Centre for International
Governance Innovation

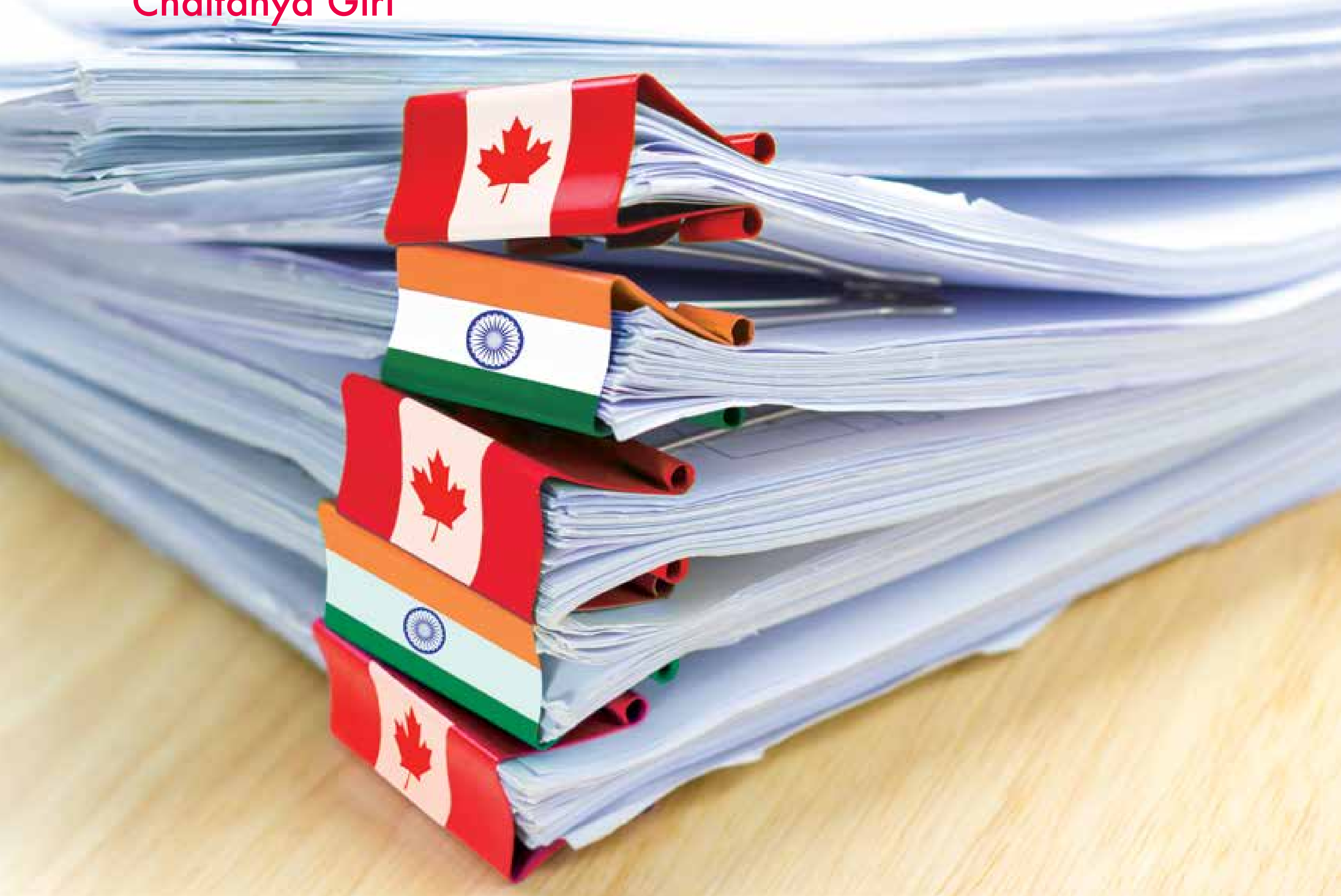
GATEWAY HOUSE
INDIAN COUNCIL ON GLOBAL RELATIONS
भारतीय वैश्विक संबंध परिषद्

Canada-India Track 1.5 Dialogue Paper No. 3

Making Terrestrial Geoengineering Technologies Viable

An Opportunity for India-Canada Climate Leadership

Chaitanya Giri



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About the Author

Chaitanya Giri is a fellow for Space and Ocean Studies at Gateway House: Indian Council for Global Relations, Mumbai, India. His present research interests include aquapolitics and astropolitics, the new-age techno-geostrategy, the space and marine industrial complex and the science of space exploration. Chaitanya has worked as a planetary scientist for nearly a decade. He has been affiliated with the Earth-Life Science Institute at the Tokyo Institute of Technology, the Carnegie Institution for Science and the NASA Goddard Space Flight Center. He was a doctoral fellow at the Max Planck Institute for Solar System Research in Germany and the University of Nice in France. Chaitanya was a scientific crew member of the European Space Agency's Rosetta mission to comet 67P/Churyumov-Gerasimenko. He is a recipient of the 2014 Dieter Rampacher Prize of the Max Planck Society, Germany, and the 2016–2018 ELSI Origins Network Fellowship by the John Templeton Foundation in the United States.

About the Project

The Canada-India Track 1.5 Dialogue on Innovation, Growth and Prosperity is a three-year initiative between CIGI and Gateway House: Indian Council on Global Relations, to explore areas for closer cooperation. Experts, government officials and business leaders will convene annually to promote bilateral economic growth and innovation in today's digital economy.

Canada and India maintain strong bilateral relations built on the foundation of shared values and healthy economic ties. Economic exchanges between Canada and India are on an upward trajectory, but there continue to be unexplored areas for mutually beneficial growth, especially in light of rapid developments in technology that are changing every facet of the economy and society in both countries. To address these challenges, the partnership is helping to develop policy recommendations to promote innovation and navigate shared governance issues that are integral to the continued growth of Canada-India bilateral relations.

The Canada-India Track 1.5 Dialogue on Innovation, Growth and Prosperity strives to build closer ties between Canada and India and nurture the relationship to its full potential. Canada and India can be global leaders in innovation, and the Canada-India Track 1.5 Dialogue seeks opportunities to work jointly on multilateral issues and identify areas where improved cooperation could benefit both countries.

In addition to its focus on innovation, the partnership examines topics such as collaboration on research and higher education, promotion of Canada-India trade and investment, energy cooperation and issues pertaining to global governance.

Through this partnership, Canada and India can be intellectual partners and cooperate in the design of their global governance frameworks.

Executive Summary

The UN's Paris Agreement is best known as the commitment by nations to reduce greenhouse gas emissions to slow the rise in global temperatures. But less-heralded provisions of the pact go further than that. In an acknowledgment that emissions-reduction alone will not resolve the unfolding climate crisis, a call has been made for the development of carbon sinks to remove gases already in the atmosphere. These less-heralded greenhouse gas removal technologies are essential to achieving the pact's goal of keeping the global average surface temperature from rising more than the 1.5 degrees Celsius. These steps are also a key to ensuring that India and Canada meet their ambitious climate-action goals without suffering severe socio-economic and climatic harm.

Greenhouse gas removal, a form of terrestrial geoengineering, stands in sharp contrast to atmospheric climate engineering, which seeks to slow global warming by altering local weather patterns. Atmospheric climate engineering does not remove greenhouse gases produced by human behaviour — the root cause of the rising average global surface temperature. Moreover, its unchecked application would pose uncertain but potentially grave planetary hazards.

Considering all the options, India and Canada must focus on utilizing the immense potential of terrestrial geoengineering while pushing for global regulations on atmospheric climate engineering.

Paris Agreement: Its Success Will Require Atmospheric Greenhouse Gas Removal

Anthropogenic, or man-made, climate change poses one of the most pronounced and complex challenges to global governance and security in the twenty-first century. Numerous policy frameworks have been developed to avert the crisis by slowing the growth in greenhouse gas emissions and ultimately capping them. Technical challenges and socio-economic realities make it unlikely that limiting emissions alone will halt, let alone reverse, the trend toward global warming. Actual removal of excessive carbon from the atmosphere must be part of a global climate-change strategy.

The 2015 Paris Agreement, an extension of the United Nations Framework Convention on Climate Change (UNFCCC) (UN 2015), acknowledges this. In a policy departure, paragraphs 1 and 13 of article 4 of the agreement commit signatory countries for the first time to use carbon sinks — natural reservoirs of carbon, such as forests, soil, oceans and new, carbon-capture technologies — to meet the agreement's goal of limiting the rise in global surface temperatures to less than 1.5 degrees Celsius.

Paragraph 1 of article 4 states that "countries must undertake rapid reductions...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..." (emphasis added).[1]

Frequent use of the terms "science," "sink" and "removal" in the agreement represents an acknowledgement of the limitations of clean-energy technologies as the lone mechanism for realizing climate goals. The science of removing already emitted anthropogenic greenhouse gases from the

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[1] 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."

atmosphere must be a cornerstone for decelerating the rise of the average global surface temperature and eventually returning it to natural levels.

"Decarbonization" is Misleading Policy Jargon

Policy makers, governments and large conglomerates have started using terms such as "decarbonization," "deep decarbonization" and "carbon neutrality" to describe the goal of reducing greenhouse gas emissions. Such terms may serve as rallying cries for a gallant cause, but they are misleading because they imply that carbon is a hazardous element to be given good riddance.

In reality, elemental carbon is anything but that. Carbon-containing greenhouse gases emitted by natural terrestrial and atmospheric processes have long produced a beneficial effect: they maintain average global surface temperatures at levels suitable for life to survive and thrive on Earth (Schwartzman and Volk 1989). The importance of carbon extends even beyond that. All life on Earth consists of carbon-based elements, and most organisms emit small volumes of greenhouse gases. Moreover, several climatic processes unrelated to global average temperatures involve natural feedback from terrestrial and atmospheric greenhouses gases that are not yet fully understood. This suggests that any attempt at absolute decarbonization or carbon neutrality, if pursued literally, could prove to be misguided or even harmful (Kungl and Geels 2018).

Of course, terms such as decarbonization and carbon neutrality are used to describe laudable sectoral policies to prevent harmful anthropogenic climate change. This objective will be difficult to realize relying on just the policies the terms are used to justify. Solar, wind and other renewable and clean-energy technologies — currently the focus of most national climate-change policies — are not likely to do the job alone, considering the overwhelming human dependence on fossil fuels, such as coal, natural gas and oil, which currently constitute 80 percent of total global primary energy consumption. Clean-energy technologies, however promising, raise their own environmental problems (Arutyunov and Lisichkin 2017). Specifically:

→ Large solar energy projects require enormous swathes of land for photovoltaic farms. In addition, research shows that current-generation photovoltaic farms generate strong heat islands, in particular in arid landscapes, where these farms are often situated. The localized ambient temperatures above the farms are found to be higher by three to four degrees Celsius than the unaltered arid landscapes. Such heat islands can affect the localized climatic patterns, altering natural environments at levels that have been unquantified until now (Barron-Gafford et al. 2016).

→ Current generation wind energy farms kill large numbers of birds. They also cause air turbulence that can interfere with regional weather patterns (Dai et al. 2015).

Further research and development (R&D), along with the advancement of existing technologies, eventually may address obstacles to large-scale deployment of photovoltaics and wind turbines. In the meantime, the world will continue to depend as much or more on fossil fuels as it does today. This is especially true for India, where industrialization is occurring rapidly, and for Canada, where there are abundant fossil fuel reserves. Their future depends not only on clean-energy technologies that can minimize greenhouse gas emissions, but on new technologies to capture and remove excessive amounts of these gases already in the atmosphere.

Incentivizing Carbon Sequestration

Carbon removal has another significant benefit — it produces a valuable commodity. Synthetic carbon materials are becoming increasingly pivotal to the global economy and technology landscape. The worldwide market for carbon composites, graphite, carbon nanotubes, carbon foams, carbon fibres, diamonds, graphene and carbonates will grow from approximately US$35 billion in 2018 to US$1 trillion by 2030. Carbon-based materials are becoming the backbone of industries that produce speciality chemicals, aerospace hardware, automobiles, semiconductors, electronics and several other types of civilian and military advanced manufactured goods.

For instance, graphene is a promising carbon material that has potential use in several innovative applications, including flexible — bendable, twistable and stretchable — electronics and next-generation semiconductors. Recognizing its potential, the European Commission has invested €1 billion in Europe's largest-ever research project, the Graphene Flagship, in hopes of achieving a lasting lead in the field (European Commission 2017). China also has entered the graphene contest; its domestic market is projected to exceed US$200 million by 2020 (Jiang 2017).

Currently, most carbon materials are either sourced from natural fossil fuels or synthesized in laboratories through power-intensive processes. Neither of these methods allow for large-scale commercialization of carbon materials nor the technical and economic benefits they could produce. Tapping atmospheric greenhouse gases could be the answer. That, in turn, requires identifying potential benefits and designing incentives to spur research leading to development of improved techniques for capturing and turning these gases into a major tradeable commodity for the synthetic carbon materials market.

Terrestrial Geoengineering versus Climate Engineering

Carbon removal, a form of terrestrial geoengineering, is distinctly different, and superior, to atmospheric climate engineering as a means of modifying Earth's climate system to undo the adverse effects of anthropogenic climate change.

Atmospheric climate engineering involves techniques undertaken in the atmosphere including stratospheric aerosol injection, cirrus cloud thinning, marine cloud brightening, cloud seeding and artificial precipitation. None of these techniques directly sequester atmospheric greenhouse gases, so they address neither the underlying source of today's problems nor the immediate climate goals laid down in the Paris Agreement.

What is more, they involve substantial risks of misuse or unintended consequences. For instance, countries in south Asia, in particular, India, Bangladesh, Nepal and Bhutan, depend heavily on rivers originating in the Himalayas and in Tibet. The region is also home to the densest human population on the planet. Any cloud seeding or weather modification pursued there, without adequate prior research and full consent, could severely affect populations in the lower riparian regions. In fact, cloud seeding in Tibet could lead to cataclysms more severe than those caused by the deadly 2010 Ladakh flash floods and the 2013 Uttarakhand flash floods (Kotal, Sen Roy and Bhowmik 2014). Nations that conduct atmospheric climate engineering, despite the knowledge of negative consequences to vulnerable nations, must be identified and called out for pursuing weather warfare.

Terrestrial geoengineering, in contrast, consists of interventions made on Earth's surface to remove greenhouse gases released into the atmosphere by industries, power plants, automobiles and similar sources. It consists of a variety of carbon capture utilization and storage technologies and better land-use practices.

Some terrestrial geoengineering techniques rely on natural processes. A prime example involves soil organic carbon, a highly carbonaceous component in soil. Since the onset of the Industrial Revolution, improper land use, agricultural practices and deforestation have made soil organic carbon more volatile, contributing approximately 191 gigatons of carbon to the atmosphere. This represents almost 24 percent of total greenhouse gas emissions since 2000 — lower than the 35 percent of contributions from the power sector, but higher than industrial emissions, which are pegged at 21 percent. Despite the enormous losses of soil organic carbon, the top one metre of soil globally is still estimated to contain 2,500 gigatons of carbon, including 1,500 gigatons of soil organic carbon; that is approximately 3.2 times the amount of atmospheric carbon and four times the amount of biomass carbon (Zomer et al. 2017).

The increase in emissions resulting from land-use change can be offset through forestation and sustainable agricultural practices, which will efficiently convert some of the absorbed gaseous

Table 1: Carbon Dioxide Emissions for India, Canada and the World, 2014

Statistics from 2014	INDIA	CANADA	WORLD
Total CO_2 emissions (kiloton)	**2,238,337.18**	537,193.50	36,138,285
CO_2 emissions (metric ton/capita)	1.73	**15.12**	4.97
CO_2 emissions from coal consumption (kiloton)	**1,492,751.36**	75,785.89	15,097,039
CO_2 emissions from petroleum-derived fuel consumption (kiloton)	**514,109.77**	248,318.24	12,027,760
CO_2 emissions from natural gas-derived fuel consumption (kiloton)	92,694.43	**203,283.81**	6,684,941
CO_2 intensity (kilogram per kilogram of oil equivalent energy use)	**2.714**	1.919	2.573
Current Emission Ranking in the World	**4**	10	-

Source: World Bank (2018).
Notes: Higher comparative figures between India and Canada are in bold.
CO_2= carbon dioxide.

carbon from the atmosphere into solidified biomass that eventually becomes soil organic carbon. Identifying the potential of this soil carbon sink, the French, German and Spanish governments in 2015 together introduced the "4 per 1000 Initiative: Soils for Food Security and Climate" during the twenty-first Conference of the Parties in Paris. This project aims to promote certain beneficial agro-ecological practices that can increase organic carbon in the top (30–40 cm) layer of soil by 0.4 percent annually, thereby sequestering 3.5 gigatons of atmospheric carbon.[2]

This natural carbon-capture utilization and storage practice is feasible all around the world. Besides, increasing soil organic carbon will restore soil fertility, ecological resilience and groundwater reserves, thereby enhancing agricultural yield.

Technology-driven carbon capture utilization and storage are distinct from such natural practices. Most such technologies attempt to capture carbon at the source of their emissions through polymer- or metal-organic, framework-based membrane scrubbers. Other technologies, in particular, direct air capture, focus on pulling in ambient air from the atmosphere and allowing it to pass through scrubbing membranes that subsequently release air free of greenhouse gases.

Terrestrial geoengineering technologies are aimed at the power generation and manufacturing industries, such as cement, steel, fertilizer and petroleum, that emit large quantities of greenhouse gases. Generally funded by fossil fuel-intensive extraction and power sectors, these technologies are becoming increasingly more efficient (refer to Tables 2 and 3). They differ from clean-energy technologies, such as solar and wind power, which reduce new emissions of greenhouse gases, but do not remove gases that are in the atmosphere already. Relying on clean energy alone, even if technically feasible, will likely not yield the desired results. In 2017, the global power-generation sector alone emitted a historic high 32.5 gigatons of carbon dioxide into the atmosphere (International Energy Agency 2018). A balanced strategy that utilizes terrestrial geoengineering and clean-energy technologies and practices efficiently would make the job of arresting global warming far less daunting.

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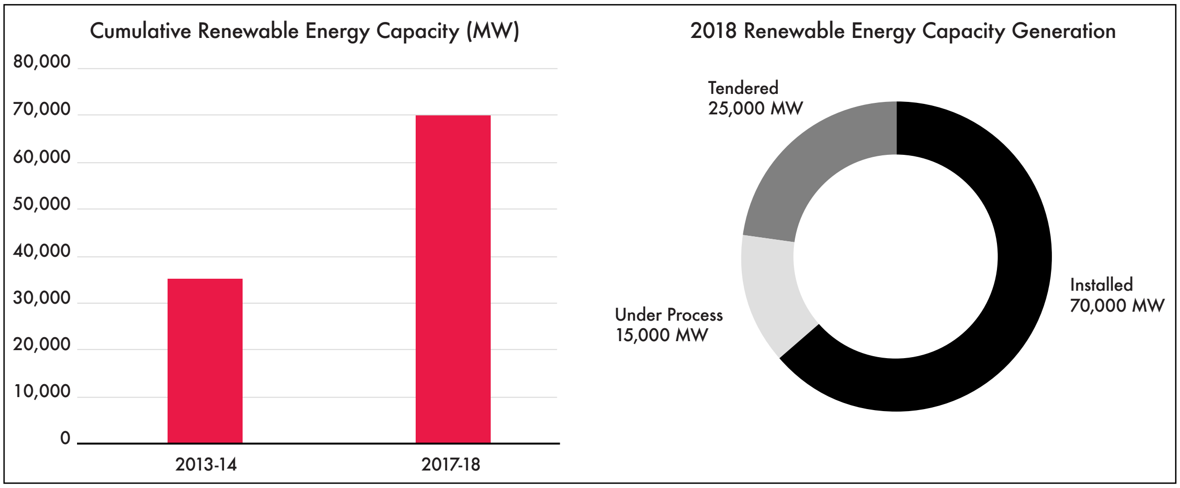
[2] Retrieved from the 4 per 1000 Initiative official website: www.4p1000.org.

Figure 1: India's Current Renewable Energy Capacity, November 2018



Source: India (2018a).

India and Canada: Common and Divergent Interests

As parties to the Paris Agreement, India and Canada have committed themselves to setting national targets for reducing greenhouse gas emissions, increasing national and global resilience to climate change and developing financing mechanisms to achieve these goals. Both countries are parliamentary democracies and the actual socio-economic environmental policies they choose to pursue to achieve these goals will depend on their individual circumstances.

India is a newly industrializing country, whereas Canada has been industrialized since before World War II. India has a massive, geographically condensed and growing middle-income population, while Canada has a sparse, but high-income population with growing standards of living. Both countries have a strong stake in fossil fuel development; India as a major fossil fuel importer (Jadhao, Pandit and Bakshi 2017) and Canada as an energy superpower with large fossil-fuel reserves (refer to Table 1) (Hester 2007). The approach and extent to which each can add carbon capture and its use in manufacturing to their economic and environmental strategies depends on the natural availability of carbon-based resources, their share as commodities in the nation's export-import portfolios and domestic consumption.

A closer look at convergences and divergences between the two countries' respective contributions to meeting the Paris Agreement objectives follows.

India's Commitments and Realities

India, which is eager to achieve sustained, high economic growth over the coming decades, is on a path to become a major energy consumer. For the foreseeable future, the country is certain to continue to depend on hydrocarbon imports, most of which come from geopolitically volatile west Asia. India, however, also aims to be an environmentally conscious country. In particular, India intends to reduce the emission intensity (amount of emissions per unit of output) of its GDP by 33 to 35 percent by 2030 from 2005 levels; to create an additional carbon sink of 2.5–3.0 billion tonnes of carbon dioxide equivalent by 2030 (United Nations n.d.) through forestation; and to become a global leader in the development of clean and renewable energy technologies, as demonstrated by its intention to be the leader of the International Solar Alliance with France.

On the clean-energy front, the country has pledged to generate a massive 172 gigawatts (GW) of clean energy by 2022, and in this pursuit the Indian government has recently built some of the largest wind and solar farms in the world. Since 2014, India's cumulative renewable energy capacity has almost doubled from 35,000 megawatts (MW) to more than 70,000 MW in 2018. As of

Table 2: Terrestrial Geoengineering and Atmospheric Climate Engineering Projects of Indian Origin

Project	Indian Agencies/Firms Involved	Project Type	Status
LOHA Fertilization Experiment	Council on Scientific and Industrial Research and Department of Space (India) and national scientific agencies from Chile, France, Germany, Italy, Spain and United Kingdom	Ocean fertilization, carbon capture and storage, R&D	Completed
Gujarat Rainfall Enhancement Project	Government of Gujarat	Weather modification, increased precipitation	Completed
Andhra Pradesh Cloud Seeding Program	Government of Andhra Pradesh	Weather modification, increased precipitation	Completed
Karnataka Cloud Seeding Program	Government of Karnataka	Weather modification, increased precipitation	Completed
Maharashtra Rainfall Enhancement Project	Government of Maharashtra	Weather modification, increased precipitation	Completed
Afforestation and Development Project	Ministry of Environment, Forest and Climate Change (India) and Japan International Cooperation Agency (Japan)	Carbon capture, afforestation	Completed
Carbon Capture Innovation Challenge	Department of Science and Technology, Department of Biotechnology, Government of India	Carbon capture and use, R&D	Ongoing
Canada's Oil Sands Innovation Alliance's (COSIA) Carbon X-Prize	Breathe Sciences Private Limited; Jawaharlal Nehru Centre for Advanced Scientific Research, X-Prize Foundation; NRG Energy Inc.	Carbon capture and use, R&D	Ongoing
Aonla Urea Manufacturing Plant	IFFCO and Mitsubishi Heavy Industries (Japan)	Carbon capture and use, commercial	Ongoing
Jagdishpur Urea Manufacturing Plant	Indo-Gulf Fertilizers — Aditya Birla Group	Carbon capture and use, commercial	Ongoing
Phulpur Urea Manufacturing Plant	IFFCO and Mitsubishi Heavy Industries (Japan)	Carbon capture and use, commercial	Ongoing
Kakinada Urea Manufacturing Plant	Nagarjuna Fertilizers and Chemicals Limited and Mitsubishi Heavy Industries (Japan)	Carbon capture and use, commercial	Ongoing
Cloud Aerosol Interaction and Precipitation Enhancement Experiment	Ministry of Earth Sciences, Government of India	Weather modification, increased precipitation, R&D	Ongoing
National Institute of Ocean Technology Ocean CO_2 Sequestration	Ministry of Earth Sciences, Government of India	Ocean fertilization, carbon capture and storage, R&D	Ongoing
Panipat Oil Refinery	LanzaTech Inc. (US) and Indian Oil Corporation	Carbon capture and use, commercial	Ongoing

Project	Indian Agencies/Firms Involved	Project Type	Status
Tuticorin Soda-Ash Plant	Tuticorin Alkali Chemicals and Fertilisers Limited and Carbon Clean Solutions	Carbon capture and use, commercial	Ongoing
Joint Venture — Industrial Re-use and Large-Scale Carbon Capture projects	Carbon Clean Solutions and Veolia (France)	Carbon capture and use, commercial	Ongoing

Source: Gateway House Research.

November 2018, almost 40,000 MW of renewable energy projects are under installation and in the tendering phase (refer to Figure 1) (India 2018a).

However, New Delhi cannot rely on clean-energy technologies alone to meet its climate commitments. The country already has begun terrestrial geoengineering efforts through forestation and development of urban greens. These are the major components of the Draft National Forest Policy, 2018, which was formulated by the Ministry of Environment, Forest and Climate Change (India 2018b).[3]

India's industrial sector has begun to reduce its carbon footprint through technology-driven terrestrial engineering (refer to Table 2). Fertilizer plants, built by the Indian Farmers Fertiliser Cooperative Limited (IFFCO) at Phulpur and Aonla in Uttar Pradesh, are equipped with two of the largest carbon capture capacities in the world; they can capture more than 100 kilotons of carbon dioxide per year. Both plants use carbon capture and removal equipment developed by Mitsubishi Heavy Industries of Japan (Kamijo 2015). The Aditya Birla Nuvo's urea plant in Jagdishpur, Uttar Pradesh, one of the two most energy-efficient plants in the nation, is consistently reducing carbon dioxide emissions by 30 percent through adaptation of the best available technologies (Aditya Birla Group Chemical Fertilizers Insulators 2017).

India's flagship state-owned oil and gas corporation, Indian Oil, recently collaborated with the US-based carbon capture company, LanzaTech Inc., to build the world's first facility that converts gas produced as a by-product of oil refining ("off-gas") into bioethanol. This carbon capture and utilization is expected to reduce greenhouse gas emissions at Indian Oil's Panipat refinery by more than 70 percent compared to conventional practices (LanzaTech 2017).

Indian start-up companies also are consistently piecing together proprietary carbon capture technologies. Carbon Clean Solutions, a new company that is now scaling up, installed its ultra-modern carbon capture technology at a coal-based thermal power station in Tuticorin, Tamil Nadu; the company estimates that this will curb 60,000 tonnes of carbon dioxide emissions annually by converting them into soda ash, a carbon-based product used in the manufacture of dyes and colouring agents, synthetic detergents and fertilizers. The same company also has forged a partnership with the French resource and utilities management company, Veolia, for blue-skies innovation in greenhouse gas removal (Veolia 2017).

India's multinational conglomerates are not far behind. The Mahindra Group, for example, is the first Indian conglomerate to pledge to attain carbon neutrality by the year 2040.[4] Its emphasis will be on energy efficiency and the use of clean and renewable energy and carbon sinks for residual emissions (Mahindra Group 2018). In a major success, Mahindra's automotive division at Igatpuri in Maharashtra state was recently certified India's first carbon-neutral industrial plant (Mahindra Rise 2018).[5]

These and many other initiatives demonstrate that:

→ India's greenhouse gas-emitting industries are proactively undertaking

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[3] The biennial State of Forest Report (India 2017) mentions that between 2015 and 2017, India's forest cover had increased by 0.94 percent, with the very-dense-forest (a widely upheld carbon sink) having increased by 0.73 percent. India's total forest cover currently is measured at 21.54 percent, whereas India aims to increase its forest cover to 33 percent of its land mass.

[4] The Mahindra Group is a founding member of Gateway House. The analysis in the paper does not endorse or advertise for the group or reflect the official policies of the Mahindra Group.

[5] This certification was performed by Bureau Veritas (India) Private Limited, an international testing, inspection and certification agency.

environmentally compliant practices and reducing their carbon footprint;

- large Indian conglomerates are adopting internal business policies for climate change that are congruent with national policies;
- the increasing importance on carbon capture, along with governmental support, can generate an indigenous industrial ecosystem for terrestrial geoengineering; and in that regard,
- Indian companies are seeking international partnerships and investments in the joint R&D and implementation of carbon capture storage and utilization technologies.

Canada's Commitments and Realities

Canada is the tenth largest greenhouse gas emitter in the world. Canada achieved developed status early in the twentieth century and is an energy superpower as well; its per capita carbon dioxide emissions are among the highest — 15.117 metric tonnes in 2013 — in the world (World Bank 2018) (refer to Table 1). However, Ottawa has committed to reduce the country's greenhouse gas emissions 30 percent below its 2005 levels by 2030 (Canada 2018).

The country has some natural assets that will help achieve that goal. For instance, it is the second-largest forested country in the world, with 38 percent of its land covered by trees (ibid.). There are also large extractable reserves of coal, petroleum, natural gas and oil sands. These fossil fuels are a major part of Canada's domestic consumption and export portfolios, which it will not jeopardize to achieve climate targets.

Numerous carbon-pricing mechanisms have been proposed to balance the country's socio-economic needs and climate targets — in particular in the fossil-fuel-abundant provinces of Alberta, Saskatchewan, Manitoba, Ontario and British Columbia (Delphi Group 2018). In addition to such tax-based, carbon-offset mechanisms, Canadian R&D companies are making tremendous progress developing innovative carbon capture, utilization and storage technologies (refer to Table 3). Some of these have already been installed in coal-based thermal power plants in Saskatchewan (SaskPower 2018), and are scheduled to be installed in the oil sands in Alberta, where they will enable cleaner oil-extraction processes and enhanced oil recovery (Shell Canada 2015). These proprietary technologies will find many takers in industrial sectors not only in Canada but also in India and other countries as well.

Status of India-Canada's energy cooperation

The India-Canada Energy Dialogue, which began in 2013 as a major bilateral initiative, so far has focused largely on Indian investments in Canadian oil and gas exploration and production; hydrocarbon imports from Canada; joint research and the development of clean energy technologies; and civil nuclear cooperation (India 2016). The two countries have not yet collaborated tangibly on developing scientific policies or joint R&D projects involving economically viable and environmentally compliant terrestrial geoengineering technologies.

While Canada is taking big leaps with carbon capture and storage technologies, there has been some public skepticism about the efficacy of such solutions (Levänen and Eloneva 2017; L'Orange Seigo, Dohle and Siegrist 2014). Teaming up with an innovation-driven economy such as India's can assuage these concerns and overcome possible shortcomings while strengthening the scientific and technological communities of the two countries.

Table 3: Terrestrial Geoengineering and Atmospheric Climate Engineering Projects of Canadian Origin

Project	Canadian Agencies/Firms Involved	Project Type	Status
South Swan Hills	Swan Hills Synfuels	Carbon capture and storage, commercial	Completed
Pembina Oil Field	Penn West, Alberta Geological Survey, Universities of Calgary and Alberta	Carbon capture and storage, commercial	Completed
Sub-Arctic Ecosystem Response to Iron Enrichment Study	Institute of Ocean Sciences, University of Laval; national scientific agencies from New Zealand, China and Japan	Ocean fertilization, carbon capture and storage, R&D	Completed
Haida Gwaii Salmon Project	Haida Salmon Restoration Corporation	Ocean fertilization, carbon capture and storage, commercial	Completed
Southern Ocean Iron Release Experiment	McGill University, University of British Columbia; national scientific agencies from Australia, United Kingdom, New Zealand and the United States	Ocean fertilization, carbon capture and storage, R&D	Completed
Alberta Saline Aquifer Project	Petro-Canada, Conoco-Phillips, Schlumberger, Enbridge, Norwest Corporation, Chevron, Shell, Tokyo Gas	Carbon capture and storage, R&D	Completed
Crown-Zellerbach Project	Weather Consultants Inc.	Increased precipitation, weather modification, commercial	Completed
Campbell River Drainage	Weather Consultants Inc., British Columbia Hydro and Power Authority	Increased precipitation, weather modification, commercial	Completed
Snowpack Augmentation Study	Weather Consultants Inc., British Columbia Hydro and Power Authority	Increased precipitation, weather modification, R&D	Completed
Southern Alberta Cloud Seeding Study	Vulcan-Lethbridge area, 1981	Increased precipitation, weather modification, R&D	Completed
Sudbury Cloud Seeding Project	Northern Ontario, 1948	Increased precipitation, weather modification, R&D	Completed
St. Mary's Cement	Pond Technologies Holding Inc., St. Mary's Cement	Carbon capture and use, commercial	Ongoing
Husky Energy Saskatchewan	Husky Energy Inc., CO_2 Solutions, Climate Change and Emissions Management Corporation, Government of Canada, ecoENERGY Innovation Initiative	Carbon capture and use, commercial	Ongoing
Fort Nelson Natural Gas Processing Plant	Spectra Energy	Carbon capture and use, commercial	Ongoing
Zama CO_2 Capture and Storage	Energy and Environment Research Center, University of North Dakota; Apache Canada; US Department of Energy	Carbon capture and storage, commercial	Ongoing

Project	Canadian Agencies/Firms Involved	Project Type	Status
Quest CO_2 Capture and Storage Project	Athabasca Oil Sands Project, Shell Canada, Chevron Canada, Marathon Oil Sands	Carbon capture and storage, commercial	Ongoing
Joffre Viking CO_2 Injection Project	PennWest Exploration and Nova Chemicals	Carbon capture and storage, commercial	Ongoing
Weyburn-Midale CO_2 Injection Project	Cenovus Energy and Apache Canada, Petroleum Technology Research Centre	Carbon capture and storage, commercial	Ongoing
Boundary Dam Coal Power Station	SaskPower; Cenovus Energy	Carbon capture and use, commercial	Ongoing
Valorisation Carbone Québec Project	CO_2 Solutions, Laval University, Hatch, Fondsvert, Government of Québec	Carbon capture and storage, R&D	Ongoing
Shand Carbon Capture Test Facility	SaskPower, Mitsubishi Hitachi Power Systems Ltd	Carbon capture and storage, commercial	Ongoing
Carbon Capture Knowledge Centre	SaskPower, BHP	Carbon capture and storage, R&D	Ongoing
Terra CO_2 Technologies Ltd.	Natural Resources Canada	Carbon capture and storage, commercial	Ongoing
NRG COSIA Carbon X-Prize	Carbon Upcycling Technologies	Carbon capture and storage, commercial	Ongoing
Ingenuity Lab Carbon Solutions	University of Alberta	Carbon capture and storage, commercial	Ongoing
NRG COSIA Carbon X-Prize	Carbicrete	Carbon capture and use, commercial	Ongoing
NRG COSIA Carbon X-Prize	CarbonCure Technologies Inc.	Carbon capture and use, commercial	Ongoing
NRG COSIA Carbon X-Prize	Tandem Technical	Carbon capture and use, commercial	Ongoing
NRG COSIA Carbon X-Prize	Carbon Electrocatalytic Recycling Toronto, University of Toronto, Ontario Centres of Excellence	Carbon capture and use, commercial	Ongoing
Innotech Alberta	Alberta Carbon Conversion Technology Centre, Enmax Corporation, Capital Power Corporation	Carbon capture and storage, commercial	Ongoing
Energy Saving Carbon Capture	Fortis British Columbia, Clean O_2 Carbon Capture Technologies	Carbon capture and storage, commercial	Ongoing
Air to Fuels Technology	Carbon Engineering	Carbon capture and storage, commercial	Ongoing
Canada Oil Sands Innovation Alliance	NRG COSIA Carbon X-Prize	Carbon capture use and storage, commercial	Ongoing
Alberta Hail Suppression Project	Weather Modification Inc., National Research Council Canada, Alberta Research Council, Intact Insurance, Costen Insurance	Reduced precipitation, weather modification, commercial	Ongoing
Alberta Carbon Trunk Line	Enhance Energy, Government of Canada Clean Energy Fund and ecoENERGY Technology Initiative	Carbon capture and storage, commercial	Planned

Project	Canadian Agencies/Firms Involved	Project Type	Status
Pikes Peak South Heavy-Oil Thermal Project	Husky Energy, Inventys	Carbon capture and storage, commercial	Planned
Saint Felicien Pulp Mill CO₂ Utilisation Project	CO2 Solutions, Fibrek General Partnership, Serres Toundra Inc.	Carbon capture use and storage, commercial	Planned
Lake Erie Works Steel Mill	Stelco, Pond Technologies	Carbon capture use, commercial	Planned

Source: Gateway House Research.

Recommendations for Making Geoengineering an Anchor of India-Canada Climate Partnership

Multilateral Cooperation

Collaborate on Developing Domestic Geoengineering Policies

India and Canada are active participants in the United Nations, Group of Twenty and many other multilateral fora. Together, the two countries account for more than 10 percent of the world's planned terrestrial geoengineering projects. A bilateral dialogue on geoengineering policies will enable both countries to build on their climate leadership and experience and to help shape international policies.

Bringing Unethical and Non-Consensual Use of Atmospheric Climate Engineering into Environmental Modification Convention

Some countries — notably the United States during the Vietnam War and, more recently, China in Tibet — have used weather modification (United States 1967; Palmo 2018) without mechanisms to ensure compliance with international norms. To avoid unethical and non-compliant use of such new technologies in the future, India and Canada must jointly advocate monitoring of atmospheric climate engineering through an international safeguards group. The two countries can work on designing protocols for such a body, with some inputs from the International Panel for Climate Change, the UN Office for Disarmament Affairs, the World Meteorological Organization and the Convention on Environmental Impact Assessment in a Transboundary Context (*Espoo Convention*). India and Canada also can push for a review of the UN's Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques with a focus on prohibiting potentially harmful cross-border use of climate engineering.

Bilateral Cooperation

India-Canada Collaboration on Carbon Capture and Utilization Storage Technologies

Canada and India can co-develop carbon capture and utilization storage technologies. This can be undertaken by pooling finances, setting up Indo-Canadian R&D centres in both countries, organizing personnel exchange programs and agreeing to joint ownership and management of innovations and inventions emerging from collaborative R&D.

High-resolution Atmospheric Greenhouse Gas Monitoring through Satellites

Canada's strength lies in developing satellite payloads for monitoring greenhouse gases, while India is a leader in building satellites of diverse dimensions and carrying capacities producing high-resolution and multi-spectral payloads and in launching satellites. In 2016, the countries combined their skills when the Indian space agency, Indian Space Research Organisation, launched a microsatellite, the Greenhouse Gas Satellite-D, which was built by a Canadian R&D consortium to monitor greenhouse gases (Indian Space Research Organization 2016).

Indian and Canadian R&D companies and institutions should expand their collaboration by co-developing a constellation of high-resolution satellites that can pinpoint industrial and non-industrial sources of greenhouse gas emissions around the globe. Given the geographic location and expanses of the two countries in the Eastern and Western Hemispheres and the Global North and Global South, an Indo-Canadian collaboration can help scan emissions in tropical, temperate and polar regions. Such a collaboration will fit well in the existing framework of space and climate cooperation between the two countries.

Conclusion

While the first and so far biggest response to global warming has been a concerted effort to develop clean energy sources as an alternative to fossil fuels, an increase in production of wind, solar and other renewable energy alone will not solve the climate change problem. Important as alternative energy sources are, human society will remain dependent on fossil fuels for the foreseeable future. Moreover, an all-out assault on carbon will risk interrupting the extremely sensitive, natural relationship between carbon and climate in ways that could spawn new planetary challenges.

In the search for other strategies that can help bring climate change under control, two distinct approaches have emerged. The first is atmospheric climate engineering, which is unlikely to attack the buildup of greenhouse gases that are the underlying cause of global warming, but will try to offset the effects by modifying global weather. Specific approaches pose uncertain, but potentially serious, risks. There also is a real danger that the new technologies could be used as weapons. Research must continue through international peer-reviewed mechanisms, but nations must recognize that non-consensual exploitation of climate engineering can have harmful environmental effects and can lead to a new kind of weather- and environment-related warfare. With any attempt at mitigating the effects of global warming, the natural climate of Earth must be left as untouched as possible.

Careful and measured use of terrestrial geoengineering — in particular through carbon capture, utilization and storage technologies — is more likely to contribute meaningfully to achieving the Paris Agreement goal of limiting the rise in the average global temperatures to below 1.5 degrees Celsius well before 2050. Terrestrial geoengineering has another advantage as well: solid carbon materials produced through these technologies are socially useful and economically valuable. Thus, they offer a way to turn today's environmental challenge into an economic opportunity.

Countries such as India and Canada should work together to turn this opportunity into a reality. Both countries are committed to paths of rapid economic growth, scientific and technological progress and environmental protection. They have complementary strengths that could make them a formidable partnership in developing a new carbon-materials industry. Through collaborative R&D, both countries could contribute to socio-economic growth that is sustainable for the entire planet.

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