development) Rules, 2021*, https://mopng.gov.in/files/Whatsnew/Draft-PNGRB-(matters-related-to-Natural-Gas-Sector-Development)-Rules,-2021.pdf.

48 PNGRB. 2020a. *Public Notice No: PNGRB/AUTH/1-CGD (02)/2020*, https://www.pngrb.gov.in/pdf/public-notice/PN02062020.pdf; and PNGRB. 2020b. Schedule 4: "*Storage, Handling and Dispensing at LNG/LCNG Dispensing Stations*", https://pngrb.gov.in/pdf/public-notice/RO-Annexure-I-18.02.2020.pdf.

Gas exploration, especially offshore fields, holds promise to augment domestic gas production. The government aims to increase the acreage available for exploration and production from 0.2 million square kilometres to 0.5 million by 2025 and one million by 2030.[49]

Private Sector Initiatives

The development of CGD systems is primarily through private sector investments (the government does own stakes in several major CGD companies such as Indraprastha Gas Limited, Mahanagar Gas Limited and Gail Gas Limited). These networks connect transmission pipelines with end consumers in the residential, commercial, small industrial and transport sectors. Today, CGDs contribute to nearly 20 per cent of the national gas demand, amounting to more than 12 bcm in 2021-22.[50] Regulations allow CGDs exclusive marketing rights using their infrastructure[51] for a predetermined period, thus allowing highly favourable economics for investment. Their volumes continue to grow as more and more areas are allocated for CGD development, and vehicles consuming compressed natural gas (CNG) fuel gain popularity.

The LNG refuelling for heavy duty vehicles mentioned in Section 3.4 will also rely on private investment for setting up refuelling stations along major highways. This is a significant latent market for gas, as there are no commercial vehicles in series production in India that are equipped with LNG engines. Once the refuelling infrastructure is set up, there is likely to be appreciable demand growth in LNG vehicles, as natural gas is typically cheaper and cleaner than diesel. To realise this demand requires research and development research and development (R&D) in LNG engines for domestic manufacture, such that the capital cost increase of LNG vehicles is kept to a minimum.

49 The Economic Times. 2022. "*India to double down on oil, gas exploration: Hardeep Singh Puri*", https://economictimes.indiatimes.com/industry/energy/oil-gas/india-to-double-down-on-oil-gas-exploration-hardeep-singh-puri/articleshow/89345188.cms?.

50 Petroleum Planning & Analysis Cell. 2022. *Monthly Report on Natural Gas Production, Availability and Consumption March 2022*, https://ppac.gov.in/WriteReadData/Reports/202204290525144285859MonthlyGasReport-March2022WebV.pdf.

51 PNGRB. 2008. *Petroleum and Natural Gas Regulatory Board (Exclusivity for City or Local Natural Gas Distribution Network) Regulations, 2008*, https://pngrb.gov.in/OurRegulation/PNGRB%20Regulations/A.%20CGD%20Network/A.3.%20CGD%20Exclusivity%20Regulations/CGD%20Excl-Post%20Amendment-01.01.2015.pdf.

While the transmission and distribution infrastructure continue to expand, there are still several areas in the country where there is currently no gas connection. Also, exclusivity of CGD infrastructure means that price discovery is limited, thus making gas less appealing, especially for industries. Small-scale LNG distribution systems can mitigate this problem by directly connecting consumers with LNG import terminals, thus doing away with transmission and distribution costs and margins.[52] A few entities such as Shell India,[53] Indian Oil,[54] Seros[55] and GasGrows[56] are engaged in small-scale LNG distribution in India; however, a lack of clarity in the regulations regarding CGD exclusivity has somewhat hindered the growth of this business. However, with an increasing demand for cleaner fuels in industries and transportation, small-scale LNG could have a significant role to play in the marginal volumes.

Investment Potential

Investment opportunities for natural gas lie primarily in the transport sector, where there is potential in as yet untapped sectors. Setting up LNG refuelling stations would cost approximately ₹100 million (S$1.8 million) per station.[57] There is also significant investment required in the R&D side for manufacturing affordable LNG engines for heavy-duty vehicles. While LNG-powered vehicles exist in Europe, Japan and China, amongst others, the Indian market for commercial vehicles is very different, dominated mainly by domestic manufacturers. There is a need to develop engines specifically for Indian markets and conditions. There is also the possibility of converting diesel engines to run on LNG – some companies offer such kits.[58] However, while some

52 Elango, Sabarish and Hemant Mallya. 2021. *Small-Scale LNG for Expanding Natural Gas Access in India*. New Delhi: Council on Energy, Environment and Water, https://www.ceew.in/publications/small-scale-lng-expanding-natural-gas-access-india.

53 Shell Energy India. 2022. *Supplying LNG via trucks to consumers*, https://www.shell.in/shellenergy/shell-energy-india/products-and-services/supplying-lng-via-trucks-to-customers.html.

54 Indian Oil Corporation Ltd. 2022. *Natural Gas – LNG at doorstep*, https://iocl.com/pages/natural-gas-overview.

55 Seros. 2022. *LNG technology*, https://www.seros.in/lng-technology.php

56 GasGrows. 2022. *About Us*, https://gasgrows.com/.

57 Hindustan Times. 2020. "*1,000 LNG stations in next 3 years for low-cost, low emission transport*", https://auto.hindustantimes.com/auto/news/1-000-lng-stations-in-next-3-years-for-low-cost-transport-dharmendra-pradhan-41605840681397.html.

58 Omnitek. 2022. *Diesel-to-Natural Gas Conversion System and Parts*, https://www.omnitekcorp.com/altfuel.htm; and CRMT. 2022. Conversion from diesel to natural gas,https://www.crmt.fr/en/nos-metiers/4/conversion-from-diesel-to-natural-gas.

companies have already started such conversions in India,[59] there are no standards or regulations governing such diesel-to-LNG kits.

Another latent demand sector is inland and coastal waterway transport, which is being developed under the Sagarmala scheme of the Ministry of Ports, Shipping and Waterways.[60] The Sagarmala scheme looks to develop extensive waterway transport in India to make use of 14,500 kilometres of potentially navigable waterways.[61] The vessels plying on inland and coastal routes typically use diesel engines, which, similar to heavy duty road vehicles, could be retrofitted/replaced to run on CNG or LNG. Refuelling stations can be set up along major waterways, supplied by small-scale LNG systems ferrying LNG from the nearest terminals to the fuel stations. However, a lack of data on the types of vessels, distances travelled and loads carried means that demand estimation is difficult at present.

Small-scale LNG systems can also benefit from investment, especially if natural gas is adopted by heavy duty vehicles and waterway vessels. In this case, there could be significant disaggregated demand for gas that can ideally be fulfilled by small-scale LNG systems as opposed to pipelines. The capital cost required to set up a small-scale LNG system for a demand of 50,000 scmd (a medium sized industrial unit) will be approximately ₹100 million (S$1.8 million); this includes the cost of LNG storage and regasification systems along with the required number of trucks and trailers to cover a one-way distance of 400 kilometres.

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59 Business Standard. 2021. "*Coal India starts pilot project to replace diesel with LNG in dumpers*", https://www.business-standard.com/article/companies/coal-india-starts-pilot-project-to-replace-diesel-with-lng-in-dumpers-121090100451_1.html; and The Times of India. 2019. "*Delhi's IGL will lead Indian trucking into gas age*", https://timesofindia.indiatimes.com/business/india-business/delhis-igl-will-lead-indian-trucking-into-gas-age/articleshow/71381159.cms.

60 Ministry of Ports, Shipping and Waterways. 2022. *Coastal Shipping & Inland Waterways*, https://sagarmala.gov.in/projects/coastal-shipping-inland-waterways.

61 Sagarmala. 2019. *Background*, https://sagarmala.gov.in/about-sagarmala/background. MoPNG. 2021. *Draft Petroleum and Natural Gas Regulatory Board (Matters Related to Natural Gas Sector Development) Rules, 2021*, https://mopng.gov.in/files/Whatsnew/Draft-PNGRB-(matters-related-to-Natural-Gas-Sector-Development)-Rules,-2021.pdf.

Potential for Collaboration

As per India's NHEM, green hydrogen produced from renewable power will be blended with natural gas carried by the national gas pipeline grid.[62] Globally, 15-20 per cent blends of hydrogen (by volume) with natural gas are being considered realistically feasible with minimal modifications to end-use equipment. Singapore's city gas distribution company is also studying the feasibility of supplying green hydrogen to homes and commercial establishments through its pipeline network. In addition, Singapore already uses town gas for residential and commercial customers, which is rich in hydrogen (50 per cent by volume).[63] The two countries can take a collaborative approach to green hydrogen blending with natural gas, looking ahead to pure green hydrogen transmission using existing and upcoming gas pipeline networks. Joint development of materials could enable Indian pipeline manufacturers and gas transmission and distribution system operators in preparing their networks for higher concentrations of green hydrogen.

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62 *The Hindu BusinessLine*. 2021. "*Govt planning to blend 15 per cent green hydrogen with piped natural gas*", https://www.thehindubusinessline.com/news/govt-planning-to-blend-15-per-cent-green-hydrogen-with-piped-natural-gas/article38073350.ece.

63 City Energy Pte Ltd. 2021. *City Energy Handbook on Gas Supply*, https://www.cityenergy.com.sg/wp-content/uploads/2021/11/City-Energy-Handbook-on-Gas-Supply-Dec-2021.pdf.

Bioenergy

Background

Bioenergy has traditionally been viewed through the lens of small-scale biogas installations and biomass power and cogeneration plants in the sugar industry. The Indian government has been cognisant of bioenergy as a renewable source of energy since the 1970s, with several support programmes and policies promoting decentralised biogas plants and biomass power applications. However, modern bioenergy is now expanding much beyond this definition and providing impactful pathways to decarbonise hard-to-abate sectors such as industry, transport, and waste management. As India prepares for the uphill battle of achieving net-zero emissions by 2070, renewable biofuels can potentially contribute to the transition from fossil fuels.

Potential

India being an agrarian country, has a huge potential for bioenergy in terms of organic feedstocks. These include agricultural waste (crop residues), industrial waste (food processing, tanneries and distilleries), organic fraction of municipal solid waste (MSW), animal litter, and sewage sludge from wastewater treatment plants.

On the feedstock potential, surplus biomass from agriculture and forestry residues amounts to about 230 million tonnes per annum, forming the majority of biomass feedstock in the country.[64] Further, 62 million tonnes of MSW are produced in the country, having around 51 per cent organic content.[65] Around 101 million tonnes of surplus grain and sugar will be utilised for ethanol production by 2025-26 to bring ethanol blending in India to 20 per cent.[66]

64 MNRE. 2022. *Bioenergy overview*, https://mnre.gov.in/bio-energy/current-status.

65 Sharma, Kapil Dev, and Siddharth Jain. 2019. "*Overview of Municipal Solid Waste Generation, Composition, and Management in India*." Journal of Environmental Engineering 145 (3). American Society of Civil Engineers (ASCE): 04018143. DOI: 10.1061/(ASCE)EE.1943-7870.0001490.

66 The World Bank. 2019. *Imports of goods and services (% of GDP) – India*, https://data.worldbank.org/indicator/NE.IMP.GNFS.ZS?locations=IN.

India has defined targets for several important bioenergy applications. These include:

- 20 per cent bioethanol blending in petrol by 2025-26;[67]
- Production of 15 million tonnes (MMT) of CBG by 2024;[68] and
- Target for co-firing 5-7 per cent biomass pellets in all coal-based thermal power plants.[69]

Government Initiatives

The bioenergy targets mentioned above are accompanied by detailed policies and schemes that are designed to facilitate the deployment of solutions required to achieve these targets. Some of the key initiatives in the bioenergy space in India are given in the following.

Increased Biofuels Blending

The National Policy on Biofuels, 2018 was notified by the MoPNG to mainstream biofuels in the country and transition away from imported petroleum products for energy and transport sectors. The policy defines an indicative target of 20 per cent ethanol blending 2030, which has been subsequently fast-tracked by the Roadmap for Ethanol Blending in India by 2025.

These policies support increasing biofuel blending by interventions such as:

- Reduced Goods and Services Tax (GST) on ethanol produced for blending
- Allowing additional raw materials for ethanol production, such as B heavy molasses, sugarcane juice, and food grains unfit for human consumption
- Different pricing of ethanol based on different raw materials; and
- Encouraging 100 per cent FDI in biofuel technologies.[70]

67 NITI Aayog. 2021. *Report of the Expert Committee on Roadmap for Ethanol Blending in India by 2025*, https://www.niti.gov.in/sites/default/files/2021-06/EthanolBlendingInIndia_compressed.pdf.
68 SATAT. 2022. *About SATAT*, https://satat.co.in/satat/about.html.
69 Ministry of Power. 2021. *Revised Policy for Biomass Utilisation for Power Generation through Co-firing in Coal-based Power plants*, https://powermin.gov.in/sites/default/files/Revised_Biomass_Policy_dtd_08102021.pdf.
70 Provided the biofuel produced will be used for domestic purposes only.

CBG for Affordable Transport and Industry Fuel

Compressed biogas (CBG), with a 90-95 per cent methane content, can fully replace natural gas in any application without the requirement of any modifications in the machinery. MoPNG, along with the oil marketing companies (OMCs) have rolled out the SATAT scheme to promote the production and use of CBG from organic feedstocks in the country. CBG has a huge potential to provide a domestic source of clean fuel while delivering on jobs, growth and sustainability.

Some of the salient features of the SATAT scheme are:

- Secured offtake of CBG by OMCs for ten years;
- Central financial assistance (CFA) for biogas plants of all sizes;
- Provisions to sell CBG to CGD networks;
- Inclusion of bio-manure as a recognised organic fertiliser in India's Fertiliser Control Order; and
- Priority sector lending for CBG projects ensuring easy access to project finance.

Replacing Coal with Biomass Pellets in Power Generation

The Ministry of Power (MoP) has issued a progressive policy on co-firing biomass pellets in coal-based thermal power plants (TPPs). The motive is to reduce the emissions due to coal use and also sustainably manage agriculture wastes which are otherwise burnt in the fields of North Indian states. The policy mandates all TPPs to use a 5-7 per cent blend of biomass pellets made using agricultural waste primarily.

The policy facilitates this co-firing through the following provisions:

- Policy enforcement for 25 years or till the useful life of TPP;
- Biomass pellets procurement contracted for a minimum period of seven years;
- Provisions to pass through increase in power cost due to co-firing; and
- Eligibility of power from co-firing for renewable purchase obligations (RPOs) for obligated entities.

Private Sector Initiatives

The private sector investment in bioenergy is still minuscule compared to utility-scale renewable energy sectors such as solar and wind. However, interest in India's bioenergy sector is slowly growing. International companies with expertise in bioenergy applications are now turning to India for new investment opportunities. Since the biomass feedstock supply chain is quite extensive and labour-intensive, a lot of entrepreneurs are now implementing innovative business models to meet the growing demand for bioenergy. Several leading companies with requirements for thermal energy and steam have begun utilising biomass pellets and steam from biomass boilers to replace fossil fuel use in their industries.[71] This aids them in further showing commitment to the environment.

The largest users of bioenergy so far, however, are the public sector undertakings (PSUs) such as NTPC, Indian Oil Corporation (IOCL), and other Oil Marketing Companies. These PSUs are leading the implementation of the policies mentioned above by procuring biomass and biofuels and providing end-use applications.

Status Quo

Compared to the objectives defined in the above-mentioned policies, progress has been relatively slow. As of January 2022, India had an installed capacity of 10.1 GW of biomass cogeneration, 200 MW of waste to power, with an additional 234 MW of off-grid waste to energy capacity.[72] The bioethanol blending with petrol was at around 8.5-9 per cent, with an estimated production of 3.32 billion litres in 2020-21.[73] For compressed biogas (CBG), the government has commissioned 15 plants with a total of 4,600 tonnes of CBG sold.[74] Further, 59,000 tonnes of biomass were co-fired in Indian TPPs between October 2021 and January 2022, while tenders for 12 million tonnes

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71 Argus Media. 2021. *Viewpoint: India's 2022 biomass use to rise*, https://www.argusmedia.com/en/news/2286826-viewpoint-indias-2022-biomass-use-to-rise.

72 MNRE. 2022. *Physical Progress Achievements*, https://mnre.gov.in/the-ministry/physical-progress.

73 NITI Aayog. 2021. *Report of the Expert Committee on Roadmap for Ethanol Blending in India by 2025*, https://www.niti.gov.in/sites/default/files/2021-06/EthanolBlendingInIndia_compressed.pdf.

74 Sagarmala. 2019. *Background*, https://sagarmala.gov.in/about-sagarmala/background.

of biomass pellets are at various stages for short-term and long-term procurements.[75]

Investment Potential

Bioenergy sector in India is poised for a huge growth as policy targets and international commitments will push industries and other sectors to increasingly use bioenergy, especially for thermal energy and fuels. Foreign Direct Investment (FDI) up to 100 per cent will allow international companies to invest in this growing sector. Opportunities lie in setting up large-scale ethanol production plants from second-generation (2G) feedstocks. Compressed biogas (CBG) production plants are also operationally and financially attractive, with potential to sell CBG to OMCs, CGDs, and even industrial users. Bio-fertiliser, which is a by-product from the CBG production process can also be sold as an organic fertiliser.

While biomass power applications have reached their stated target of 10 GW, there is still tremendous scope for decentralised biomass power projects that can support off-grid communities. Waste-to-energy plants are also important for India's growing MSW production. These plants can be especially useful if combined with biogas recovery from organic fraction of MSW.

Further opportunities lie in biomass supply chains, and biomass-powered decentralised applications such as cold storage and dryers. There is also scope to introduce market interventions such as biomass exchanges, procurement platforms, and resource availability databases.

Potential for Collaboration

While Singapore may not have the vast biomass resources that India has, there is a considerable amount of organic waste that needs to be managed sustainably. Food waste, horticulture waste,

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75 PIB. 2022. 59,000 *metric tonnes of biomass co-fired in coal fired Thermal power plants*, https://pib.gov.in/PressReleasePage.aspx?PRID=1790832.

and sewage sludge are all urban organic wastes that are potential feedstocks for bioenergy. Singapore has already taken a global lead on waste management by operationalising the Tuas Nexus Integrated Waste Management Facility, which will co-digest source-segregated food waste and dewatered sludge from Tuas Water Reclamation Plant (WRP).[76] The biogas produced from this will be converted to electricity and heat to improve overall plant efficiency for both thermal energy and electricity generation.

Potential areas for collaboration between India and Singapore can primarily focus on urban solutions for organic waste. Indian biogas manufacturers have developed various biogas models that are fit for urban applications. Solutions for wastewater reclamation and management could also be a potential area for collaboration. Singaporean companies could also invest in the bioenergy and biomass industry in India and participate in the growing sector.

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76 World Biogas Association. 2020. *Biogas to power mighty $1.5 billion integrated waste management facility in Singapore*, https://www.worldbiogasassociation.org/biogas-to-power-mighty-1-5-billion-integrated-waste-management-facility-in-singapore/.

Green Hydrogen and Derivatives

Hydrogen is the most abundant element in the universe. It has been used for various applications since the start of the 20th century. The research on hydrogen energy technologies gathered momentum after the oil crisis in the 1970s. Since then, hydrogen has witnessed multiple cycles of hype and disappointment. Today, there is a global resurgence in the use of hydrogen primarily due to focus on mitigating emissions from the hard-to-abate sectors in the industry and mobility that are difficult to electrify. The emphasis is on using renewable electricity for producing green hydrogen from water. Today, about 33 countries have announced their hydrogen missions or are developing national-level policies and strategies for hydrogen[77] India is also aiming to be a global leader in developing a green hydrogen economy.

Background

Green hydrogen can be used across all major sectors of the economy – industry, mobility and power sector. In the industrial sector, green hydrogen can be used as a feedstock for producing various chemical commodities and also for process heat applications. In the mobility sector, green hydrogen is especially promising for heavy-duty long-distance transportation in buses and trucks, aviation and shipping applications. Green hydrogen can be a globally traded commodity and used as an energy carrier by blending in natural gas pipelines. Green hydrogen can also complement battery energy storage for seasonal storage of energy, especially for micro and mini-grid applications.

India had prepared a roadmap for deploying green hydrogen technologies in 2006.[78] However, it could not achieve the desired results due to the high cost of renewable energy that constitutes 50-70 per cent of the total cost of hydrogen. Today, the cost of renewable energy has reduced

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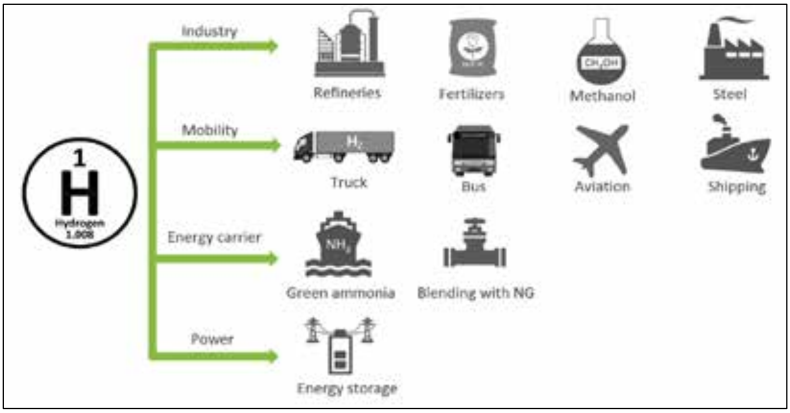
77 Ghosh, Arunabha, and Sanjana Chhabra. 2021. *Speed and Scale for Disruptive Climate Technologies: Case for a Global Green Hydrogen Alliance*. A GCF-CEEW Report. Stockholm: Global Challenges Foundation, https://www.ceew.in/publications/how-can-global-green-hydrogen-alliance-meet-international-clean-energy-needs.

78 MNRE. 2007. *National hydrogen energy roadmap*, http://164.100.94.214/sites/default/files/uploads/abridged-nherm.pdf.

significantly, there is an increased emphasis on climate change and GHG emissions mitigation, a vision for self-reliance and energy security, and a global consensus on the role of green hydrogen that has created business opportunities in the clean energy space.

Figure 3: Potential Use Cases for Green Hydrogen



Source: Authors' illustration

Status Quo

The industrial sector is a low hanging fruit for rapid uptake of green hydrogen. In India, industries already consume hydrogen for refining crude oil and producing chemical commodities like ammonia (subsequently processed to urea) and methanol. This hydrogen is produced by using natural gas or naphtha as a feedstock in the steam methane reforming (SMR) process. The steam-methane reformation process directly produces CO2 when steam (H2O) and methane (CH4) from natural gas react. Such hydrogen produced from SMR using natural gas is called grey hydrogen. Today, the price of grey hydrogen produced by SMR is around US$1.5 /kilogramme (kg) [S$2.1 /kg] assuming a natural gas price of US$8/MMBtu. Green hydrogen produced using renewable electricity costs around US$4 /kg (S$5.6 / kg) , making it uncompetitive with all conventional fossil fuels.

Green hydrogen can be Incrementally blended in these industries. This creates a guaranteed demand for green hydrogen and ensures a decrease in the cost of green hydrogen due to economies of scale. Subsequently, green hydrogen can then be taken up across other hard-to-abate sectors of the economy like mobility. However, significant investment and development is required to scale up green hydrogen production to achieve cost-competitiveness.

Potential

According to CEEW's analysis, India consumes about 5.6 million tonnes per annum (MTPA) of hydrogen across refineries, fertiliser and petrochemical units. Green hydrogen can offset the natural gas consumption in these industrial sectors. However, the scale of renewable energy deployment for uptake of green hydrogen in India's industrial sector is unprecedented. India would need about 110 GW of renewable energy (solar and wind), 42 GW of electrolyser capacity and a capital investment of US$110 billion (S$153 billion) to offset fossil fuel consumption in these industrial sectors.

Figure 4: Existing Demand for Hydrogen in India

Source: Authors' illustration using data from Ministry of Petroleum and Natural Gas [MoPNG]. 2022. Indian Petroleum & Natural Gas Statistics 2020-21, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf; and Ministry of Coal. 2022. Production and Supplies, https://coal.nic.in/en/major-statistics/production-and-supplies. and PNGRB. 2021. Gas Infrastructure of India – 2021, https://pngrb.gov.in/pdf/GAS_INFRASTRUCTURE_MOI_26102021.pdf.

In addition to hydrogen consumption in industries, India also imports significant amount of methanol, ammonia and fertilisers that constitute additional 2.1 MTPA of implicit hydrogen demand. Green hydrogen can also find new applications in the steel industry, mobility sector and can be blended in natural gas pipelines. The iron and steel industry in India can utilise 2.7 MTPA of green hydrogen in blast and shaft furnaces to displace some of the existing coal consumption. Although the mobility sector in India is expected to consume only 0.1 MTPA of green hydrogen by 2030, US$8 billion (S$16 billion) investment would be needed in setting up the hydrogen refuelling stations (HRSs) and vehicles. Similarly, green hydrogen blend of 15 per cent (by volume) would need an investment of US$14 billion (S$19 billion). The total investment for meeting the 5.55 MTPA of implicit demand of green hydrogen in India is expected to be US$120 billion (S$167 billion). This will also need an additional 110 GW of renewable energy and 45 GW of electrolyser deployment.

Figure 5: Demand from Potential Consumers of Green Hydrogen

Source: Authors' analysis

The electrolyser demand in India to cater to 11 MTPA of total (existing + implicit) green hydrogen demand is about 90 GW. Achieving this target by 2030 would need an electrolyser manufacturing capacity of 13 GW per year. Setting up electrolyser manufacturing capacity of 13 GW per year would need an investment of about US$0.9 billion (S$1.3 billion).[79]

Sustainable Aviation Fuels

Before the COVID pandemic hit, India was the seventh largest consumer of aviation fuel in the world. It is expected to become the third largest market by 2024.[80] India is also the world's third largest domestic aviation market. Globally, the aviation industry contributes to roughly 2.5 per cent of the total emissions. There are no immediate alternatives for decarbonising the commercial aviation sector.

The International Air Transport Association (IATA) has committed to achieving net zero emissions by 2050.[81] Sustainable aviation fuel (SAF) can be produced through multiple pathways by using green

79 IRENA. 2020. *Green hydrogen cost reduction: Scaling up electrolysers*, https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf.

80 IATA. 2018. "*IATA Forecast Predicts 8.2 billion Air Travelers in 2037*", https://www.iata.org/en/pressroom/pr/2018-10-24-02/.

81 IATA. 2021. "*Net-Zero Carbon Emissions by 2050*", https://www.iata.org/en/pressroom/2021-releases/2021-10-04-03/.

hydrogen, biomass (including crop residue), MSW, used cooking oil and ethanol.[82] Unlike other mobility applications like electric vehicles and fuel cell electric vehicles (FCEVs), SAF is a drop-in fuel that can be easily blended with existing jet fuel. ASTM has approved SAF blend up to 50 per cent in existing applications. SAF produced in India can also be exported to other countries by refuelling flights originating in India to destination countries.

Green Methanol

Carbon capture and utilisation is expected to play a key role in India, achieving net zero emissions by 2050. India has a legacy manufacturing capacity, especially in the hard-to-abate iron and steel sector that is not amenable to direct decarbonisation using green hydrogen. Methanol provides a potential option to utilise carbon-dioxide from these hard-to-abate sectors and permanently trap the carbon if used as a feedstock for producing chemicals like ethylene and propylene that forms the building block of various chemical commodities. Methanol can be blended in gasoline for use in internal combustion engines and reduce crude oil imports. Methanol can also be converted into aviation fuels using alcohol to jet route. Methanol also finds potential application in marine engines as a shipping fuel. However, the competitiveness over the longer team with green ammonia has to be evaluated.

Green Ammonia

Ammonia is widely used in India for producing fertilisers. Indian fertiliser plants consume about 18 MTPA of ammonia per year for producing urea and other fertilisers. In addition to these, India also imports 2.4 MTPA of ammonia to produce fertilisers. This hydrogen is obtained from natural gas. Ammonia is also an energy vector, that is, a carrier for hydrogen. Inter-continental transport of green hydrogen will be preferred through green ammonia primarily because of its higher energy density. However, given ammonia's toxicity, there is a requirement for enhanced safety and protection standards. Alongside green methanol, green ammonia is also a promising fuel for marine transport.

82 WEF. 2021. *Deploying sustainable aviation fuels at scale in India: A clean skies for tomorrow publication*, https://www3.weforum.org/docs/WEF_Clean_Skies_for_Tomorrow_India_Report_2021.pdf.

Government Initiatives

Green Hydrogen/Ammonia Policy

The Ministry of Power (MoP) notified an enabling green hydrogen/ammonia policy[83] using renewable sources of energy. This policy is a precursor and first step toward the upcoming national green hydrogen mission (NGHM).[84] The policy provides a waiver on interstate transmission charges on renewable energy for 25 years for green hydrogen projects commissioned before 2025. The policy has also set a target of producing five MTPA of green hydrogen by 2030. Further, the policy has provisions for the banking of renewable energy and has set norms for the banking charges. Finally, the policy aims at promoting exports of green ammonia and has provisions for bunkering and exports near ports.

National Green Hydrogen Mission

MNRE is developing a national green hydrogen mission. The mission aims to decarbonise consumers of grey hydrogen (refineries and fertiliser plants) and also create pilots on other hard-to-abate sectors of the economy. The mission will likely have a green hydrogen purchase obligation (GHPO) on refineries and fertiliser units to blend green hydrogen along with grey hydrogen obtained from fossil fuels.[85] It is expected that GHPO will create a guaranteed market of green hydrogen in India and reduce the costs due to economy of scale. It will also mitigate investment risks in the green hydrogen ecosystem.

The Mission may also have a production linked incentive (PLI) scheme for the manufacturing of electrolysers - a key step to support the Make-in-India scheme of the government and reduce dependence on imported technologies. CEEW estimates that about 45 per cent of the industrial hydrogen demand in India is from public sector undertakings (PSUs) that can be mandated to uptake made-in-India electrolysers. The mission might also have provisions for blending

83 Ministry of Power. 2022. *Green Hydrogen Policy*, https://powermin.gov.in/sites/default/files/Green_Hydrogen_Policy.pdf.

84 Press Information Bureau. 2022. "*Ministry of Power notifies Green Hydrogen/Green Ammonia Policy*", https://pib.gov.in/PressReleasePage.aspx?PRID=1799067.

85 Council on Energy, Environment and Water. 2021. "*India's Green Hydrogen Economy to Operate at Scale, Fall in Costs Expected: Minister R K Singh*", https://www.ceew.in/press-releases/indias-green-hydrogen-economy-operate-scale-fall-costs-expected-minister-r-k-singh.

green hydrogen in natural gas pipelines to offset LNG imports. Finally, it is expected that the mission will support pilots across other end-use applications like steel, and heavy-duty long-range mobility like trucks and buses and shipping.

Private Sector Initiatives

There are a few private sector initiatives in the green hydrogen domain across manufacturing, developers, end consumers and in transportation infrastructure.

<u>Manufacturing</u>

In India, manufacturing of various components across the hydrogen value chain is in very early stages. Most companies are exploring tie ups with original equipment manufacturers in the west. A few companies have already started investing in setting up manufacturing units.

Table 1: Manufacturers of Green Hydrogen Components

Reliance Industries Ltd.	Reliance Industries Ltd. has announced the construction of a green hydrogen 'gigafactory' in the state of Gujarat. The company will invest US$10 billion (S$14 billion) over the next three years to develop the facility, which will produce solar PV modules, advanced battery storage systems, electrolysers, and fuel cells. The company intends to achieve a green hydrogen cost of US$1/kg (S$1.41) in the next decade, from US$4-5/kg (S$5-7) today.[86]
Ohmium	Ohmium has set up a 500 MW per year electrolyser manufacturing facility in the state of Karnataka. They now plan to increase the capacity to 2 GW per year by the end of 2022.[87]
Larsen & Toubro (L&T)	L&T is exploring setting up electrolyser manufacturing in India in partnership with HydrogenPro AS (OSE: HYPRO), a leading Norway-based electrolyser technology and manufacturing company.[88]

86 ET EnergyWorld. 2021. "*Indian refining giant Reliance unveils $10-billion green energy plan.*" Reuters: 24 June 2021, https://energy.economictimes.indiatimes.com/news/renewable/indian-refining-giant-reliance-unveils-10-billion-green-energy-plan/83813264.

87 Ohmium. 2021. "*Ohmium launches India's first green hydrogen electrolyzer Gigafactory*". Bengaluru: 24 August 2021, https://www.ohmium.com/news/ohmium-launches-indias-first-green-hydrogen-electrolyzer-gigafactory-

88 Larsen & Toubro. 2022. "*L&T signs MoU with HydrogenPro for manufacturing Hydrogen Electrolysers in India*". Mumbai/Porsgrunn: 27 January 2022, https://www.larsentoubro.com/pressreleases/2022/2022-01-27-lt-signs-mou-with-hydrogenpro-for-manufacturing-hydrogen-electrolysers-in-india/.

Greenko	Greenko in partnership with Belgium's John Cockerill plans to set up a two-gigawatt (GW) electrolyser factory in India with an investment of US$500 million (S$704 million).[89]
H2e Power	H2e plans to set up a one GW per year solid oxide electrolyser manufacturing facility in the state of Maharashtra by 2023.[90]
GAIL (India) Ltd	GAIL is a PSU that owns and operates natural gas pipeline in India. It has invited expressions of interest (EoI) from select partners for setting up an electrolyser manufacturing facility in India.[91]
Bharat Heavy Electricals Ltd (BHEL)	BHEL is a PSU that is into the engineering and manufacturing of various power generation equipment. It has invited EoIs from select partners for setting up an electrolyser manufacturing facility in India.[92]

Source: Authors' compilation

Developers

Project developers in India have already started investments in green hydrogen and ammonia plants. ACME is leading in scaling the green hydrogen ecosystem in India through pilot projects. Other developers like ReNew power are also exploring developing green hydrogen projects in India.

Table 2: Future Producers of Green Hydrogen

ACME Group	ACME Group is in the process of commissioning a five MW green ammonia plant in the state of Rajasthan.[93] The group also plans an investment of US$3.5 billion (S$4.9 billion) over the next three years in Oman in the production of green hydrogen and ammonia. Further, the company signed an initial agreement with the state government of Tamil Nadu to set up a 5 GW solar plant, 1.5 GW electrolyser capacity and 1.1 million tonnes per annum capacity for green ammonia; ACME will invest over US$6.6 billion (S$9.3 billion) in this project.[94]

Source: Authors' compilation

89 John Cockerill. 2022. "*Greenko and John Cockerill partner in hydrogen to contribute to Indian economy's decarbonation*". Hyderabad: 18 March 2022, https://johncockerill.com/wp-content/uploads/2022/04/20220405_joint-press-release-signature-agreement-jc-greenko_final-2.pdf.

90 The Hindu BusinessLine. 2022. "*Pune-based H2e Power to set up 1 GW electrolyser plant*", https://www.thehindubusinessline.com/companies/pune-based-h2e-power-to-set-up-1gw-electrolyser-plant/article64852483.ece.

91 GAIL (India) Ltd. 2021. *Expression of Interest (EoI) for Partner Selection in Electrolyser Manufacturing for Production of Green Hydrogen*, https://www.gailonline.com/pdf/EOIHydrogenElectrolyser26112021.pdf.

92 BHEL. 2021. *Expression of Interest (EoI) for partnering with BHEL with regard to i) Electrolyser System for Hydrogen Production ii) Hydrogen based PEM Fuel Cell System*, https://www.bhel.com/sites/default/files/EoI-%20Hydrogen%20Economy_10-11-2021.pdf.

93 Green Hydrogen & Chemicals (UK) Pvt Ltd. n.d. *India Projects: Rajasthan*, https://www.acme-ghc.com/india-green-hydrogen-project/rajasthan.

94 ACME Group. 2022. "*ACME Group announces Green Hydrogen and Ammonia project in Tamil Nadu*".

End Consumers

The end consumers of green hydrogen in India today are mostly public sector undertakings across thermal power plants and refineries. The fertiliser sector, although the largest consumer of industrial hydrogen, has not shown enthusiasm to uptake green hydrogen. Nitrogenous fertilisers like urea are very heavily subsidised by the government and the blending green hydrogen will only increase the cost of fertiliser. Therefore, the uptake of green hydrogen in the fertiliser sector will need government support.

Table 3: Future End Consumers of Green Hydrogen

National Thermal Power Corporation (NTPC)	National Thermal Power Corporation (NTPC) has started developing pilots for green methanol in India. There are plans for a 10 TPD flue gas-to-methanol project.[95] The plant will capture 20 TPD of CO2 and use 2 TPD of green hydrogen to produce e-methanol. NTPC has also started pilots on hydrogen buses in Ladakh. It has awarded a tender on green hydrogen-based microgrid. Further, it has signed an agreement with Gujarat Gas Limited (GGL) for blending green hydrogen in Piped Natural Gas (PNG) network of the state government.
Indian Oil Corporation Ltd. (IOCL)	Indian Oil Corporation Limited (IOCL) is one of the largest industrial consumers of hydrogen in India. IOCL is planning green hydrogen plants at its Mathura and Panipat refineries.
Oil India Ltd. (OIL)	Oil India Limited (OIL) commissioned India's first green hydrogen project having a production capacity of 10 kg per day.[96]

Source: Authors' compilation

Infrastructure

Infrastructure development would be the key to moving green hydrogen in India. Green hydrogen can be blended in natural gas pipelines and moved over the country. Dedicated movement of green hydrogen can be achieved using roads and existing rail infrastructure.

95 NTPC Ltd. 2022. *Technology*, https://www.ntpc.co.in/en/technology.

96 PIB. 2022. "*India's first pure green hydrogen plant commissioned in Jorhat*". Delhi, 20 April 2022, https://www.pib.gov.in/PressReleasePage.aspx?PRID=1818482.

Table 4: Future Transport Infrastructure Providers for Green Hydrogen

GAIL (India) Ltd.	GAIL (India) Ltd. is assessing the suitability of the transmission system and demand sectors to absorb hydrogen at various blends with natural gas.
Chart Industries	Chart Industries has expertise in the transportation of green hydrogen and derivatives and is exploring investments for developing infrastructure for moving green hydrogen.

Source: Authors' compilation

Partnerships

There are industry joint ventures, alliances and research platforms collaborating for scaling up the green hydrogen ecosystem in India.

Table 5: Partnerships for Scaling up the Green Hydrogen Economy in India

Indian Oil Corporation Ltd + Larsen & Toubro + ReNew Power	IOCL, L&T and ReNew Power have formed a joint venture (JV) to scale up the green hydrogen sector in India.[97]
Hydrogen Association of India (HAI)	Hydrogen Association of India (HAI) is an industry association that was formed in 2010.[98]
India Hydrogen Alliance (IH2A)	India Hydrogen Alliance (IH2A) was formed in 2020. Its founding members include Reliance Industries Ltd., JSW, Chart Industries and other industries.[99]
Green Hydrogen Consortium of Indian Industry (GHCII)	National Solar Energy Federation of India (NSEFI) in partnership with HAI launched the Green Hydrogen Consortium of Indian Industry (GHCII) in March 2022.[100]
Energy Storage Platform on Hydrogen (ESPHy)	ESPHy is a multi-Institutional Centre for research on Hydrogen Energy Systems. The participants are the IITs and NITs in India.[101]

Source: Authors' compilation

97 ReNew Power. 2022. "*IndianOil, L&T and ReNew to form JV for development of Green Hydrogen Business*". Gurugram: 3 April 2022, https://investor.renewpower.in/news-releases/news-release-details/indianoil-lt-and-renew-form-jv-development-green-hydrogen.

98 HAI. 2021. *About*, https://www.hai.org.in/about.php.

99 IH2A. 2021. *About IH2A*, https://ih2a.com/about-ih2a/.

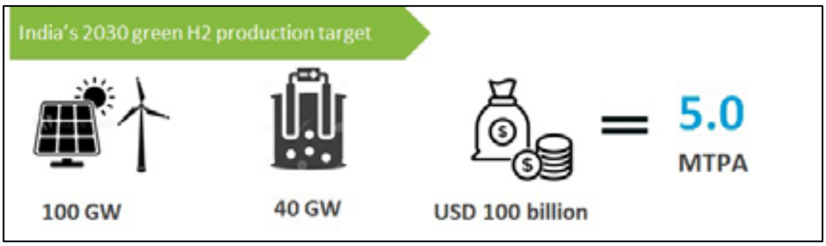
100 NSEFI. 2022. *NSEFI Press Release*, https://nsefi.in/press_release/.

101 Energy Storage Platform on Hydrogen (ESPHy). N.d, https://www.ese.iitb.ac.in/esphy/#.

Investment Potential

Producing five MTPA of green hydrogen by 2030 as per the Indian government's policy would need at least 100 GW of solar and wind installed capacity, 40 GW of electrolyser capacity and US$100 billion (S$139 billion) in investments. If there are any further commitments in the upcoming NGHM document for steel, mobility and blending in gas pipelines, the investment requirement could increase in the future. Additional investments would also be required for setting up supply chains and logistics for raw materials and investing in electrolyser manufacturing. Significant R&D funding would be required to develop new materials, technologies and processes to reduce the cost of electrolysers (which are the major contributors to a high green hydrogen price).

Figure 6: Requirements for Achieving India's 2030 Green Hydrogen Target



Source: Authors' analysis

Potential for Collaboration

There is significant scope for collaboration between India and Singapore to scale up the green hydrogen ecosystem. Firstly, India and Singapore can collaborate on financing green hydrogen projects in India. Singapore is a big financial hub and India needs capital of at least US$100 billion (S$139 billion) to deploy green hydrogen technologies.

Secondly, India and Singapore can collaborate on clean trade-in fuels like ammonia. Singapore aspires to halve its emissions by 2050 and to achieve net-zero emissions in the second half of the 21st century. Given that Singapore lacks renewable energy resources, it can meet its targets by importing clean fuels from India. India has one of the lowest renewable energy tariffs in the world and has huge renewable potential. India is also geographically in proximity to Singapore for the movement of clean fuels. India and Singapore can get into bilateral agreements to trade clean fuels like green ammonia. Singapore is also a major bunkering hub and can benefit from green ammonia bunkering for maritime transport in the future.

Singapore has experience in handling town gas in the existing gas pipelines. India plans to start blending green hydrogen in natural gas pipelines. India can benefit from Singapore's experience in handling town gas (which contains a significant amount of hydrogen). In addition, the exchange of technical know-how on handling green hydrogen will be mutually beneficial for both countries.

Singapore is an exporter of major electronic products to India and the world. India needs at least 40 GW of electrolysers to meet its 2030 green hydrogen target. Power electronics constitute 25-30 per cent of the total electrolyser costs. This opens a potential US$5 billion (S$6.9 billion) market opportunity in India for power electronics in the electrolyser manufacturing sector alone (assuming an electrolyser cost of US$500 [S$704] per kW).

India and Singapore have some of the world's leading research and development institutions and laboratories. For a rapidly growing green hydrogen economy, India and Singapore can collaborate on joint R&D projects to develop upcoming technologies across electrolysers and fuel cells. Collaboration is also possible with other end-use equipment like hydrogen boilers and furnaces, hydrogen storage and pipelines.

Risks and Challenges

While it is difficult to label India's efforts in clean energy as outrightly successful or unsuccessful, there are several barriers and challenges that the domestic market and industry face going forward.

i. **Competition from Foreign Markets**
We have already seen in the past how domestic manufacturing for solar power failed to scale up sufficiently in India. Now, according to our analyses, more than 75 per cent of the existing global capacity for solar PV manufacturing is located in China. With developing markets such as bioenergy and green hydrogen, India runs a similar risk in three key areas:

   a. **Fuel Production:** Aside from improving energy security by reducing import dependency, there is a large latent market for the export of clean fuels, such as green ammonia, SAF and biofuels. If India is not a first mover in establishing capacity for exports, a significant source of revenue could be lost to other countries such as China, Australia and countries in the Middle East where there are significant renewable energy resources. Lack of early capacity will limit the ability to compete on price at a later stage.

   b. **Technology Development:** Newer technologies for clean energy production and storage systems need to be indigenously developed to avoid high costs associated with imported technology and patented components. This is essential to develop sufficient domestic capacity at competitive prices.

   c. **Trade Agreements:** First movers have the advantage of getting early access to latent demand centres through trade agreements for the supply of energy/components.

ii. **Managing a just transition**

According to a CEEW study, India can create 3.4 million jobs (short and long-term) by installing 238 GW of solar and 101 GW of wind capacity in addition to existing renewable power capacity.[102] However, India's economy today is highly dependent on fossil fuels. Around 350,000 people are directly employed by just the public sector coal, oil and gas industries in India.[103] An accelerated phase-out of fossil fuels could thus leave hundreds of thousands of people with insufficient time to retrain for jobs in other sectors, putting millions at risk of income loss. Ensuring a just transition for the nation's workforce will be crucial to ensure stability and acceptance of the transition.

iii. **Impact of bilateral and multilateral trading mechanisms**

Several interregional free trade mechanisms are in place to allow for enhanced trading amongst partners by reducing barriers to imports and exports. India has trade agreements with, for example, the ASEAN member states (India-ASEAN Free Trade Agreement [FTA]),[104] South Asian Association for Regional Cooperation nations (Agreement on South Asian Free Trade Area)[105] and with Singapore (Comprehensive Economic Cooperation Agreement).[106] Goods qualifying for the benefits of a trade mechanism are usually restricted based on the origin of the good, with 40-45 per cent domestic content requirement.[107]

An analysis of trade between Singapore to India shows that the total value of imports from Singapore increased from US$7 billion

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102 Tyagi, Akanksha, Charu Lata, Jessica Korsh, Ankit Nagarwal, Deepak Rai, Sameer Kwatra, Neeraj Kuldeep, and Praveen Saxena. 2021. *India's Expanding Clean Energy Workforce*. New Delhi: Council on Energy, Environment and Water, Natural Resources Defense Council, and Skill Council for Green Jobs, https://www.ceew.in/publications/indias-expanding-clean-energy-workforce.

103 Coal India Limited. 2022. *Physical – Manpower*, https://www.coalindia.in/performance/physical/; and MoPNG. 2022. *Indian Petroleum & Natural Gas Statistics 2020-21*, https://mopng.gov.in/files/TableManagements/Indian-Petroleum--Natural-Gas_2020-21.pdf; and Ministry of Coal. 2022. Production and Supplies, https://coal.nic.in/en/major-statistics/production-and-supplies.

104 Department of Commerce. 2022. *India-ASEAN Trade Agreements*, https://commerce.gov.in/international-trade/trade-agreements/india-asean-agreements/.

105 Department of Commerce. 2009. *Agreement on South Asian Free Trade Area (SAFTA)*, https://commerce.gov.in/wp-content/uploads/2020/05/safta.pdf.

106 Department of Commerce. 2022. *Comprehensive Economic Cooperation Agreement between The Republic of India and the Republic of Singapore*, https://commerce.gov.in/international-trade/trade-agreements/comprehensive-economic-cooperation-agreement-between-the-republic-of-india-and-the-republic-of-singapore/.

107 Department of Commerce. 2022. op. cit.

(S$9.7 billion) to about US$19 billion (S$26.3 billion) from 2017-18 to 2021-22.[108] A similar case is observed with Vietnam – from 2012-13 to 2020-21, India saw a threefold increase in imports of electronics and telecom goods from Vietnam (the India-ASEAN FTA was signed in 2014).[109]

Both Singapore and the ASEAN member states are part of the Regional Comprehensive Economic Partnership with other major countries including China, Japan, New Zealand and Australia.[110] The difference between cost-competitiveness of trade between Singapore/ASEAN and India (through the CECA and ASEAN-FTA) versus RCEP members could cause a burgeoning trade imbalance going forward. Such imbalances could evoke protectionist measures or even exits from trade agreements to support the domestic industry.

iv. **Land and water stresses for renewable power, green hydrogen, and bioenergy**

Green hydrogen needs a significant amount of renewable energy and water. Water is consumed not only for producing hydrogen but also for cleaning solar panels that generate electricity for powering the electrolysers. Similarly, the production of biofuels such as ethanol and bioCNG requires large amounts of water during the production process. Most of the renewable energy rich states in India are water starved. Renewable energy projects also need a significant amount of land which results in social conflicts in a few areas. Land requirements for biofuels may also be large if new areas are brought under cultivation for growing feedstock crops. Therefore, scaling up the green hydrogen and bioenergy ecosystem would need a proper understanding of the renewable energy-land-water nexus and minimise the social impacts of the transition.

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108 NCCS. n.d. *Renewable Energy*, https://www.nccs.gov.sg/faqs/renewable-energy/.

109 Majumder, Subrata. 2021. "*Backdoor entry*". *The Millennium Post*, http://www.millenniumpost.in/opinion/backdoor-entry-453720.

110 ASEAN. 2022. RCEP *Agreement Enters into force*. Jakarta, 1 January 2022, https://asean.org/rcep-agreement-enters-into-force/.

v. **Availability and supply of critical mineral resources and processing capacity**
Critical mineral resources such as cobalt and lithium are not domestically available in sufficient quantities in India. Therefore, scaling up of energy storage systems is difficult without ensuring a stable supply of these minerals through imports. Investments need to be made by India in other countries to access the minerals or there is a need to find substitutes for such minerals.

The capacity to process critical minerals for the production of solar panels and battery storage systems is currently concentrated in China. Overcapacity of Chinese plants allows for cheap exports of components, thus making a difficult financial case for domestic production currently. However, to ensure independence from geopolitical issues, to support the local economy and workforce and to better prepare for strong future demand, domestic manufacturing is necessary.

vi. **Technology challenges with existing systems**
As mentioned in the previous point, reliance on imports of mineral resources to sustain the domestic industry is not advisable in the long term. Therefore, we need to invest and develop new technologies which can utilise locally available resources (for example, sodium-ion batteries).

vii. **Limited supply chain infrastructure for bioenergy deployment**
While the bioenergy technologies are mostly at the pilot or commercial scale, significant efforts need to be made to build out the necessary supply chains to move the biomass feedstocks from their source to processing centres, and the bioenergy products (bioCNG, biomass pellets, bioethanol) to end-users. The supply chains need to be supported by a conducive policy framework that provides incentives and regulatory support to build supply chain infrastructure and services.

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