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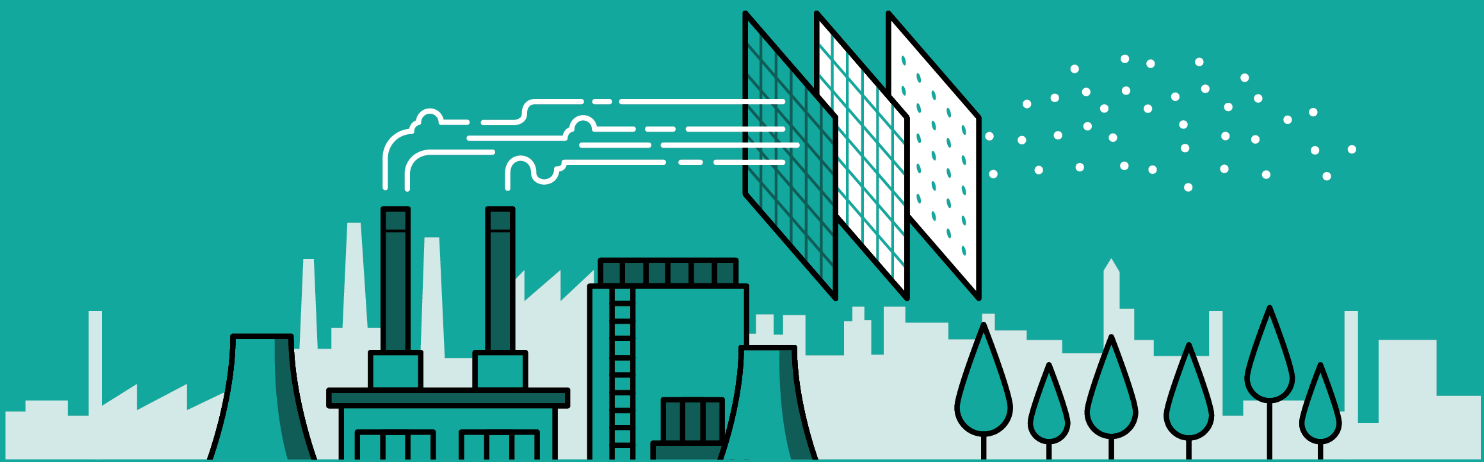
# THE METHANE ECONOMY

**by Chaitanya Giri**
Fellow, Space & Ocean Studies



GATEWAY HOUSE
INDIAN COUNCIL ON GLOBAL RELATIONS

# The Methane Economy

## Prospects for a New-Age Fuel and Material in India

Chaitanya Giri
Fellow, Space and Ocean Studies Programme

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## Background

The United Nations' (U.N.) 2015 Paris Agreement forecast grave global warming scenarios, a consequence of rising global greenhouse gas (GHG) emissions. It called for the immediate sequestration of atmospheric anthropogenic GHGs to assist averting serious environmental degradation.

Among the many GHGs being considered for sequestration by countries and companies globally, methane has the qualities to be the most successful in the near future. Methane is the cleanest of the hydrocarbons and strongest of natural GHGs: it absorbs more heat than carbon dioxide, is a stronger GHG than carbon dioxide and has a longer lifetime in the atmosphere. [Annexure 6.1]

Methane cracking will go a long way in meeting the Paris Agreement's goals. Recent scientific advances in chemical and energy engineering technologies are making it possible to crack methane into gaseous hydrogen and solid carbon on a commercial scale. The costs of sequestering atmospheric anthropogenic GHGs, including methane, are also falling steadily. Therefore, it is now possible to overcome the deficit of the in-demand hydrogen gas and solid carbon materials by cracking methane, sequestered from the atmosphere and natural gas.

India is the second largest emitter of methane in the world. It is also poised to become the third largest economy of the world by 2047, the 100th year of the nation's independence. Unlike the approach of other major economies, it aims to grow, complying with the global call for climate change mitigation. India, which presently is on a mega infrastructure drive, has the potential to build a clean and efficient hydrogen-powered transportation sector from methane-cracked hydrogen. Similarly, India's objective of becoming a high-technology manufacturing powerhouse can be met by a steady supply of methane-derived solid carbon materials — graphene, carbon nanotubes, fullerenes, carbides, synthetic diamonds — which are central to futuristic electronics, transportation and the marine, aerospace and space industries.

Several Indian ministries and companies are already working on this technology. The Indian Ministry of New and Renewable Energy, the Ministry of Petroleum and Natural Gas (Oil Industry Development Board), the Department of Space and the Ministry of Science and Technology have made incongruous attempts to develop indigenous capacities in carbon capture, hydrogen fuel production and fuel cell technologies. The need, therefore, is to streamline such efforts, draw up India's climate action goals and realise the economic potential of methane sequestration.

Many global industrial corporations, particularly in the automotive, chemical, petroleum and electronics sectors, have formed interest groups, such as the Hydrogen Council and Carbon Capture Coalition. The corporations, along with their respective governments, will use these coalitions to collectively gain first-mover advantage in hydrogen-fuel technologies and carbon materials manufacturing and thereby shape national legislations and global geoeconomic strategies.

India's industrial corporations should step up, forming national coalitions on methane-derived carbon sequestration and hydrogen fuel technologies, participate actively in the global groupings, and at home, invest in end-to-end inventions and innovations. India Inc. and the government must together prepare to shape national and global policies, increase their heft in the world market and strengthen India's resource and energy security.


*Image 1: India and France are leaders of the International Solar Alliance and the global clean energy movement. Source: Prime Minister Narendra Modi's official website*

## About the Author

***Chaitanya Giri*** *is the Gateway House Fellow of the Space and Ocean Studies Programme. His present research focuses on aquapolitics and astropolitics, new-age techno-geostrategy, the space and marine industrial complex, and the science of space exploration. Prior to Gateway House, Dr. Giri has worked as planetary and astromaterials scientist for nearly a decade. He was affiliated to the Earth-Life Science Institute at Tokyo Institute of Technology, the Geophysical Laboratory at Carnegie Institution for Science, and the NASA Goddard Space Flight Center as an ELSI Origins Network Fellow. He was earlier an International Max Planck Research Fellow at the Max Planck Institute for Solar System Research in Germany and the University of Nice in France. Dr. Giri was also a scientific crew member of the European Space Agency's Rosetta mission to comet 67P/Churyumov-Gerasimenko. He is a recipient of several fellowships and awards, including the 2014 Dieter Rampacher Prize of the Max Planck Society for the Advancement of Science, Germany and the 2016-2018 ELSI Origins Network Fellowship by the John Templeton Foundation, USA, to name a few.*

## 1. Growing Global Emphasis on Atmospheric Greenhouse Gas Removal

Under the 2015 United Nations Framework Convention on Climate Change (UNFCCC), better known as the Paris Agreement, a number of national pledges were made to achieve the goal of off-putting greenhouse gas (GHG) emissions and limiting the rise of global average temperature to 1.5°C below pre-industrial levels.[1] Since then, a neologism, "decarbonisation", has started to appear prominently in the policy white papers of governments and multinational corporations as a catch-all word for the processes and policies supporting GHG removal.[†] However, there are some significant lacunae.

Reducing GHG emissions, as decarbonisation implies, cannot singly reverse the trend of global warming. Effective removal of existing – already-emitted – anthropogenic GHGs from the atmosphere and bringing them to concentrations found prior to the Industrial Revolution (1750 CE) is central to the global climate change action plan. This is evident from Paragraph 1 of Article 4 of the Paris Agreement, which requires signatory nations to use carbon sequestration, including the use of forests and soil as carbon sinks, to meet climate goals.[‡]

It is time to move from generic decarbonisation to removal of specific GHGs. [Annexure 6.2] Around the world, the emissions of fluorinated GHGs [Groups 3 and 4 in Table 1] have been contained and regulated under the U.N.'s 1985 Vienna Convention for the Protection of the Ozone Layer.[§] [Annexure 6.3] The focus should now be on Groups 1, 2 and 5. (Refer Table 1.) Of these, methane is the most appropriate and future-ready for India to pursue.

The hydrogen fuel and carbon materials derived from methane can be used for next-generation transportation, energy and high-end electronics manufacturing sectors. Innovation ecosystems around methane-derived commodities are already being delivered in countries like Japan, Germany, the U.S., France, Australia, Saudi Arabia, China and the European Union. India should prepare itself to join this club.

Since the Paris Agreement has left it to the so-called Parties to the agreement to work out how to go about achieving the targets, forward-looking and innovative Indian companies can step in, form domestic innovation ecosystems and seize the business opportunity emerging from a methane economy.

Table 1. List of GHGs, their longevity in the atmosphere, and their global warming potential as compared to carbon dioxide[2, 3]

| Species | Chemical Formula | Lifetime (Years) | Global Warming Potential (Time Horizon) | | |
|---|---|---|---|---|---|
| | | | 20 years | 100 years | 500 years |
| **Carbonaceous Greenhouse Gases (Group 1)** | | | | | |
| Carbon Dioxide | CO2 | variable[§] | 1 | 1 | 1 |
| Methane | CH4 | 12±3 | 56 | 21 | 6.5 |
| **Non-Carbonaceous Greenhouse Gases (Group 2)** | | | | | |
| Nitrous Oxide | N2O | 120 | 280 | 310 | 170 |
| **Carbonaceous Fluorinated Greenhouse Gases (Group 3)** | | | | | |
| Perfluoromethane | CF4 | 50000 | 4400 | 6500 | 10000 |
| Perfluoroethane | C2F6 | 10000 | 6200 | 9200 | 14000 |
| Perfluoropropane | C3F8 | 2600 | 4800 | 7000 | 10100 |
| Perfluorobutane | C4F10 | 2600 | 4800 | 7000 | 10100 |
| Perfluorocyclobutane | c-C4F8 | 3200 | 6000 | 8700 | 12700 |
| Perfluoropentane | C5F12 | 4100 | 5100 | 7500 | 11000 |
| Perfluorohexane | C6F14 | 3200 | 5000 | 7400 | 10700 |
| **Carbonaceous Hydrogenated Fluorinated Greenhouse Gases (Group 4)** | | | | | |
| HFC – 23 | CHF3 | 264 | 9100 | 11700 | 9800 |
| HFC – 32 | CH2F2 | 5.6 | 2100 | 650 | 200 |
| HFC – 41 | CH3F | 3.7 | 490 | 150 | 45 |
| HFC – 41 – 10mee | C5H2F10 | 17.1 | 3000 | 1300 | 400 |
| HFC-125 | C2HF5 | 32.6 | 4600 | 2800 | 920 |
| HFC-134 | C2H2F4 | 10.6 | 2900 | 1000 | 310 |
| HFC-134a | CH2FCF3 | 14.6 | 3400 | 1300 | 320 |
| HFC-152a | C2H4F2 | 1.5 | 460 | 140 | 42 |
| HFC-143 | C2H3F3 | 3.8 | 1000 | 300 | 94 |
| HFC-143a | C2H3F3 | 48.3 | 5000 | 3800 | 1400 |
| HFC-227ea | C3HF7 | 36.5 | 4300 | 2900 | 950 |
| HFC-236fa | C3H2F6 | 209 | 5100 | 6300 | 4700 |
| HFC-245ca | C3H3F5 | 6.6 | 1800 | 560 | 170 |
| **Non-Carbonaceous Fluorinated Greenhouse Gases (Group 5)** | | | | | |
| Sulphur hexafluoride | SF6 | 3200 | 16300 | 23900 | 34900 |
| Nitrogen trifluoride | NF3 | 550 | 12300 | 17200 | 20700 |

*Source: The United Nations Framework Convention on Climate Change*



## 2. Cracking Methane — Global Companies are Leading Innovation & Commercialisation

Methane cracking is a promising chemical technology that can potentially solve some of the world's global warming conundrums (refer Annexure 1). It involves the efficient splitting of the methane molecule into two value-added products – solid carbon and gaseous hydrogen – as shown in the following reaction:

$$CH_4 \text{ (methane gas)} \longrightarrow C \text{ (solid carbon)} + 2H_2 \text{ (hydrogen gas)}$$

The significance of methane cracking is increasing with the prospect of sequestering methane directly from the air,[**] a promising carbon capture technology.[4, 5, 6] Where gaseous hydrogen is poised to become a keystone energy fuel, carbon materials are sought after in an ever-growing high-technology market. The expanding demand for these two methane-cracked products is therefore incentivising carbon capture and methane cracking into a business opportunity.

### 2.1. Hydrogen from Methane: Investing in Next-Generation Fuel

$$CH_4 \rightarrow 2H_2 + C$$

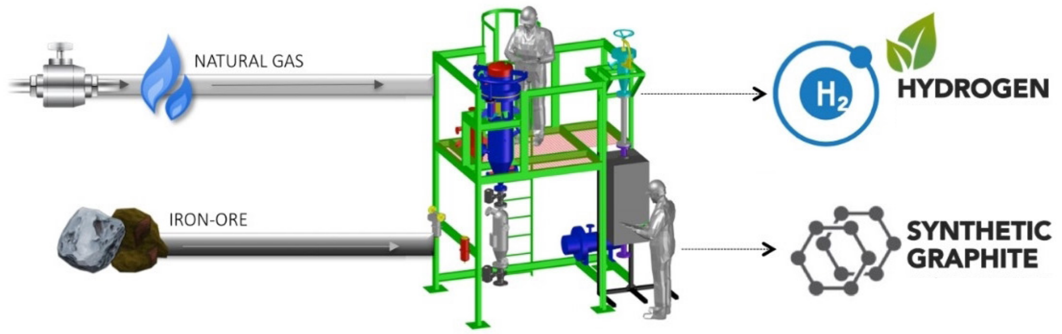



*Image 2: Natural gas in the presence of iron ore can yield hydrogen gas and carbon materials, two valuable commodities of the near future. Photo credit: Hazer Group & Gas Liquid Processing, Australia*

The market for hydrogen fuel has been increasing steadily in the past four years, and much of its current production comes from hydrocarbons – oil, coal and natural gas. (Image 3.) Recent R&D advances are making the cracking process cleaner, devoid of carbon dioxide and other GHG by-products and are also concomitant with efficient production of hydrogen fuel[4] and carbon materials.[5] Such R&D is being scientifically pursued to commercialise the resulting technologies and processes rapidly.

For instance, the University of Western Australia along with a Perth-based chemical technology company, the Hazer Group, has come up with a proprietary process, whereby methane, derived from natural gas and unprocessed iron ore, both of which are abundant in Australia, is used to produce clean hydrogen gas and synthetic graphite.[7] Similarly, scientists at the King Abdullah University of Science and Technology in Saudi Arabia claim to have patented a new catalyst that cracks methane, derived from natural gas, into hydrogen and carbon nanotubes without emitting carbon dioxide or other GHGs.[8] In the run-up to commercial-scale production of hydrogen gas, the current R&D is attuned to attaining production efficiencies and lowering costs.

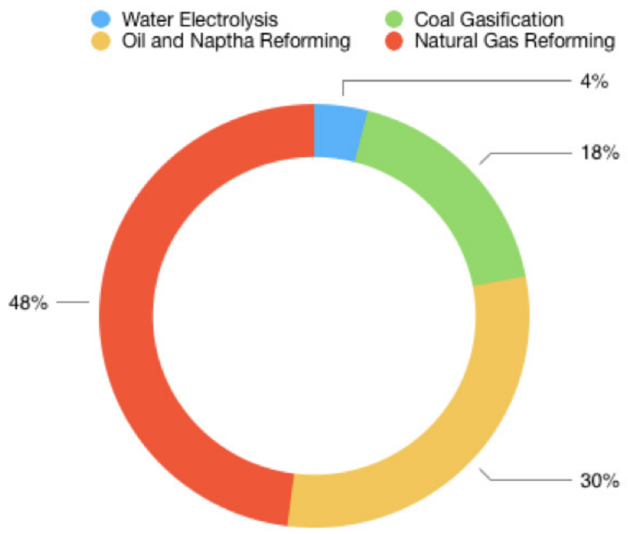



*Image 3: Percentage share of processes for production of gaseous hydrogen.*
*Photo credit: K.S.V. Santhanam, R.J. Press, M.J. Miri, A.V. Bailey, G.A. Takacs (2018)* [9]

Automobile and transportation companies have recently launched hydrogen-powered vehicles in the market: cars, such as Honda's FC-X Clarity, Hyundai's Nexo and Toyota's Mirai; Mercedes Benz with its Citaro O530BZ buses and rail transport giant, Siemens-Alstom, with its hydrogen-powered train. These vehicles, though more expensive than their conventionally powered counterparts, are now commercially manufactured for lease and sale in select regions of the world. Compared to electricity-powered vehicles, those powered by hydrogen have a quicker refuelling time, can operate over longer distances and can be cleaner and more energy-efficient than electric vehicles.[10]

### 2.2. Carbon from Methane: Next-Generation Materials

Carbon materials – namely graphite, carbon composites, carbon foams, carbon nanotubes, carbon fibres, synthetic diamonds and graphene – are increasingly becoming indispensable commodities, crucial to the global technology landscape. These materials are now the backbone of speciality chemicals, aerospace, hardware, automobiles, semi-conductors, electronics products and are used across civilian and military domains. Their global market will grow from approximately $35 billion in 2018 to $1 trillion by 2030.[11]

For instance, graphene holds promise in several cutting-edge applications, including flexible – bendable, twistable and stretchable – electronics and next-generation semiconductors. Recognising its potential, the European Commission has invested €1 billion in Europe's largest ever research project, the Graphene Flagship, with hopes of achieving a lasting lead in the field.[12] China has also entered the graphene contest; its domestic market is projected to exceed $200 million by 2020.



Global petroleum and petrochemical industries have begun to overhaul their business strategies, anticipating the phasing out of fossil fuels and the growing demand for speciality chemicals and materials. A trend-setting example of this metamorphosis is SABIC, the Saudi-based petrochemical giant, which has recently entered into a joint venture with Texas-based carbon nanomaterials firm, Molecular Rebar Design, for the manufacture of carbon nanotubes for high-energy storage applications and to expand its portfolio of next-generation materials.[13] On similar lines, the U.S. petroleum major, ExxonMobil, has entered into a strategic alliance with the Massachusetts Institute of Technology Energy Initiative Programme to undertake research on carbon capture storage and utilisation technologies and processes.[14]

The apparently diverse business interests of carbon capture technology and petroleum and advanced materials companies are now converging and have begun to financially incentivise the cracking of methane into synthetic carbon materials.

*Image 4: The demand for carbon allotropes and composites, synthesised from methane, will grow considerably in the coming years. The Lamborghini Terzino Millenio is the world's first concept car that has a body frame built of light-weight carbon materials, which can double up as an unconventional energy-storage device (supercapacitator). The same material can also self-heal.*
*Photo credit: Lamborghini S.p.A, Italy*

## 3. Creating Ecosystems for the Methane Economy

The growing demand for natural gas, hydrogen fuel and carbon materials is hinting at the emergence of a new methane economy. Far-sighted industrial conglomerates have begun to form national and international coalitions to take collective advantage of the business opportunities inherent in a methane era. Partners in such coalitions belong to different industrial sectors. Such coalitions are helping member companies:

- plan symbiotic goal-setting;
- pool financial, technical and human resources;
- reduce duplication of efforts;
- enlarge technical support mechanisms, material supply chains and market base more powerfully than possible through solitary efforts;
- shield against economic risks associated with early stage technology development;
- accord each of the members a first-mover advantage;
- overcome the early vulnerable phase of any technology innovation business; and
- survive to reap profits and gain a market foothold as the business matures.

### 3.1. National Coalitions

Many far-sighted nations realise that a methane economy needs active synergies between the public and private sectors which are likely to function better and yield tangible results more than solitary, government-driven or private, particularly start-up, ventures can. In 2009, the European Parliament established a legal framework for environment-friendly storage of captured carbon. Despite allotting several billion euros ever since, it has been unable to spawn commercial-scale carbon capture storage projects in any of its member countries.[15]

This most likely has been due to a lack of synergies between Europe's private industrial sector, the national governments and the European Commission. Unlike Europe's regulation-first model – they initially formed a legal framework and then waited for the industrial sector to step in – the U.S. worked on an innovation-first model, and that has demonstrated success.

**Carbon Capture Coalition (U.S.)** was formed in 2011 with active participation from more than 50 U.S. based entities – think tanks, corporations, start-ups, universities and trade unions.[Table 2.] This ecosystem coalition aims to boost domestic energy production, create and sustain employment and reduce GHG emissions simultaneously.[16]

The strategic foresight and sustained efforts of this coalition have resulted in the U.S. Congress passing the H.R. 3761 Carbon Capture Act. This legislation has greatly incentivised R&D, implementation and marketisation of carbon capture technologies by extending financial credits for carbon dioxide capture. It now legislates for crediting the industries $20 per metric tonne of carbon dioxide that is captured and kept in secure geological storage in mines and $10 per metric tonne for that captured and used for enhanced oil and natural gas recovery.[17]



**Clean Energy Partnership (Germany)** is a coalition of 14 cross-sectoral companies – Air Liquide, Audi, Hyundai, Honda, Linde, Shell, Total, Toyota, Westfalen Group, GP Joule, BMW Group, H2 Mobility, OMV, and Daimler AG – based in Germany.[18] These companies are complementarily undertaking R&D and commercialisation of hydrogen production, storage, refuelling and hydrogen fuel cell vehicles.

The Clean Energy Partnership is working in sync with the German Federal Ministry of Transport and Digital Infrastructure, which intends to install hydrogen infrastructure at municipal levels.[19] The ministry's National Innovation Programme for Hydrogen and Fuel Cell Technology assists the Clean Energy Partnership in carrying out high-risk-high-reward R&D; it is considered to be a feat of public-private cooperation.[20]

### 3.2 International Coalitions

**The European Hydrogen and Fuel Cell Association (Hydrogen Europe)** has emerged as a major trade association and a public-private innovation funding and incubation body. It is currently represented by more than 100 industries, 13 national associations and 67 research organisations, focusing on research, technology development, evaluation and commercialisation of hydrogen technologies.[21]

**The Hydrogen Council** is a global business alliance of more than 50 large global corporations across various sectors. It was formed during the 2017 World Economic Forum in Davos. [Table 3.] This Council intends to devise a mutually agreed upon action plan and shape pioneering international policies for the emerging hydrogen economy.[22]

These intra-industrial innovation-driven partnerships, supported by public institutions, have already begun to strategise on how to reap the economic and environmental profits of the methane economy.

Table 2. Members of the Carbon Capture Coalition

| Sector | Company |
|---|---|
| Advanced Materials, Mining and Speciality Chemicals | • Arch Coal<br>• Cloud Peak Energy<br>• ION Engineering LLC<br>• LanzaTech<br>• Peabody Energy<br>• United Mine Workers of America |
| Food Processing | Archer Daniels Midland Co |
| Manufacturing/ Trade Union | • International Brotherhood of Boilermakers<br>• American Federation of Labour and Congress of Industrial Organisations<br>• International Brotherhood of Electrical Workers<br>• National Farmers Union<br>• Sheet Metal, Air, Rail and Transportation Division<br>• United Steel Workers<br>• Utility Workers Union of America |
| New Energy Companies | • ClearPath Foundation<br>• Conestoga Energy Partners<br>• EBR Development LLC<br>• EnergyBlue Project<br>• Energy Innovation Reform Project<br>• Greene Street Capital<br>• NET Power<br>• NRG Energy<br>• Thunderbolt Clean Energy LLC<br>• White Energy |
| Not-for-profit | • Bipartisan Policy Center<br>• Carbon180<br>• Jackson Hole Center for Global Affairs<br>• National Audubon Society<br>• The Nature Conservancy<br>• Third Way<br>• Wyoming Outdoor Council |



Table 2. Members of the Carbon Capture Coalition (Continued)

| Sector | Company |
|---|---|
| Oil, Gas and Industrial Gas | • Air Liquide<br>• Air Products<br>• American Carbon Registry<br>• Baker Hughes, a GE Company<br>• Carbon Wrangler LLC<br>• Clean Air Task Force<br>• Core Energy LLC<br>• Glenrock Petroleum<br>• Impact Natural Resources LLC<br>• Jupiter Oxygen Corporation<br>• Lake Charles Methanol<br>• Linde LLC<br>• Mitsubishi Heavy Industries America, Inc.<br>• Occidental Petroleum Corporation<br>• Prairie State Generating Company<br>• Praxair, Inc.<br>• Renewable Fuels Association<br>• Shell<br>• Summit Power Group<br>• Tenaska Energy |
| Public Utilities | Great River Energy |
| Steel Manufacturing | • ArcelorMittal<br>• New SteelW International, Inc |

*Source: Members of the Carbon Capture Coalition*

Table 3. Members of the Hydrogen Council, formed during the 2017 World Economic Forum

| Automotive | Oil, Gas & Industrial Gas | New Energy Companies | Aerospace & Rail | Advanced Materials, Mining and Speciality Chemicals |
|---|---|---|---|---|
| **Steering Members** | | | | |
| • Toyota<br>• Hyundai<br>• BMW Group<br>• Daimler<br>• Great Wall Motors<br>• General Motors<br>• Audi<br>• Faurecia<br>• Honda<br>• Kawasaki<br>• Weichai Group<br>• Robert Bosch<br>• Cummins | • JXTG Nippon<br>• KOGAS<br>• SINOPEC<br>• Linde<br>• Air Liquide<br>• Air Products<br>• CHN Energy<br>• Iwatani<br>• Total<br>• Equinor | • EDF Energy<br>• Engie<br>• CHN Energy Investment<br>• Cummins | • Airbus<br>• Alstom | • 3M<br>• Johnson Matthey<br>• Plastic Omnium<br>• Thyssenkrupp<br>• Anglo American |
| **Supporting Members** | | | | |
| • NGK Spark Plug Co. Ltd.<br>• Plug Power<br>• Re Fire | • Faber Cylinders<br>• Mitsui & Co.<br>• SoCalGas<br>• Royal Vopak N.V. | • True Zero<br>• Sumitomo Mitsui Banking Corporation<br>• AFC Energy<br>• Ballard Power Systems<br>• Hydrogenics<br>• McPhy Energy<br>• Nel Hydrogen | • Mitsubish Heavy Industries | • Mitsubishi Corporation<br>• Sumitomo Corporation<br>• W.L. Gore & Associates<br>• ToyotaTsusho Corporation<br>• Maruben Corporation<br>• Hexagon Composites |

*Source: World Economic Forum*



## 4. Recommendations for Establishing a Methane Economy in India

### 4.1. Reorder India's Hydrogen Energy Agenda

The Standing Committee on Petroleum and Natural Gas of the 16th Lok Sabha has identified hydrogen fuel as one of the crucial R&D areas of national interest and vital for the nation's energy security.[23] To meet this strategic demand the Ministry of Petroleum and Natural Gas (MoP&NG), has, since 2004, been funding the R&D of hydrogen storage, gas-refuelling stations and hydrogen fuel cell vehicles in India through its Hydrogen Corpus Fund.††

But in the last 15 years since its inception, the initial corpus of Rs. 100 crores has not grown. Only Rs. 28.42 crores from it was utilised by eight projects (as of 3 January 2018). The parliamentary committee has observed that the nodal institution, Centre for High Technology of the MoP&NG, which is managing this fund, has not commenced serious activities pertaining to hydrogen-technology projects.

The Ministry of New and Renewable Energy (MoN&RE) has been working on its own National Hydrogen Energy Roadmap since February 2004.[24] Notwithstanding its impressive name, the roadmap managed to attain only incremental R&D targets mostly for the automotive industry.‡‡

This paper recommends that the Indian public and private sector together proactively prepare a comprehensive national strategy on hydrogen energy in sync with the Indian government. Only an industry-led, innovation-first model can break the R&D of hydrogen technologies away from the under-performing silos, stagnating with the MoP&NG and MoN&RE.

### 4.2. Hydrogenise India's Transportation Sector Using National Megaprojects

Although the MoP&NG and MoN&RE are important entities, they can only facilitate the upstream R&D of hydrogen technologies. The Ministry of Railways (MoR) and the Ministry of Road Transport and Highways (MoRT&H), which can frame and implement downstream policies for a hydrogen-enabled transportation sector, are yet to intervene.


*Image 5: Hydrogen is the cleanest of chemical fuels and is an alternative to electric mobility. Photo credit: Department of Energy, USA*

In 2018, the MoRT&H began the Bharatmala Pariyojana under which it is constructing and upgrading nearly 84,000 km of new roads, highways and expressways.[25][26] The MoRT&H must initiate a spin-off, called HyBharatmala Pariyojana, with the goal of boosting the installation of hydrogen storage and refuelling infrastructure§ § along the vast stretches of the highways and expressways, constructed under the Bharatmala scheme.

HyBharatmala has the potential to stimulate H-CNG and hydrogen gas production in the country, make India a greenfield market for hydrogen technologies, including hydrogen-powered vehicles, and drastically reduce GHG emissions from road transportation.

The Indian Railways is targeting total electrification of India's broad-gauge rail network by the year 2022.[27] Currently, most of its non-electrified rail routes, including the narrow-gauge and metre-gauge, are operated by steam- and diesel-powered locomotives. There is immense potential for converting these non-electrified railway routes into hydrogen-powered ones.

The MoR must initiate the Hydrogen Indian Railways *(HINDRail)* megaproject, which can enable the construction of hydrogen storage and fuelling infrastructure and running of hydrogen-powered locomotives on regional and inter-city routes.

The Indian Railways Organisation for Alternate Fuels is currently testing a hydrogen fuel cell-based hybrid locomotive, which it claims is the most powerful and heaviest locomotive of its kind.[28] To kickstart *HINDRail,* the Indian Railways can swiftly commercialise this prototype and allow it to compete with international rail manufacturers, like Siemens-Alstom, which has begun to operate hydrogen-powered passenger trains on a short-haul route in Germany since September 2018.[29]

*HINDRail* will be a game-changer project. It will eliminate the use of electrification apparatus, can be rapidly operationalised and is much cleaner than electrified rail, which will continue to be largely generated through India's GHG-emitting, coal-fired power stations for the considerable future.

### 4.3. Establish a Cross-Sectoral National Coalition – Hydrogen India

Many Indian associations promoting hydrogen technologies – particularly the Hydrogen Association of India and the Indian Association for Hydrogen Energy and Advanced Materials – have pursued siloed and stagnating approaches. In existence for almost a decade, these groups have yet to:

1. utilise and channelise the residual funds from the Hydrogen Corpus Fund for R&D, expand the corpus and undertake new market-relevant R&D of hydrogen technologies;
2. make hydrogen transportation compete with the now preferred electric transportation; and
3. successfully market the developed hydrogen technologies the way the national coalitions in the United States and Germany have.

The Mahindra Group can lead by forming a market-driven, national, cross-sectoral, industrial coalition called Hydrogen India – an Indian equivalent of the Clean Energy Partnership.



Hydrogen India can collaborate with the government on the feasibly ambitious *HINDRail* and *HyBharatmala* megaprojects and thereby assist in the achievement of national goals, carve out futuristic business interests and stay at the cutting-edge of technology. Many of the Mahindra Group's technologies, particularly the Tech Mahindra-developed rail software and hardware,[30] and the Mahindra & Mahindra-developed fuel cell automotive technologies,[31] will find a large market through these two proposed megaprojects.

This coalition must include oil and gas, speciality chemicals, industrial gas, advanced materials, automotive and rail manufacturing companies, originating and based in India. It can also include think tanks, private R&D laboratories and venture investors, focusing on hardware and software innovations and policy.

### 4.4. Plug Hydrogen India into Global Hydrogen Coalitions

In 2016, the MoN&RE presented a draft report on hydrogen energy and fuel cells. Though the report offers detailed technical recommendations which are incrementally important, it does not offer India Inc. the national vision and a larger global preparedness strategy for the impending global hydrogen economy.[32]

Where Hydrogen India can catalyse the hydrogen economy in India, it should also be made to partake in global hydrogen coalitions, like the Hydrogen Council. Through this involvement, New Delhi can:

1. make strategic overseas investments and export hydrogen fuel generation systems, storage infrastructure, gas-filling stations and hydrogen-powered transport systems, to different regions of the developing world, particularly South-East Asia, Central Asia, Africa and South America; and
2. attain competence to represent India on a metastrategic high-table – one formed on the lines of the Oil & Petroleum Exporting Countries (OPEC) – for the hydrogen economy as soon as possible.

### 4.5. A Public-Private Carbon Capture Technology Development Fund

Several ministries of the Government of India [Image 6.] and public and private companies have analysed and developed their own plans to sequester GHG in sectors in which they are involved. In the absence of a comprehensive and all-encompassing national vision for capturing GHG, their efforts are too narrow and do not meet the necessary sustainable climate action goals. To overcome this, the ministries and the public-private sector companies together can raise a Carbon Capture Technology Development Fund under the Government of India's flagship Make in India programme.

The fund can:

1. finance development of carbon capture technologies – from near maturity to complete maturity levels when the product is ready to enter the market;
2. import substitution of components that have never been manufactured in India and are available to Indian industry at steep import costs;
3. invent novel components and technologies that generate intellectual property within India.

Government of India ministries segregated as per GHG-emitting activities

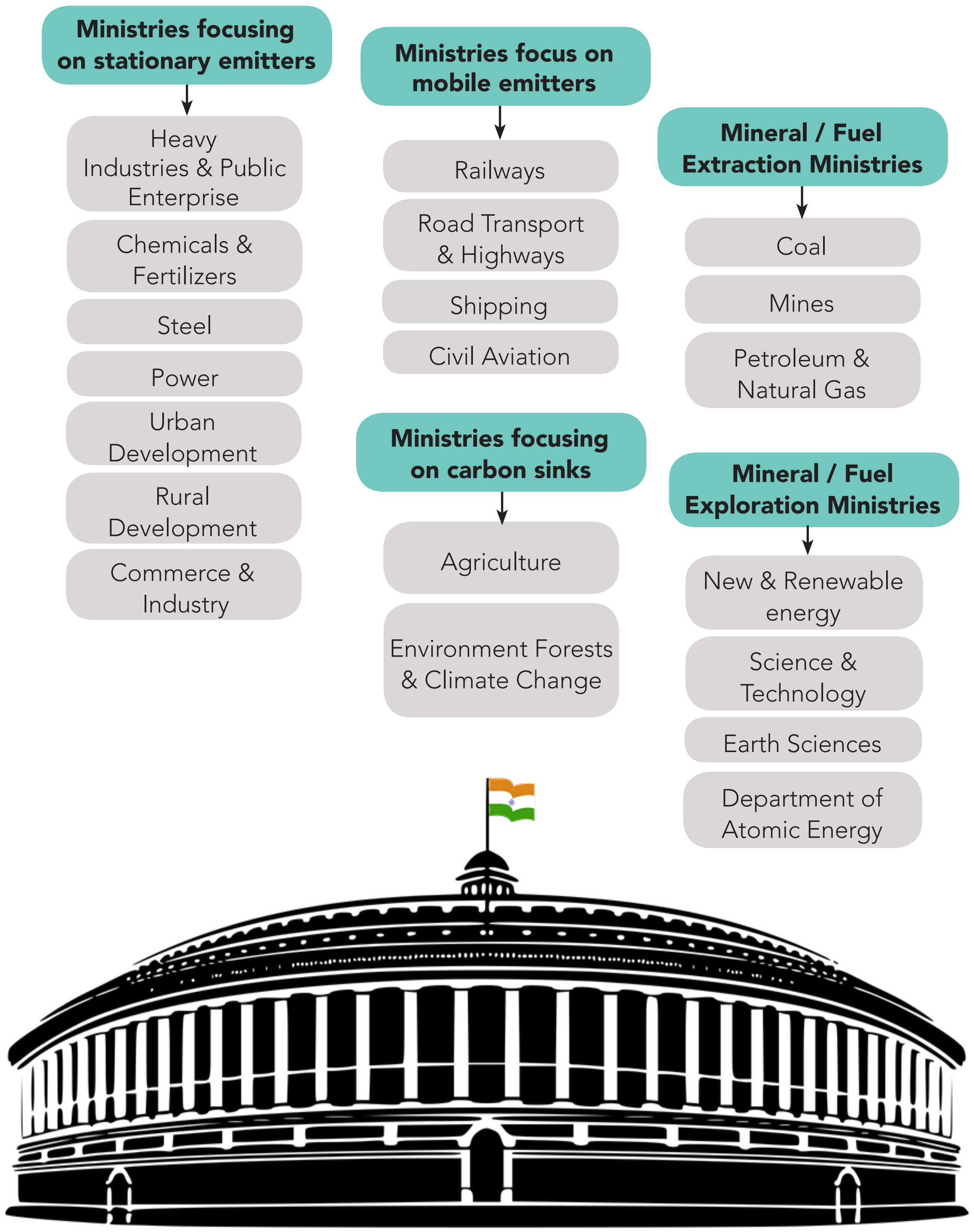



*Image 6: The Government of India has invested in reduction of atmospheric GHG emissions in the economic activities they administer. Image credit: Gateway House*



## Conclusion

India Inc. should recognise climate change mitigation technologies as a big 'business opportunity' and a rare prospect for positioning itself ahead of the global innovation curve. It must, intramurally, within its own research laboratories, as well as extramurally, i.e. in universities and independent research institutions, fund and support research, development, testing and evaluation of carbon capture, methane cracking and hydrogen fuel cell science and technologies. Only a home-grown invention and innovation ecosystem can assist the Indian government in shaping domestic policies and securing the national interest when global policies on GHG removal and the methane economy are being formulated.

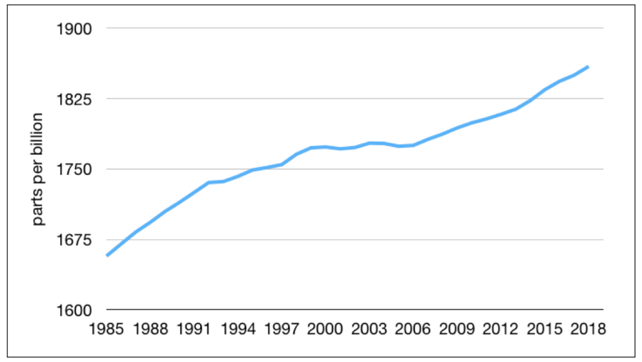
If India's socio-economic growth is to be environmentally efficient and more technologically innovative than that of China and the United States, then alongside the use of clean energy technologies and increasing forest cover, it must, without delay, avail of the business opportunity that major global corporations and nations are about to tap.

Hydrogenising the transportation sector and using new and efficient processes to form carbon materials will be among the key areas for India's transformation into a $5-trillion-dollar economy by 2030. Methane, as this paper has discussed, is an untapped resource with which to meet these two strategic demands and promote India's growth into an environmentally efficient global economic powerhouse.

## 6. Annexures

### Annexure 6.1. Reversing the Rise of Atmospheric Methane Emissions

The global atmospheric monthly mean methane concentration has shown a steady rise from approximately 1620 parts per billion (ppb) in 1983 to 1867 ppb in 2018. [Annexure Fig. 1] This rise is due to increased land-use change; growing extraction and consumption of fossil fuels; and urban processes, such as expanding landfills, waste water treatment and agricultural biomass. The rising methane levels are caused directly by anthropogenic activities, while increasing global average temperature is causing methane emissions from the permafrost in the Russian, Scandinavian and North American Arctic.




*Annexure Fig. 1: Increasing atmospheric methane concentration from 1620 ppb in 1985 to 1867.2 ppb in 2018. Photo Credit:* E. Dlugokencky, National Oceanic & Atmospheric Administration.[A1]

Many GHG-emitting countries are decarbonising their coal-based energy sector and those abundant with coal are making its extraction cleaner and environmentally efficient. China, India's closest economic competitor, has yoked its economy to natural gas, moving away from coal. China's coal consumption peaked in 2013 and has been declining ever since. Besides its thrust on solar, wind and nuclear energy, China's shift to natural gas has yielded it enormous dividends. In 2018, China's rate of decarbonisation was 5.2%, the highest among all the G20 nations and in the world. India ranked ninth in the decarbonisation index with a rate of 2.5%. By transitioning to the cleaner hydrocarbon, China has reduced its carbon intensity (tonnes of carbon dioxide per million dollars of Gross Domestic Product) by a massive 41% since 2008.[A2]

Beijing's shift towards cleaner fuels is likely to increase its economic productivity, reduce chronic pollution issues, consolidate energy security, allow it to attain heft in the enormous clean energy and transportation market, and thereby strengthen its stake while framing global climate policies. Despite China's success with decarbonisation, it has not reduced its methane emissions because the rate of decarbonisation factors in only carbon dioxide, and not methane and other GHGs. And here, Indian climate policy-makers have lessons to learn.

India is currently the world's second largest methane emitter behind China. Its enormous ruminant population — the largest in the world — and cultivation of 20% of the total global rice produced, contribute heavily to these emissions.[A3] In 2015, China's methane emissions stood at 61.5 ± 2.7 teragram, making it the world's largest emitter of methane,[A4] followed by India's average emissions of about 22 teragram annually between 2010 and 2015.[A3] In the same five-year period, China's methane emissions, despite its success with decarbonisation, were found to grow largely due to coal mining. Whereas India's



comparatively lower emissions showed little growth and originated mostly from ruminant animals, rural-urban waste, rice paddy and its coal-based energy sector.

### Annexure 6.2. Not all Greenhouse Gases are Carbonaceous: GHG-Specific Mitigation Strategies Needed

The Earth's greenhouse effect is mostly contributed by water vapour. Among the other atmospheric GHGs, at 72%, carbon dioxide is the most abundant; methane follows at 19%, nitrous oxide at 6%, and halogenated gases (hydrofluorocarbons [HFCs], perfluorocarbons [PFCs], nitrogen trifluoride [$NF_3$] and sulphur hexafluoride [$SF_6$]) at 3%.[A5] The removal of all anthropogenic GHGs [see Table 1] from the atmosphere is important, but there is a need for having specific mitigation strategies for each GHG. The reasons to pursue GHG-specific mitigation strategies are as follows:

While decarbonisation may be useful as a rallying cry for the nonce, it is only a subset of long-ongoing larger initiatives for reducing GHG emissions. It terminologically tends to neglect the mitigation of non-carbonaceous GHGs. This one-sided focus impedes the taking of strong mitigatory action against other more potent non-carbonaceous GHGs, such as $N_2O$, $SF_6$ and $NF_3$.

For example, nitrous oxide ($N_2O$) is a more potent GHG than methane and carbon dioxide. Its global warming potential extends over 100 years — almost 300 times that of carbon dioxide. $N_2O$ serves as a medical anaesthetic and analgesic, is used in internal combustion engines and as rocket propellant; but its highest emissions come from agricultural activities, urban waste and sewage.[A6]

Manufacture of semiconductors, liquid crystal display panels, certain types of solar panels and chemical lasers, contribute most of the nitrogen trifluoride ($NF_3$) emissions.[A7] Sulphur hexafluoride ($SF_6$) is used as a dielectric medium in the electrical industry, in high-voltage particle accelerators, microwave systems, electron microscopes – for eye surgeries – and as a tracer gas in air pollution studies.[A8]

### Annexure 6.3. Most Greenhouse Gases Already Regulated by the United Nations

All known chlorofluorocarbons (CFCs) and hydrogenated chlorofluorocarbons (HCFCs) are regulated by the Vienna Convention for the Protection of the Ozone Layer. These GHGs have been regulated mostly for their potential to damage the ozone layer in the Earth's atmosphere along with their ultra-long lifetime in the atmosphere than for their global warming potential. The other GHGs do not demonstrate properties detrimental to the ozone layer; a large fraction of them are of natural origin, and hence cannot be regulated by a strong Vienna Convention-like regulatory mechanism.

Indian policy-makers and industry should therefore avoid falling into the narrative trap of assuming decarbonisation is equivalent to the removal of GHGs. To fulfil its Paris Agreement commitments, India needs to devise specific mitigation, adaptation and sequestration plans for each of the GHGs.

India has recently increased its thrust on renewables and is gaining leadership in global energy mega projects, such as the International Solar Alliance.[A9] It also has increased its forest cover by 1%, which has helped reduce its carbon intensity.[A10] Despite these gains, India is yet to rise from its current ninth rank in the decarbonisation index.[A11] It is impossible to reduce atmospheric methane emissions by solely focusing on mitigation of carbon dioxide and fluorinated GHGs. This paper therefore recommends a specific strategy for methane.

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† The 2016 White House vision document lays down the U.S. strategy for deep decarbonisation till the middle of the 21st century. It prioritises implementation of a low-carbon energy system, sequestering carbon through forests and soil and by carbon dioxide removal technologies, and reducing emissions of other potent GHGs, such as methane and hydrofluorocarbons.[F1]The European Commission (EC) has called for a 'Marshall Plan for Climate Readiness' to attain net zero greenhouse gas emissions by 2050.[F2] The EC plans to spend approximately €16 billion on climate-related research and innovation activities. This funding will sustain research and innovation across industries, scientific academia, humanities, and through mission-oriented cross-disciplinary programmes.[F3]

‡ Paragraph 1 of Article 4 of the Paris Agreement states, "In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty."

§ The U.N. first began to phase out carbonaceous halogenated GHGs—particularly, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)—under the 1989 Montreal Protocol on Substances that Deplete the Ozone Layer.[F4] They were phased out, not for their global warming potential, but because they severely damaged the ozone layer of the Earth's atmosphere. The recent U.N. Kigali Amendment, which came into effect from 1 January 2019, is the newest of the eight successors to the Montreal Protocol. With this amendment, the U.N. aims to phase out the production and consumption of HCFCs, known for their high global warming potential.[F5] The reduction of HCFC emissions by 85% until 2047 is expected to prevent the global average surface temperature from rising by 0.4 °C by 2100.[F5, F6]

** Direct air capture involves sequestration of GHG from ambient atmospheric air via absorption, adsorption (adhesion of atoms from a gas) or mineralisation processes. This process is different from carbon capture equipment which is fitted on industrial chimneys and exhausts from which GHGs and the flue gas are captured, and the cleansed air is released.[F7] Direct air capture technology did not find favour in the past. Its pain points were low sequestration efficiency and high costs. In 2010, a Massachusetts Institute of Technology and Stanford University study had estimated the cost of direct air capture at about $1000 per metric tonne of carbon dioxide.[F8] It has dropped to $94 per metric tonne in 2018. Similarly, present-day direct air capture technology has an efficiency of around 62%,[F9] which will only improve hereafter.

† † The Hydrogen Corpus Fund is built with contributions from the Oil Industrial Development Board of the Ministry of Petroleum and Natural Gas (Rs. 40 crore), the Indian Oil Corporation, Oil & Natural Gas Corporation, and GAIL India Limited (Rs. 16 crore each); and from Hindustan Petroleum Corporation Limited and Bharat Petroleum Corporation Limited (Rs. 6 crore each).[F10]

‡ ‡ In 2011, Mahindra & Mahindra, along with the Indian Oil Corporation and the Society of Indian Automobile Manufacturers (SIAM), tested hydrogen-blended compressed natural gas (H-CNG) on its Bolero sports utility vehicle and the Champion three-wheeler. Following the tests, the fuel consumption of H-CNG and the carbon monoxide emissions were found to be lower than the conventional CNG engine. However, the emission of oxides of nitrogen (NOx) was found to be unexpectedly high. [F11] The SIAM, including M&M, were unable to use the Hydrogen Corpus Fund to undertake incremental, but important, R&D of H-CNG and hydrogen fuel cell vehicles.

§ § The Indian Oil Corporation, in collaboration with the U.S.-based company, Air Products, is successfully operating hydrogen-blended compressed natural gas (H-CNG) refilling stations at Faridabad, Haryana and Dwarka, New Delhi.[F12]

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