DISCUSSION PAPER

Towards a Technology Roadmap for achieving India's NDC goals

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Towards a Technology Roadmap for achieving India's NDC goals

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Introduction

The Paris Agreement is seen by many as a major milestone in the global climate policy. If the Nationally Determined Contributions (NDCs) submitted by the Parties to the Paris Agreement are fully implemented, projected temperature rise would be noticeably lower than pre-Paris projections (Climate Action Tracker 2015). Yet, there would be a need to increase global ambition in order to achieve the aspirational target of the Paris Agreement to limit temperature rise to 1.5 degree Celsius. While the provisions of the Global Stocktake and the progressive revision of NDCs every five years have institutionalized the imperative that global action corresponds to scientific assessment, the effectiveness of the Paris Agreement in achieving its goal rests in individual countries' capabilities to transform their production and consumption patterns into low-carbon development pathways over a long horizon. Mere achievement of current NDCs will not be enough. The groundwork for low-carbon transition beyond current NDC timeframes has to begin now. Arguably, the progressive revision of NDCs implies that by the time of NDC revision, countries would have already done, fully or partially, the necessary groundwork to move upwards in their national climate policy.

A necessary component of groundwork for long-term national climate policy, as already recognized by the United Nations Framework Convention on Climate Change and subsequent agreements, including the Paris Agreement, is to develop a detailed technology road map (TRM) compatible with the national developmental imperatives and the demands of progressive revision of NDCs. Most importantly, an integral part of this national technology road map is to identify international cooperation needs, a critical pillar for successful implementation of the UNFCCC and achieving the goals of the Paris Agreement. The technology mechanism of the Paris Agreement, the Climate Technology Centre and Network (CTCN) has the mandate to support developing countries develop such technology road maps (TRMs)[1], and the Technology Executive Committee (TEC 2013) has already developed guidelines towards using TRMs for enhanced mitigation and adaptation actions. It is important for developing countries to have an assessment of immediate, current NDC relevant technological options, their appropriateness in national context, and their cost implications. Recognizing the grandeur of such an exercise, this discussion paper aims only to provide inputs for more informed deliberations towards a technological road map for India's NDCs, and seek meaningful assistance from the CTCN.

Technological context of India's NDC

India has submitted an ambitious NDC to the UNFCCC. Towards mitigation of greenhouse gas (GHG) emissions, by 2030, it intends to (a) reduce the emissions intensity of its gross domestic product (GDP) by 33 to 35 percent from 2005 level, (b) achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy sources, and (c) create an additional carbon sink of 2.5 to 3 billion tonnes of CO2 equivalent through additional forest and tree cover. India's NDC also underscores the need for capacity building; technology development, diffusion and transfer; and mobilization of domestic and new and additional funds from developed countries to achieve these goals. Moreover, the NDC document contains an illustrative list of technologies that would be critical for India in achieving its intended climate policy goals.

It is evident that the mainstay of India's NDC implementation is the transformation of the energy sector, as it accounts for over three-quarters of the country's total emission levels (see Table 1). India's energy consumption has grown at a CAGR of 5.11% between 2008/09 and 2017/18 (MoSPI 2019). Studies project that the industry sector will continue to account for more than 50% of final energy consumption, closely followed by the transport sector and the residential and commercial sectors also claiming marginally an increased share through 2030 (Mathur and Shrivastava 2017). Accordingly, in this discussion paper we look at the technological options before India in the industries relevant to energy and IPPU sectors.

[1] FCCC/CP/2013/10/Add.3

Table 1: India's time-series GHG emissions

No.	Category	Reporting year	(all values in $MtCO_2e$)		
		1994 (MoEF 2004)	2000 (MoEF 2008)	2010 (MoEFCC 2015)	2014 (MoEFCC 2018)
1	Energy	743.8	1027.0	1,510.1	1909.8
2	IPPU	102.7	88.6	171.5	202.3
3	Agriculture	344.5	355.6	390.2	417.2
4	LULUCF	14.3	(222.6)	(252.5)	(301.2)
5	Waste	23.2	52.6	65.1	78.3
6	Total (without LULUCF)	1214.2	1,523.8	2136.8	2306.3
7	Total (with LULUCF)	1228.5	1,301.2	1884.3	2607.5
Source: Authors' compilation from India's NATCOMs and BURs Submissions to the UNFCCC					

Methodology

This discussion paper builds on the approach for developing a TRM provided by Shrivastava (2017), which builds on the guidelines suggested by the Technology Executive Committee (TEC, 2013), and the International Energy Agency's (IEA) Technology Roadmap Report (IEA 2014). The Technology Executive Committee (TEC 2013) identifies TRMs as an important tool to visualize and implement transformative changes and defines a TRM as 'specific technology development and transfer activities, providing a common (preferably quantifiable) objective, time-specific milestones and a consistent set of concrete actions; developed jointly with relevant stakeholders, who commit to their roles in the TRM implementation.' A prerequisite for using TRM techniques is identification of technology. Conducting Technology Need Assessments (TNAs) or similar exercises are the commonly used tools for identification of technologies. However, the Technology Executive Committee also observes that technologies selected in TNAs are often inadequately accompanied by the information about the business case for technology projects and programmes (TEC, 2015). Shrivastava (2017) suggests that the exercise of developing a TRM should be preceded by the following:

a. Given that the countries are pursuing climate policy goals simultaneously with the sustainable development goals (SDGs), it is important to identify technologies that contribute to both, addressing climate change and SDGs. Since climate policies have to be implemented in the context of sustainable development, such screening is necessary. Since it is possible that for specific technologies, there are trade-offs between climate change and the SDGs, it is all the more important to know about the implications of individual climate friendly technologies for different SDGs. Ideally, those technologies which show strong synergies for climate change and SDGs should be prioritized.

b. Development of a structured scenario of how various competing technologies may play out in the future and what should be the governance structure, and elaborating the roles of different stakeholders in regulating the interplay of competing technologies and removal of barriers in greater diffusion.

c. A comprehensive understanding of the sectoral dynamics of actors involved in determining the demand and supply of specific technologies, and accordingly, consideration of changes required in the governance structures to promote diffusion of new and futuristic technology substitutes. An ideal scenario, of course, would be to develop a governance structure for current technologies which would also be suitable for future technology substitutes when they become available. For example, the experience with diffusion of CFLs has been readily useful for the diffusion of LEDs for lighting in India.

d. A description of interventions, including international cooperation, at different temporal or diffusion milestone intervals at national and international levels.

In this discussion paper, we focus only on identifying the list of current and future technologies scoring high on climate change mitigation and SDGs. Considering the emphasis on stakeholder participation in developing as well as implementing a TRM, the list of technologies presented in this paper is prepared based on consultation with industry representatives and experts. Drawing from literature review and existing government documents such as the NDC,

Second Biennial Update Report (BUR) (MoEFCC 2018), *Technology Vision 2035* (Technology Information, Forecasting and Assessment Council 2015), an initial list of sector-specific technologies, totaling 60, was prepared. The industry representatives and experts were then asked to review these technological options and suggest additions along with sharing their opinions about the relevant time span for each technology (pre- or post-2030), the level of technological maturity (readily deployable, need of targeted R&D, nascent R&D stage), potential mitigation impact (high, medium, low), and relevant SDGs contribution. After including the suggested technological options by industry representatives and experts, we surveyed over 119 technologies (tabulated in Annex 1) across 12 sectors (Aluminium, Buildings, Cement, Chlor-Alkali, Fertilizer, Iron and Steel, Pulp and Paper, Refrigeration, Renewables, Textile, Thermal Power, Transmission, and Transport). A total of 21 experts were consulted.

Key Observations

The consultation process yielded some interesting observations. In interpreting the findings, two factors must be kept in mind. First, the observations are based on opinions, instead of quantitative analysis. Hence, comparative observations such as mitigation impacts of technologies need to be taken as indicative instead of conclusive. Second, most of the respondents are technical experts working on site in respective industries; therefore, their opinions are based on day-to-day experience of operating technological systems. Hence, their opinions are to be taken as inclusive of on-site deployment considerations. The observations from the consultation process are organized into three broad categories: technology landscape, knowledge gaps, and key barriers.

a. Technology landscape: The category of technology landscape describes information relevant to NDC and SDGs. The following are the main observation:

- **Progressive revision faces technological uncertainty:** Of the 119 technologies, 86 technologies are more relevant till 2030 and 33 technologies would be important post-2030. The respective numbers of readily deployable technologies are 51 and 3. Considering that the progressive revision of NDCs would eventually cover a timeframe beyond 2030 (the timeframe of present NDC submitted by India), these observations reveal that the technological pathways for scaling up NDC targets beyond 2030 are perceived as reasonably uncertain, only a small number of relevant technologies for post-2030 scenario are ready for deployment as of now. However, there may be some scope of frontloading climate action by immediately providing targeted support for rapid deployment of ready-to-deploy technologies. It is important to note that for mitigation in post-2030 timeframe, fewer relevant technologies are on horizon/known except for cement, transport, buildings, textile, and power sectors (Table 2).

Table 2: Technologies, GHG impact, and timeframe

No.	Sectors	No. of technology options identified	Relative GHG emission reduction impact			Timeline	
			High	Medium	Low	Before 2030	Beyond 2030
1	Aluminum	4	4			4	
2	Buildings	24	13	7	4	20	4
3	Cement	13	6	7		6	7
4	Chlor-Alkali	2	2			2	
5	Fertilizer	12	9	3		8	1
6	Iron and Steel	7	5	2		7	1
7	Pulp and Paper	9	4	2	3	8	1
8	Refrigeration	10	5	4	1	6	2
9	Renewables	14	7	7		7	4
10	Textile	10	5	4	1	9	4
11	Thermal Power plant	5	3	2		4	3
12	Transmission	6		3	3	2	
13	Transport	3	3			3	6
	Sub-total 1	119	66	41	12	86	33

- **Aggressive R&D is a precondition for ambition**: It is intuitive to recognize the importance of R&D for transformative action post-2030, also reflected in the dominant number of technologies (26 of the 33) needing significant R&D attention. However, the period upto 2030 too would need significant emphasis on R&D as only 41 out of 86 technologies that will have high mitigation impact are readily deployable. 13 high impact technologies would need open-ended R&D efforts while 4 high impact technologies would require targeted R&D. The list of high mitigation impact technologies with their status of maturity is given in Annex 1.

b. **Knowledge gaps**: The observations in the knowledge gap category describe the aspects which are important for prioritization of technologies and further development of strategy but on which no systematic knowledge is available. Such knowledge, however, is not difficult to generate.

- **Weak understanding of SDG implications:** Recent literature has emphasized on the need to focus on strong synergies between climate action and SDGs (Raj and Pahuja 2017). However, consultations with industry representatives and experts revealed that there is a lack of systematic understanding of technology-specific SDG implications. With expected overlaps with the SDGs relating to affordable and clean energy; industry, innovation and infrastructure; and climate action, respondents from industries (except from buildings, cement and transport) could not relate any technologies with any other SDGs. More importantly, barring cement and buildings sectors, the need for partnership was surprisingly not recognized at all. It is unlikely that the technological shifts in industries would have no impact on employment, poverty, gender, etc. Yet, the respondents had little to say about it. While it may be argued that the respondents might not be aware of the SDGs as such, this nevertheless indicates an important knowledge gap.
- **Technology-specific barriers are not known:** While the respondents informed about general barriers faced in the sector for deployment of advanced technologies, specific challenges to individual technologies did not find any mention. This is also reflected in the lack of overlap between technologies and SDG 17 (Partnerships and collaborations).

c. **Major barriers:** The implementation/upscaling of 119 identified technology options were hindered due to several intrinsic and exogenous barriers which are broadly classified into four categories as depicted in Figure 1. These barriers are based on the in-person conversations with fewer number of respondents, hence are less representative of the overall consultative process. Moreover, these responses are more sectoral in nature and do not provide technology-specific information.

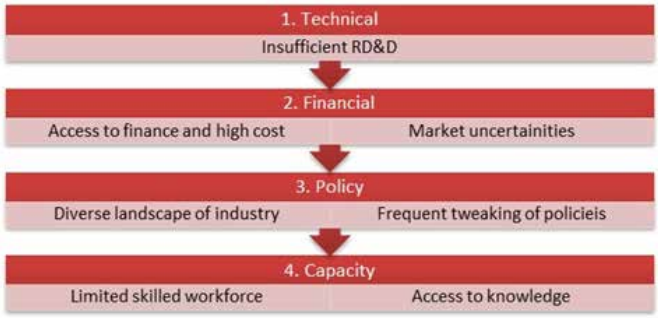

Figure 1: Categorization of barriers

- **Access to knowledge:** In many cases, the industry is not aware of the alternative technological options, on account of high transaction cost of acquiring such information or general reluctance to search for better technological options and practices. The lack of understanding about SDGs is illustrative of the poor level of awareness about policy discourses that will have significant bearing upon the process of industrialization.
- **Access to finance and high cost:** Finance plays a crucial role in piloting the latest technology options, particularly for MSME industries. Most of the industries under this category look for subsidy/ incentive-based models to support adoption of new technological options. On other hand, large-scale integrated plants invest huge outlay on their infrastructure and utilities, so the retrofitting/ revamping/replacement of utilities affects their outturns and production immensely. For example, in iron and steel industry, the replacement of a blast furnace with a new advanced blast furnace would perhaps need to wait for about 30 years in the case of a recent plant.

- **Lack of skilled workforce:** Most of the Indian industries are operated by unskilled and semi-skilled workers who lack the knowledge necessary to operate the latest integrated/automated utilities and machineries. This averts industries from deploying/piloting the new technology options as the cost of deploying new technology also includes retraining the workforce.
- **Insufficient RD&D:** India severely lacks in efforts on developing indigenous technological options as well improving upon existing technologies. Most of the technology options/practices/utilities are imported from abroad. The import of technological options from these regions significantly increases the project outlay for industries and involves meticulous paperwork.
- **Diverse landscape of industry:** India's industry is a complex network of diverse, as well as numerous, industries. In most of the cases, each industry segment uses a wide range of technologies depending upon the scale, inputs, skill sets, awareness, attitude towards technology, and market demand. This makes it difficult to conceive of a single, coherent policy solution to encourage the industry to go for technological upgradation.
- **Market uncertainties:** In the case of ready-to-deploy technologies, market fragmentation and lack of consolidation of demand act as a barrier to large-scale deployment. Extreme price elasticity of demand prevents companies from deploying new technologies that may lead to increased cost of production, and in turn, loss of competitiveness.

Responses to questions relating to types of barriers impeding the uptake of proposed technology options reveal that experts emphasize on financial factors (see Table 3) as a major barrier in hindering the implementation of technology options/practices across the Indian industries. This was followed by capacity; technological and policy barriers. The experts' perspective on SDGs inter-linkages with the identified technology options were also captured in the survey and presented in Annex 1.The broad findings are summarized as follows:

- Out of 119 options, 66 technology options were recommended as high GHG mitigation impact options (Annex 1; No. 1 – 66)
- From the classified list of 119 options, 44 technology options tabulated in Annex 1 are at readily deployable stage. Their implementations are largely impeded due to financial and capacity factors. In many cases, the deployment is also limited due to lack of skilled workforce to operate any new advanced technology practices. An innovative market and fiscal instruments, and the enhancement of technical skillsets of workforce, could swiftly steer the deployment of these readily available technology options. The survey also divulged that five technology options under this category were not facing any barriers for deployment.
- Similarly, the deployment of technology options listed in Annex 1 (16 options at R&D stage and 6 options requiring targeted research), were facing commensurably weightage of all four barrier categories.

Table 3: Perception analysis - barriers impeding the implementation of technology options

No.	Barriers	No. of surveyed technologies (out of 119)
1	Technological barriers	68
2	Financial barriers	91
3	Policy barriers	57
4	Capacity barriers	77
Source: perception analysis with industry experts		

Way forward

It is evident that there exists a wide array of technological options that can offer the necessary flexibility across timeframes, enabling India to respond to the demands of the five-year cycle of global stocktake and progressive revision of NDCs. It is also clear that these technological options are not necessarily the low hanging fruits or easy to deploy. Most importantly, the required transition to low-carbon development pathways will depend on the commercially viable outcomes of the ongoing (or yet to be initiated) R&D efforts on technologies relevant for the post-2030 period. Based on the broad observations emerging out of the consultation process, the following strategies may be considered as an integral part of developing a technology road map for India's strategy for climate change as well as sustainable development goals:

A. Develop sector-specific SDG impact assessments

It is absolutely critical to have a definitive assessment of SDG implications of deploying any GHG mitigation technologies. Given the range of technological options available within each sector, it may not be possible to conduct such an assessment for each and every technology. However, at least such an assessment in a sectoral context should be undertaken. For example, it is possible to conceive of a technology policy for a sector (e.g. cement) that focuses on achieving both GHG mitigation and relevant SDGs. An important step in this direction should be to make industries aware and report on their contributions towards various SDG targets. A common template for Sustainability Reports for large companies may be considered to begin with. This would not only force industry to think of possible ways in which different technologies in a sector interact with the imperatives of SDGs but also generate extremely relevant information for public policy on climate change and sustainable development.

C. Identify and address technology-specific barriers to ready-to-deploy technologies

While it is imperative for industrial development and technological advancement to facilitate rapid deployment of ready to deploy technologies, the progressive revision of NDCs requires that a careful scrutiny of available technological options be carried out in order to avoid lock-ins into relatively high emission technologies. Nevertheless, it is important to identify technology-specific barriers and address them to improve synergies between climate policy and SDGs. Market aggregation, access to information, and appropriate financing model to prevent loss of competitiveness should be integral to any strategy for diffusion of available technologies. Such a strategy should be made and implemented using a participatory model of governance, as it is important to understand different barriers faced by different stakeholders.

G. Develop innovative market-mechanisms to address financial barriers

In the recent past, a number of experiments with market-based mechanisms for promoting GHG emission reduction, energy savings, and renewable energy at lower cost have yielded positive impacts for technology diffusion. These markets are also deeply entrenched in well-defined policy and regulatory frameworks of countries, in many cases also supplemented with significant hand-holding and capacity-building efforts. It is, therefore, worth exploring innovative market-based mechanisms that primarily aim at not only addressing financial barriers, but are also linked with appropriate redressal of capacity, technological, and policy barriers.

H. Targeted RD&D strategy of technologies in R&D stage

Given the low levels of expenditure on RD&D in India, it is imperative to have a carefully crafted RD&D strategy for technologies that hold promise upto and beyond 2030. Two approaches may be adopted simultaneously. First, focusing on encouraging domestic RD&D, and second, encouraging RD&D linked to international collaborations. Domestic RD&D may prioritize adaptation as well as improvement in existing technologies, whereas international collaborations as condition of enhancing NDC ambition should be used as diplomatic means to ensure access to technical and financial resources and/or stake claim in global technological advancements for global benefits. Again, SDG impacts of selected technologies need to be taken into consideration.

I. Ensure easy access to information on latest technologies

As has been seen in many instances of technology promotion, handholding of industries is an effective way to build capacities to assess new technological options as well as deploy them successfully. While many platforms under various global governance institutions exist which provide

assistance as well as information on latest technological developments, a number of factors such as language, exposure, and scale of operation limit the Indian industry's access to them. ICT-based information dissemination platforms along the lines of weather information services to farmers may be considered for better access to not only technologies but also other support mechanisms.

M. Strategic use of technology and finance mechanism under the Paris Agreement

Technological knowledge gaps as well as lack of financial resources are among the prime barriers for large-scale technology diffusion. The CTCN and the GCF under the Paris Agreement are aimed at addressing these gaps. Currently, these mechanisms are being used as support vehicles for implementing large-scale project based on specific technological systems. Strategic use of such mechanisms towards developing a national system of technological transition should be explored. For example, the CTCN may be requested to support India in developing a market-based mechanism to address technological and financial barriers to rapid deployment of ready to deploy technologies, whereas initial support from the finance mechanism of the Paris Agreement, the Green Climate Fund, could be used to demonstrate and establish effective governance of such a national mechanism.

Annex

Annex 1: Technologies for NDC and their SDG inter-linkages (India)

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
1	Drained cell technology with wet table cathode	Aluminium	R&D	High	Yes		Yes				SDG 7; SDG 9; SDG 12; SDG 13
2	Improved design of anode assembly	Aluminium	R&D	High	Yes		Yes				SDG 7; SDG 9; SDG 12; SDG 13
3	Cu-insert collector bar technology in aluminum smelter	Aluminium	Readily deployable	High	Yes		Yes	Yes			SDG 7; SDG 9; SDG 12; SDG 13
4	Improved design of cathode assembly and cell lining.	Aluminium	Readily deployable	High	Yes		Yes	Yes			SDG 7; SDG 9; SDG 12; SDG 13
5	All new construction to be Net zero energy buildings Buildings	Buildings	R&D	High	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
6	Building automation (IOT devices and smart appliances)	Buildings	R&D	High	Yes		Yes	Yes		Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
7	Low energy thermal comfort systems (COP>5)	Buildings	R&D	High	Yes			Yes			SDG 3; SDG 7; SDG 8; SDG 9; SDG 10; SDG 11; SDG 13; SDG 17
8	BLDC fans (super-efficient Fans)	Buildings	Readily deployable	High	Yes			Yes		Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
9	Building management systems (centralized automatic operation based on pre-set algorithms and machine learning)	Buildings	Readily deployable	High	Yes			Yes			SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
10	District Cooling	Buildings	Readily deployable	High	Yes			Yes		Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
11	Radiant Cooling	Buildings	Readily deployable	High	Yes					Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
12	Building Codes/ Rating system to ensure 35% improvement (2005 levels) in new construction	Buildings	Readily deployable	High	Yes			Yes	Yes		SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
13	Energy Efficiency in Buildings	Buildings	Readily deployable	High	Yes				Yes	Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
14	Energy Efficient lighting system (minimum 100 lm/W)	Buildings	Readily deployable	High	Yes		Yes	Yes		Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
15	Green and net zero energy buildings	Buildings	Readily deployable	High	Yes			Yes	Yes	Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
16	LED home lighting	Buildings	Readily deployable	High	Yes			Yes		Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
17	All existing buildings to be Net zero energy buildings	Buildings	Requires targeted research	High		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
18	Hydrogen energy & Fuel cell technology	Cement	R&D	High		Yes	Yes	Yes	Yes	Yes	SDG 3; SDG 4; SDG 7
19	Solar & renewables	Cement	Readily deployable	High	Yes				Yes		SDG 3; SDG 4; SDG 7
20	Low temperature Waste Heat recovery generation from cement plants	Cement	Readily deployable	High	Yes		Yes	Yes	Yes		SDG 7;
21	Utilization of Advanced Automation systems in Cement Manufacturing with online CFD analysis, Analytics and Predictive Contr(data analysis and remote asset monitoring)	Cement	Readily deployable	High	Yes			Yes		Yes	SDG 7;
22	Horrow mill for cement grinding or Futuristic comminution technologies / Contact less grinding under electrical technology	Cement	Readily deployable	High		Yes		Yes			SDG 3; SDG 4; SDG 7

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
23	Increasing Thermal Substitution Rate (TSR) in Indian cement plants beyond 30%	Cement	Readily deployable	High		Yes		Yes	Yes		SDG 3; SDG 4; SDG 7
24	Oxygen - Depolarized Cathodes (ODCs)	Chlor-Alkali	R&D	High	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
25	6th generation Zero Gap Electrolyzer	Chlor-Alkali	Readily deployable	High	Yes		Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
26	Heat Recovery System (HRS) in sulphuric acid plant	Fertilizer	Readily deployable	High	Yes		No	No	No	No	SDG 7; SDG 9; SDG 13
27	Improvement in Internals of Urea reactor for improving conversion efficiency	Fertilizer	Readily deployable	High	Yes		Yes	Yes	Yes		SDG 7; SDG 9; SDG 13
28	Installation of a high efficiency turbine for air blower in sulphuric acid plant	Fertilizer	Readily deployable	High	Yes		No	No	No	No	SDG 7; SDG 9; SDG 13
29	Installation of high Efficiency Waste Heat Boilers	Fertilizer	Readily deployable	High	Yes				Yes		SDG 7; SDG 9; SDG 13
30	Installation of Plate Type Heat Exchanger in Convection Section of Primary Reformer	Fertilizer	Readily deployable	High	Yes			Yes	Yes		SDG 7; SDG 9; SDG 13
31	Installation vapour absorption system with low temperature	Fertilizer	Readily deployable	High	Yes			Yes	Yes		SDG 7; SDG 9; SDG 13
32	Replacement of steam driven generators in CPP with Gas turbine with HRSG	Fertilizer	Readily deployable	High	Yes			Yes	Yes		SDG 7; SDG 9; SDG 13
33	Waste heat utilization from return chilling water of Air handling unit to heat ammonia for NPK fertilizer plant	Fertilizer	Readily deployable	High	Yes		No	No	No	No	SDG 7; SDG 9; SDG 13
34	Hydrogen energy from water electrolysis	Fertilizer	R&D	High		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
35	Coke Dry Quenching (CDQ)	Iron and Steel	Readily deployable	High	Yes		Yes			Yes	SDG 7; SDG 9; SDG 13

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
36	Pulverized coal injection system in Blast Furnace	Iron and Steel	Readily deployable	High	Yes		No	Yes	No	Yes	SDG 7; SDG 9; SDG 13
37	Regenerative Burner for Reheating Furnace	Iron and Steel	Readily deployable	High	Yes			Yes		Yes	SDG 7; SDG 9; SDG 13
38	Waste heat recovery in sinter plant	Iron and Steel	Readily deployable	High	Yes			Yes		Yes	SDG 7; SDG 9; SDG 13
39	Hydrogen based iron reduction process	Iron and Steel	Requires targeted research	High		Yes	Yes			Yes	SDG 7; SDG 9; SDG 13
40	Installation of extended delignification system for cooking of wood	Pulp and Paper	Readily deployable	High	Yes		Yes	Yes			SDG 7; SDG 9; SDG 13
41	Internet of Things (IOT) & advanced analytics	Pulp and Paper	Readily deployable	High	Yes			Yes		Yes	SDG 7; SDG 9; SDG 13
42	Oxygen delignification and efficient screening to obtain low kappa	Pulp and Paper	Readily deployable	High	Yes			Yes			SDG 7; SDG 9; SDG 13
43	Zero liquid discharge	Pulp and Paper	Requires targeted research	High	Yes		Yes	Yes			SDG 7; SDG 9; SDG 13
44	Evaporative cooling for comfort application	Refrigeration	Readily deployable	High	Yes				Yes	Yes	SDG 7; SDG 9; SDG 13
45	Refrigeration and Air-conditioning with solar cells to generate electricity	Refrigeration	Readily deployable	High	Yes			Yes		Yes	SDG 7; SDG 9; SDG 13
46	Materials that will have ultra-high capacity to absorb humidity with solar heat to regenerate	Refrigeration	Requires targeted research	High	Yes				Yes	Yes	SDG 7; SDG 9; SDG 13
47	Refrigeration using solar heat in absorption technology	Refrigeration	Requires targeted research	High	Yes				Yes	Yes	SDG 7; SDG 9; SDG 13
48	Solar heat to augment refrigeration cycle	Refrigeration	Requires targeted research	High	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
49	Solar + battery storage	Renewables	R&D	High	Yes				Yes	Yes	SDG 7; SDG 9; SDG 13
50	Solar + wind (hybrid)	Renewables	R&D	High	Yes				Yes	Yes	SDG 7; SDG 9; SDG 13
51	Bio-fuels	Renewables	Readily deployable	High	Yes		Yes			Yes	SDG 7; SDG 9; SDG 13
52	Improved cook-stoves	Renewables	Readily deployable	High	Yes					Yes	SDG 7; SDG 9; SDG 13

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
53	Micro-gasifier cook stove	Renewables	Readily deployable	High	Yes		Yes			Yes	SDG 7; SDG 9; SDG 13
54	Waste to energy	Renewables	Readily deployable	High	Yes			Yes	Yes		SDG 7; SDG 9; SDG 13
55	Algal energy	Renewables	R&D	High		Yes		Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
56	Heat Pump for heating and cooling applications	Textile	R&D	High	Yes		No	No	No	No	SDG 7; SDG 9; SDG 13
57	High Efficiency low NOX burners	Textile	R&D	High	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
58	IIoT (Industrial internet of things)	Textile	R&D	High	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
59	Industry (Textile) 4.0	Textile	R&D	High	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
60	Switched Reluctance motors	Textile	R&D	High	Yes		Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
61	Ammonia based Desulphurization	Thermal Power plant	Readily deployable	High	Yes		No	No	No	No	SDG 7; SDG 9; SDG 13
62	Coal benefaction technologies	Thermal Power plant	Readily deployable	High	Yes		Yes	Yes	Yes		SDG 7; SDG 9; SDG 13
63	Pulverized Combustion Ultra Super Critical (PC USC)- Main steam and reheat temperature around/ above 600 deg C	Thermal Power plant	Readily deployable	High	Yes			Yes	Yes		SDG 7; SDG 9; SDG 13
64	Electrical vehicle (Battery)	Transport	Readily deployable	High	Yes		Yes	Yes	Yes	Yes	SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13
65	Road Transport - Use of bio-fuels/ CNG	Transport	Readily deployable	High	Yes					Yes	SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13
66	Railways - solar technology for n-traction operation	Transport	Readily deployable	High		Yes	No	No	No	No	SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13
67	Geothermal Heating and cooling	Buildings	Requires targeted research	Medium		Yes	Yes	Yes	Yes	Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
68	Deep Energy Retrofits in existing buildings (>40% improvement)	Buildings	R&D	Medium	Yes		Yes	Yes		Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
69	Building integrated Photovoltaic systems	Buildings	R&D	Medium	Yes		Yes	Yes	Yes	Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
70	Zero energy artificial lighting	Buildings	R&D	Medium	Yes			Yes		Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
71	Thermal Storage for efficient cooling and heating	Buildings	R&D	Medium	Yes		Yes	Yes		Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
72	Energy Retrofits in existing buildings (<40% improvement)	Buildings	Readily deployable	Medium	Yes		Yes			Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
73	Trigeneration	Buildings	Readily deployable	Medium	Yes			Yes	Yes	Yes	SDG 3; SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13
74	Carbon capture and usage into chemicals	Cement	R&D	Medium	Yes		Yes	Yes	Yes	Yes	SDG 3; SDG 4; SDG 7
75	Oxy-fuel combustion technology	Cement	R&D	Medium	Yes		Yes	Yes	Yes		SDG 7;
76	Recuperation of radiating heat from kiln and Preheater sections using panel heat exchanger	Cement	R&D	Medium	Yes			Yes	Yes		SDG 7;
77	Carbon capture through algal growth and use of biofuels	Cement	R&D	Medium		Yes	Yes	Yes	Yes		SDG 3; SDG 4; SDG 7
78	Manufacturing of Polymer Cement from Waste of Iron Sludge	Cement	R&D	Medium		Yes	Yes	Yes	Yes		SDG 7;
79	Carbon sequestration	Cement	Requires targeted research	Medium		Yes	Yes	Yes	Yes	Yes	SDG 3; SDG 4; SDG 7
80	Use of nano technology in cement production	Cement	Requires targeted research	Medium		Yes	Yes	Yes	Yes		SDG 3; SDG 4; SDG 7
81	Converter gas recovery	Iron and Steel	Readily deployable	Medium	Yes		Yes			Yes	SDG 7; SDG 9; SDG 13
82	Top recovery turbine (TRT)	Iron and Steel	Readily deployable	Medium	Yes		Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
83	Waste Heat recovery generation from Low TPD Sponge Iron Plants	Iron and Steel	Readily deployable	Medium	Yes		Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
84	Installation of Multi-Port Dryer in Paper Machine to reduce steam Consumption	Pulp and Paper	Requires targeted research	Medium	Yes		Yes	Yes			SDG 7; SDG 9; SDG 13

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
85	Nansulate Coating of Dryer end of Paper machine 5 [SPB-Erode] for surface temperature reduction thereby lowering Radiation heat loss - Demonstration (Netherlands)	Pulp and Paper	Requires targeted research	Medium	Yes		Yes				SDG 7; SDG 9; SDG 13
86	Deep sea water at lower temp for cooling the temp at the depth of 1000 m is 3 to 4 Deg C	Refrigeration	Still in imagination	Medium	Yes			Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
87	Heat reflective material to reflect infra red radiation back to outer space	Refrigeration	Still in imagination	Medium		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
88	Fuel cell (battery chemical)	Renewables	Requires targeted research	Medium	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
89	Nuclear energy (fusion)	Renewables	R&D	Medium		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
90	Microbial fuel cell	Renewables	Requires targeted research	Medium		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
91	Tidal energy	Renewables	Requires targeted research	Medium		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
92	Advanced reciprocating engines	Textile	R&D	Medium	Yes		Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
93	Heat recovery technologies	Textile	R&D	Medium	Yes		Yes	Yes			SDG 7; SDG 9; SDG 13
94	Supercritical - CO2 Dyeing Technique	Textile	R&D	Medium	Yes			Yes		Yes	SDG 7; SDG 9; SDG 13
95	Free Flot Steam Trap	Textile	Readily deployable	Medium	Yes					Yes	SDG 7; SDG 9; SDG 13
96	Closed condensate recovery pump	Textile	R&D	Medium		Yes	Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
97	Decentralized electricity generation	Textile	R&D	Medium		Yes	Yes	Yes	Yes		SDG 7; SDG 9; SDG 13
98	Flywheel energy storage systems	Textile	R&D	Medium		Yes	Yes	Yes			SDG 7; SDG 9; SDG 13

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
99	Pulverized Combustion Advanced Ultra Super Critical (PC USC) - Main steam and reheat steam temperature more than 700 deg C	Thermal Power plant	Requires targeted research	Medium	Yes			Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
100	Integration of CCS with Computation Fluid Dynamics (CFD) Analysis of Flue gas path in ducts	Thermal Power plant	R&D	Medium		Yes		Yes	Yes		SDG 7; SDG 9; SDG 13
101	Organic Rankine Cycle Power Generation	Thermal Power plant	R&D	Medium		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
102	Micro oil ignition system (MOIS)	Thermal Power plant	Requires targeted research	Medium		Yes	Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
103	Grid-up gradation	Transmission	Readily deployable	Medium	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
104	Smart Mini-Grids	Transmission	Readily deployable	Medium	Yes		Yes	Yes	Yes		SDG 7; SDG 9; SDG 13
105	Railways - CNG-based locomotive	Transport	Readily deployable	Medium	Yes					Yes	SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13
106	Mass rapid transport systems	Transport	R&D	Medium		Yes		Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
107	Railways - LNG-based locomotive	Transport	R&D	Medium		Yes		Yes			SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13
108	Home Automation systems for enhanced Energy Efficiency in residential dwellings	Buildings	R&D	Low		Yes	Yes	Yes		Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
109	Energy Efficient lighting system (minimum 150 lm/W)	Buildings	Requires targeted research	Low		Yes	Yes	Yes		Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
110	Building Management Systems for enhanced Energy Efficiency in Commercial buildings	Buildings	Readily deployable	Low	Yes		Yes	Yes	Yes	Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 13; SDG 17
111	Low embodied energy construction technology & materials	Buildings	Requires targeted research	Low	Yes			Yes		Yes	SDG 7; SDG 8; SDG 9; SDG 11; SDG 12; SDG 13; SDG 17
112	Black Liquor Gasification	Pulp and Paper	Requires targeted research	Low	Yes		Yes	Yes			SDG 7; SDG 9; SDG 13

No.	Technology	Sector	Status	Relative GHG mitigation	Before 2030	Beyond 2030	Technical Barrier	Financial Barrier	Policy Barrier	Capacity Barrier	SDG inter-linkages
113	Introduction of Alkaline bleaching sequence to reduce COD/AOX	Pulp and Paper	Requires targeted research	Low	Yes		Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
114	Hydrogen energy	Pulp and Paper	Still in Imagination	Low		Yes	Yes	Yes		Yes	SDG 7; SDG 9; SDG 13
115	Night Sky cooling to radiate heat during night to outer space	Refrigeration	Still in imagination	Low		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
116	Geothermal energy for humidification HVAC	Textile	R&D	Low		Yes	Yes	Yes	Yes	Yes	SDG 7; SDG 9; SDG 13
117	Railways - Battery (Li-Ion) locomotive	Transport	R&D	Low		Yes	Yes	Yes		Yes	SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13
118	Road Transport - electric traction based highway operation for HDVs	Transport	Requires targeted research	Low		Yes	Yes	Yes	Yes	Yes	SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13
119	Road Transport - Hydrogen fuel	Transport	Still in imagination	Low		Yes	Yes	Yes		Yes	SDG 3; SDG 7; SDG 9; SDG 11; SDG 12; SDG 13

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