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# Decarbonising India

Charting a pathway for sustainable growth

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# Preface

The physical manifestations of climate change are increasingly visible across the globe, and India is not untouched. More than 75 percent of India's districts—home to 638 million people, or 1.4 times the population of the European Union (EU)—are categorised as hotspots for extreme climate events already.[1] India has acknowledged this threat in multiple forums, has set ambitious targets and is taking bold measures to address the risks.

Though India's emissions currently stand at a mere 1.8 tons $CO_2e$ per capita (versus the United States at 14.7 and China at 7.6), it is still the world's third-largest emitter at 2.9 $GtCO_2e$ (4.9 percent of global emissions).[2] As India grows,[3] emissions will only increase without a concerted effort across multiple sectors of the Indian economy. We use external sources for GDP growth scenarios in this report and don't make projections or forecasts. These scenarios range between long term forecasts from reputed international agencies such as EIU and Oxford Economics and aspirational estimates, based on employment needs. We have used the former as a basis to develop sector growth scenarios and hence, GHG emissions. With careful planning and execution, India can meet its growth ambitions while decarbonising.

At COP26, India set out its plan to help slow down and halt global warming, with a 2070 net-zero target. While we support the global net-zero ambition of decarbonising by 2050, we have used India's stated national plan as the basis for the analysis and scenario modelling in this paper. Our analysis also shows that the transition though difficult is feasible—and could even be accelerated. However, we don't foresee India getting all the way to net zero in either of our scenarios – the last 10 percent will be particularly difficult to decarbonise.

This report presents an in-depth analysis of ways to decarbonise the six sectors which contribute to roughly 70 percent of India's overall emissions: power, automotive, aviation, steel, cement and agriculture. Additionally, we analyse four cross-cutting enablers which can help decarbonise multiple sectors: carbon-capture usage and storage (CCUS), natural climate solutions (NCS), material circularity and green hydrogen. More than 100 emission-reduction initiatives have been identified for these key sectors and themes, across two scenarios, both of which assume an orderly transition: (a) The Line of Sight (LoS) scenario with current (and announced) policies and foreseeable technology adoption, and (b) The Accelerated scenario with further reaching policies such as carbon prices and accelerated technology adoption including those of technologies like CCUS. It also includes estimates for the likely investments this transition will need and ways in which to finance it.

We started our effort with a comprehensive literature review of similar knowledge efforts conducted in this space. While there are several good reports out there, published by credentialled organisations, this report attempts to differentiate itself from others in the following ways: it is comprehensive across sectors, examines these in depth (including with customised and detailed sector models), explores implications of inter-linkages across sectors, and takes a practical, yet aspirational, view of the abatement levers. Finally, it defines a set of actions that need to be executed with urgency if this orderly transition is to get underway.

In keeping with our history of exploring environmental sustainability issues, we offer this report not to prescribe what policymakers and industry should do, but to provide a factual basis for comparing emission-reduction approaches. Further, we hope the report will help leaders in the public and private sectors launch emission-reduction projects to help secure a healthy and prosperous future for India and the world.

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[1] Council for energy, environment and water (CEEW).

[2] As per the World Bank data, 2019.

[3] India's GDP estimated to grow from $3 trillion today to $12 trillion by 2050; The Economist Intelligence Unit (EIU)-Real gross domestic product in USD at 2010 prices.

# Acknowledgements

This report is the product of a year-long, cross-disciplinary research effort by McKinsey's Sustainability Practice in India. We owe special thanks to the core team and co-authors for key sections of this report as well as to all the other sector experts and support team who worked tirelessly on the report:

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# Executive summary

In 2021, at COP26, India announced its ambition to become a net-zero emitter by 2070.[1] Despite low per-capita emissions (1.8 tons $CO_2$ per capita), India is the third-largest emitting country globally.[2] Therefore, if we are to win the global war on climate change, India will need to play an important role. With this in mind, India has taken several proactive steps and made commitments. For instance, its updated Nationally Determined Contribution (NDC) for 2030 commits to using half of power-installed capacity from non-fossil fuel-based energy resources and to achieving a 45 percent reduction in emissions intensity from its 2005 levels.[3]

India currently emits a net of 2.9 $GtCO_2e$ every year (as of 2019). The bulk of these emissions (about 70 percent) are driven by six sectors: power, steel, automotive, aviation, cement and agriculture (Exhibit A).

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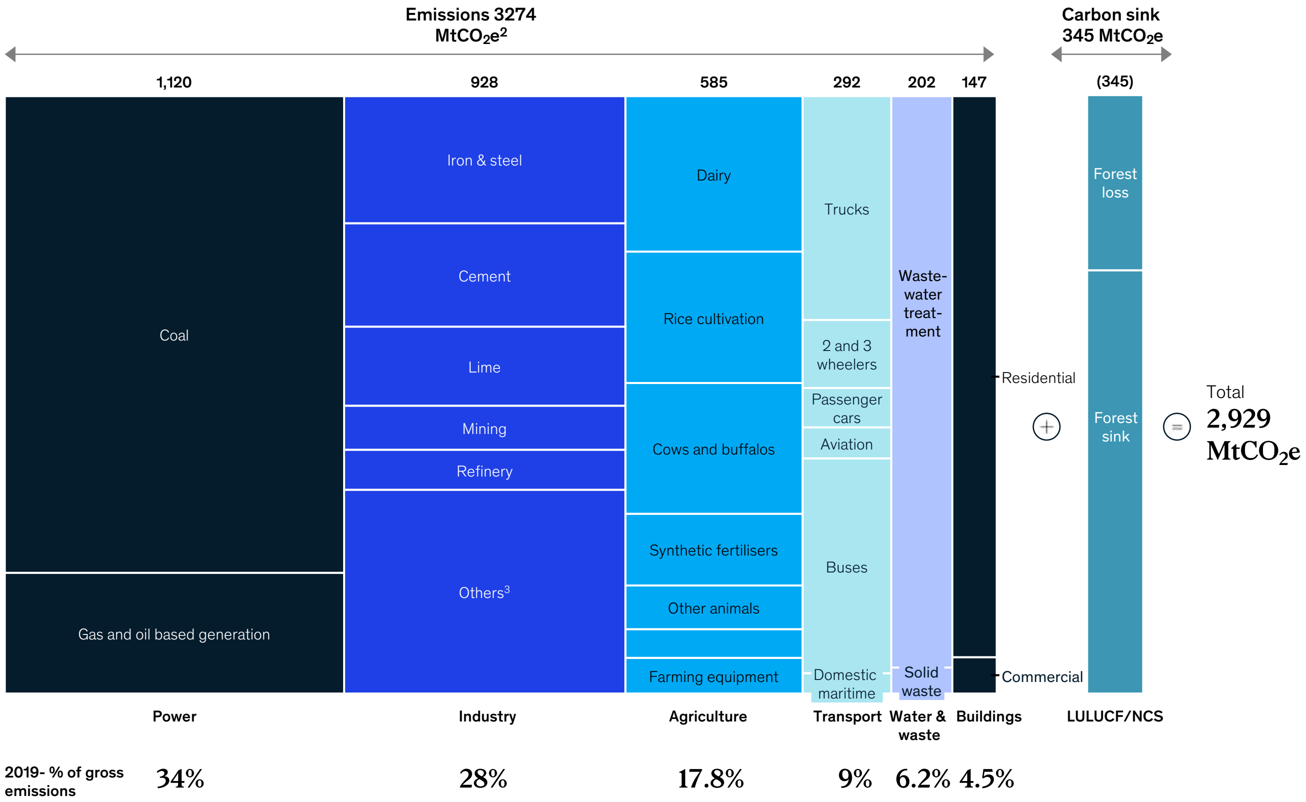
[1] India's NDC.
[2] World Bank; Worldometer.
[3] India's NDC.

Exhibit A

## India's current carbon emission mix.

**Baseline emissions,** $MtCO_2e^1$, 2019



1. Converting GHGs into $CO_2e$ assuming GWP-100 and AR5 methodology with India's BUR-3 reported emissions for 2016 as baseline.
2. Gross and net emissions for 2019 based on Climate Action Tracker overall emissions for India.
3. Others include: other industry oil & coal use, ammonia, aluminium, F-gases and ethylene.

Source: McKinsey India Decarbonisation Scenario Explorer

This report identifies the optimal uses of more than 100 emission-reduction levers in these sectors, across two scenarios, both of which assume an orderly transition: (a) the Line of Sight (LoS) scenario with current (and announced) policies and foreseeable technology adoption and (b) the Accelerated scenario with further reaching polices like carbon prices and accelerated technology adoption, including those of technologies like CCUS. This report attempts to be comprehensive across sectors, examining them in depth, highlighting linkages across them while taking a practical, yet aspirational, view of the abatement levers. It attempts to define two possible roadmaps for an orderly transition for India in the context of its continued expected growth. Finally, it proposes a set of actions that could be executed for an orderly transition to get underway. This report does not address physical risks and adaptation topics.

Our analysis shows that the benefits of a well-planned, orderly, accelerated transition could far outweigh the downsides for India, given its growth outlook. India must take steps within this decade to set things up. Doing so will allow it to use its growth momentum and build the country 'right' for the decades thereafter. Also, while the actions needed for India to decarbonise are challenging, most of them are 'in-the-money', and hence the journey is doable. Eight important messages emerge from this:

1. **There is an opportunity for India to create 287 Gt of carbon space for the world.** In the growth scenario assumed for this report,[4] India will likely be a $22 trillion economy in real 2010-dollar terms[5] (about seven times its current GDP) with a population of 1.7 billion by 2070. Even if its current GDP emission intensity reduction were to continue at the same rate, India's annual emissions would still rise to 11.8 $GtCO_2e$ by 2070 (from 2.9 $GtCO_2e$ in 2019).[6] Getting to the LoS scenario would create 207 $GtCO_2e$ of carbon space till 2070, while the Accelerated scenario would add a further 80 $GtCO_2e$. This is equivalent to 36 percent and 14 percent, respectively, of the remaining carbon budget for an even chance at limiting warming to 1.5 degrees Celsius. This is despite India not reaching net zero in either of our scenarios, due to the residual emissions from agriculture and select industrial sectors (remaining emissions in 2070 of 1.8 and 0.4 $GtCO_2e$ in the LoS and Accelerated scenarios, respectively). These emissions have been largely estimated with currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture {DAC}).
2. **While achieving the LoS scenario reductions will be challenging, achieving those of the Accelerated scenario will be even more so.** While there are emerging tailwinds in the form of falling costs of renewables and electrical vehicles (EVs) and some policies are beginning to be implemented (e.g., Faster Adoption and Manufacturing of {Hybrid &} Electric Vehicles in India {FAME} for EVs, an imputed $140–240 per ton of $CO_2e$ tax on motor fuels[7]), several other actions with significant scale up are needed. For example, renewable capacity addition has to increase from 10 GW to 40–50 GW per year, a carbon price has to be put in place to make green steel competitive, battery costs have to decline by 80 percent by 2050, hydrogen by two-thirds by 2035, a nationwide roll out of charging infrastructure has to happen, farmers have to adopt new practices for rice cultivation, targets for circularity have to be met and higher targets have to be set.
3. **If India is to have an orderly and accelerated decarbonisation, the transition has to be set up within this decade.** Over three-fourths of the India of 2050 (and 80+ percent of the India of 2070) is yet to be built. This growth could multiply demand across sectors: power (eightfold), steel (eightfold), cement (triple), automotive (triple) and food (double). If policies are set in place to create the right demand signals within this decade, then the capacities India adds in the two decades thereafter will be low carbon ones. For example, in steel, the early imposition of a carbon price could lead to 200 Mt of steel capacity being built on the low carbon hydrogen route instead of the coal route by 2050. This has happened before – policies put in place early in the decade of the 2010s have led to the explosion of renewables capacity in the recent past and will continue to enable even greater capacity expansion going forward.[8] These policies could provide a clear outlook on carbon prices in three years, as also on forward-looking blending mandates (e.g., for aviation fuels) and a national land use plan, encourage local manufacturing capabilities and gear up financial institutions to lend to green projects at scale, amongst other things. The government can also define its plans and policies

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[4] Real GDP growth rate assumption based on Economist Intelligence Unit (EIU) projection for 2020–30 is 5.8 percent, 2030–40 is 5.1 percent and 2040–50 is 4.7 percent. 2050–70 Real GDP growth rate has been assumed to be about 3 percent annually.

[5] Based on Economist Intelligence Unit projection of $12.5 trillion by 2050 (Real GDP - USD at 2010 prices) and extrapolated to 2070 with 3 percent CAGR assumption; This GDP forecast represents a more conservative estimate compared to other estimates - we have considered the lower range of growth in our analyses to build a more robust decarbonisation pathway.

[6] United Nations framework convention on climate change (UNFCC); climate action tracker; India's biennial update report.

[7] Analysis discussed in Chapter 2, automotive section.

[8] IEA - India Energy Outlook.

such that they are fully in concert with investment across sectors, technology development, customer-demand creation, economic viability and funding, if it is to enable an orderly transition.

4. **India would benefit from this.** India's transition from thermal power to renewables is expected to decrease the average cost of power supply from INR 6.15/kWh in FY20 to INR 5.25/kWh and INR 5.4/kWh by 2050 in the LoS and Accelerated scenarios, respectively.[9] Sustainable farming practices could help generate additional farmer income of INR 3400/hectares (ha)/annum in the LoS scenario which could increase to INR 4800/ha/annum in the Accelerated scenario. India may save a cumulative $1.7 trillion in Forex which may otherwise be spent on energy imports till 2070. In addition, India will have the opportunity to build right the first time, minimising asset stranding. Finally, if India can get manufacturing in newer technologies going, it can be a world leader in batteries, electrolysers, green steel and many other areas.

5. **There would be shifts in the energy system.** Fossil fuels, which comprise 75 percent of India's commercial energy mix today, decline to half in the LoS scenario and one-sixth in the Accelerated scenario by 2050.[10] In the Accelerated scenario, over 60 percent of India's refining capacity, 90 percent of its coal-mining capacity, 100 percent of its coal power generation would not be needed. Tax collections from automotive fuel, which at $85 billion comprise 18 percent of the annual central government income, could decline to $36 billion by 2050.[11] Scarce biomass feedstock would need to be directed to the right use. For example, the biomass currently being used by households for cooking and which in future could be used for thermal power generation might need to get directed to the hard-to-abate sectors like cement; or sugarcane-based methanol for the transport sector might need to get directed to aviation.

6. **The pressure on land systems will increase.** Growth and decarbonisation combined may require 45 million ha more land than is available (Accelerated scenario). Almost 10 million ha of this would be needed for renewable power and 8 million ha for carbon sinks and forests. Innovative land optimisation techniques such as maximising barren land use for renewable power, vertical urbanisation, improved agricultural productivity, higher forest density would all be needed to ensure there is sufficient land to use for decarbonisation.

7. **There would be a moderate impact on household spending and jobs**. A critical consideration is what impact accelerated decarbonisation would have on Indian household spending and jobs. We estimate that by 2040, the adverse income impact on people with low incomes from decarbonisation through increased housing costs would mostly be balanced by the limited impact on food costs (excluding impact on yields from direct climate change) and the decrease in the costs of energy and transport. This, of course, presumes an orderly transition – if there is a disorderly transition, the inflationary impact on people with low incomes could be adverse. This also assumes that households can mobilise financing for spends where the Capex is higher upfront even though the Opex is lower later (e.g., EVs). Without this support, their up-front capital expenditure may go up. Accelerated decarbonisation could transform over 30 million jobs (24 million new jobs could be created while six million of the existing jobs could be lost) by 2050.[12] However, this number is relatively small in the context of the macro trends affecting India's workforce (e.g., 60 million joining the workforce by 2030, 30 million needing to come off farms into non-farm jobs).[13] That said, specific communities (e.g., coal mining and associated enterprises, Eastern India) could be adversely impacted, requiring reskilling and alternative industrial development in particular areas.

8. **Large funding would be needed (3.5–6 percent of GDP), front loaded, but substantially in the money.** India may need an estimated $7.2 trillion of green investments until 2050 to decarbonise in the LoS scenario and an additional $4.9 trillion for the Accelerated scenario (about 3.5 percent and 2.4 percent of India's GDP through this period, respectively). 50 percent of the abatement between the LoS and the Accelerated scenarios is 'in the money', particularly across the renewable energy (RE), automotive and agriculture sectors; others would need policy support. The net spend (Capex minus Opex savings) is front loaded – the Accelerated scenario would, net of operational savings, require $1.8 trillion more in the decade of the 2030s and $0.6 trillion more in the decade of the 2040s than the LoS scenario.

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[9] Full system cost of power including costs (factoring reasonable returns and system losses) for generation, transmission and distribution. The corresponding cost of power generation Is INR 3.9/KwH.

[10] Ministry of power annual report, 2021–22.

[11] International Energy Agency (IEA) data for fossil based energy; tax value as per petroleum planning and analysis cell (PPAC) using INR 75/USD as conversion rate.

[12] McKinsey Global Institute: The net-zero transition - what it would cost, what it would bring.

[13] McKinsey Global Institute: India's turning point.

## The decarbonisation pathway

India has reduced its emissions intensity of GDP by 1.3 percent per annum over the last decade, somewhat decoupling emissions from GDP growth.[14] However, this pace of intensity reduction is not quick enough. It will not cause India's emissions curve to bend, given the fast growth expected. India's GHG emissions would likely increase to 11.8 GtCO$_2$e by 2070 even assuming the reduction in current GDP emissions intensity. The LoS pathway would reduce annual emissions to 1.9 GtCO$_2$e by 2070 leading to a 90 percent reduction in economic emissions intensity versus 2019. The Accelerated pathway could further close the gap to net zero and reduce annual emissions to 0.4 GtCO$_2$e leading to a 98 percent reduction in emissions intensity by 2070 versus 2019. The LoS scenario would lead to cumulative carbon savings of 207 GtCO$_2$e by 2070 while the Accelerated scenario would create further savings of 80 GtCO$_2$e cumulatively by 2070 (Exhibits B, C, D).[15]

Tackling the 0.4 GtCO$_2$e of annual emissions in 2070, remaining in the Accelerated scenario (Exhibit D) predominantly from industry and agriculture, will require technological advancements, including improved capture technologies, newer recycling technologies and ocean-based carbon sequestration.

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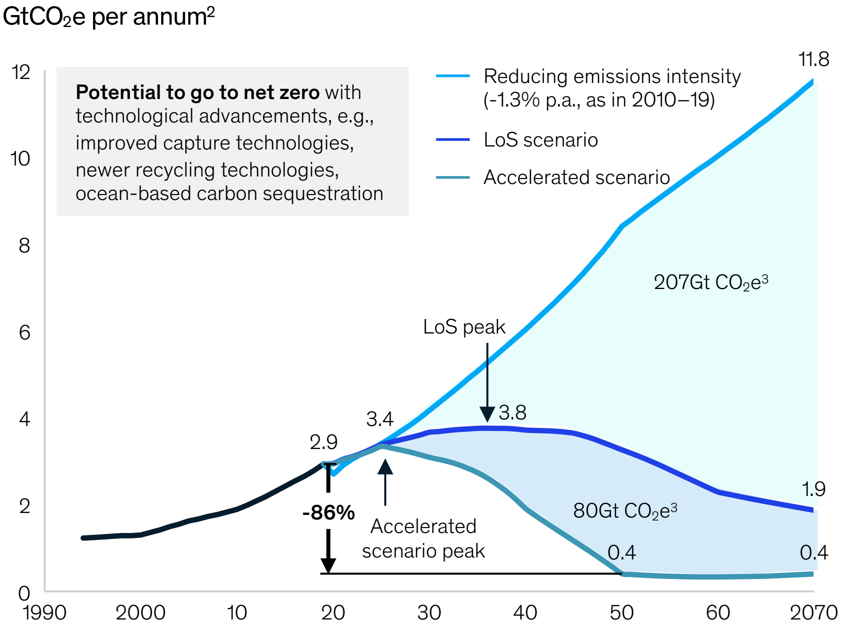
[14] UNFCCC, climate action tracker, McKinsey India DSE, EIU, India's biennial update report 3.

[15] UNFCCC, climate action tracker, India's biennial update report.

Exhibit B

## Possible pathways for India to decarbonise.

**India's GHG emissions**[1]



**LoS scenario**

- **Implementation** of India's NDC, existing and currently announced policies
- Technology advancement as per current trajectory
- Shift in demand to sustainable alternatives in selected areas, e.g., EV

**Accelerated scenario**

- Adoption of **new policies** such as carbon pricing
- **Technology breakthroughs,** e.g., CCUS and faster implementation of existing levers
- **Accelerated shift** to sustainable consumption, e.g., EV, alternative materials, coarse cereals, green steel

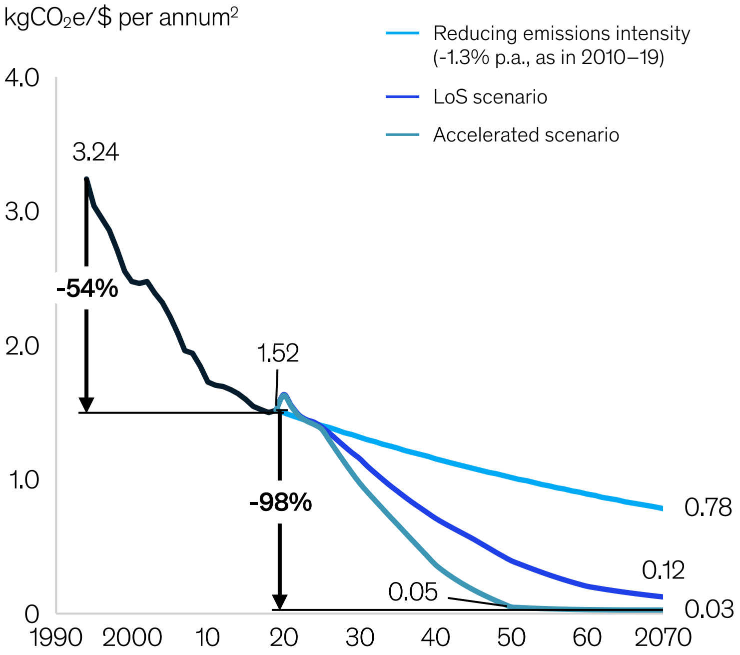
1. These emissions have been estimated with largely currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture).
2. Including LULUCF emissions and offset.
3. Global carbon budget for 1.5 degree pathway as per IPCC AR5 is 580 GtCO$_2$e.

Source: UNFCCC, climate action tracker, McKinsey India DSE, India's biennial update report 3

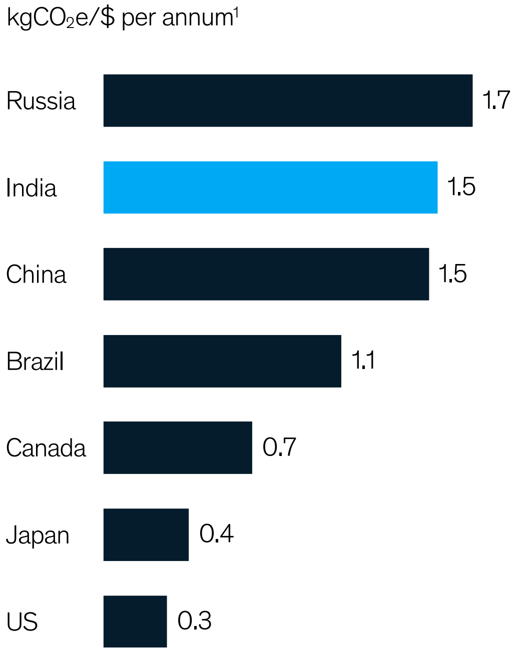
Exhibit C

## Economic emission intensity reduction for India.

**India's GHG economic emissions intensity**[1] (volume of emissions/unit of GDP)



**Current economic intensity of world's top emitter countries**[3]

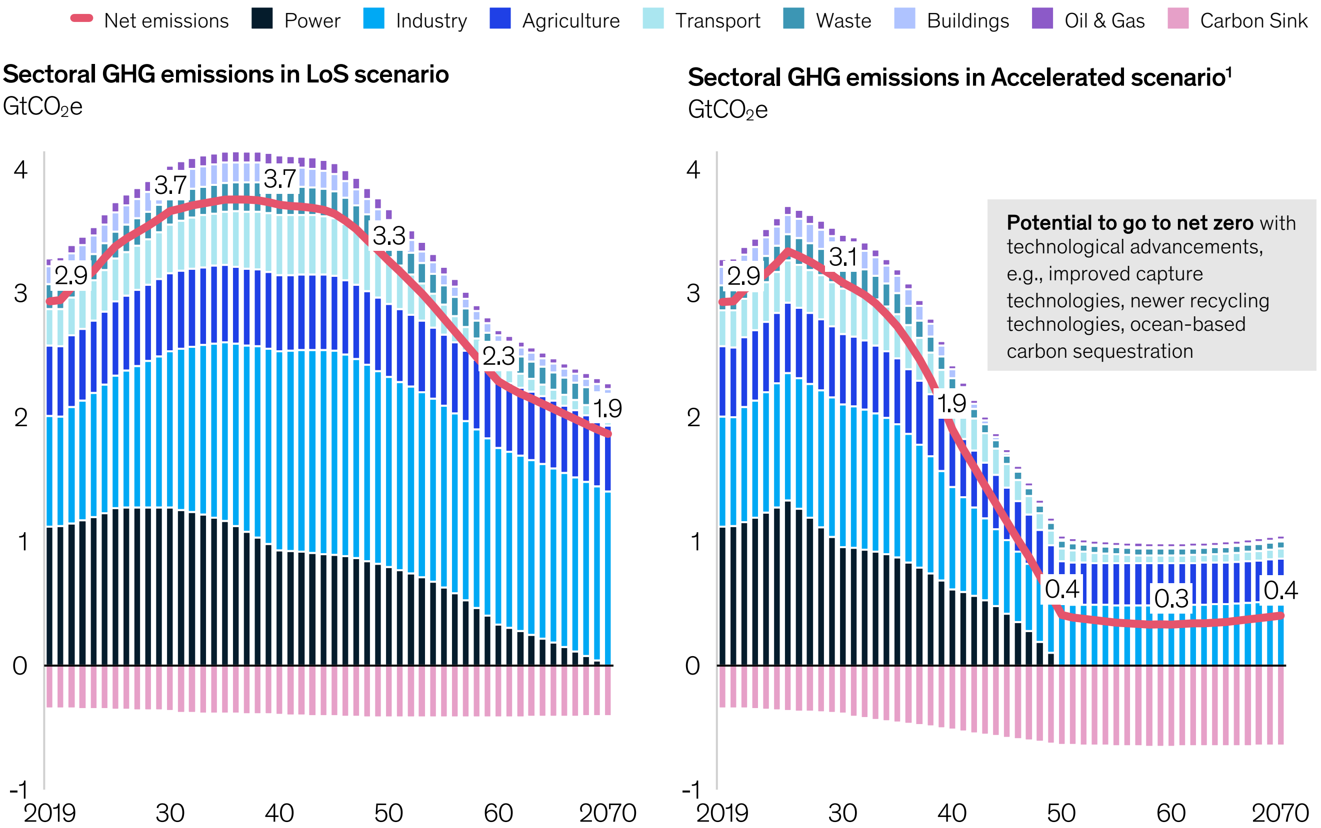


1. These emissions have been estimated with largely currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture).
2. Including LULUCF emissions and offset.
3. Economic emission intensity from annexed and non-annexed countries in UNFCCC.

Source: UNFCCC, climate action tracker, McKinsey India DSE, India's biennial update report 3

Exhibit D

## Emission curves for the LoS and Accelerated scenarios.



**Potential to go to net zero** with technological advancements, e.g., improved capture technologies, newer recycling technologies, ocean-based carbon sequestration

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1. These emissions have been estimated with largely currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture).

## The challenge of rapid decarbonisation

Achieving the LoS reductions will be challenging, those in the Accelerated scenario even more so. India has moved in several sectors with rapid pace – renewables, energy efficiency, EVs, hydrogen. While the results are there for all to see in the continued reduction in carbon intensity of GDP, and with several sectors poised for scale up, there are also major challenges to be overcome (Exhibit E).

For example, in the Accelerated scenario, **renewable** (wind and solar) capacity addition will likely increase from 10–12 GW per year today to 50 GW per year in 2030 and 90 GW per year in 2040. Ten times as much land as is used today would need to be identified and made available. Panels and corresponding raw material manufacturing may need to be scaled up, given 80–90 percent of the solar panels are imported currently.

**In automotive,** 100 percent of two wheelers, three wheelers and light truck sales may need to be electric early in the next decade, all car sales would have to be electric by 2035 and trucks by 2050. For this, battery costs may need to decline by 40 percent in 2030 relative to today. Charging stations would need to increase 13 times by 2030 and 40 times by 2040 relative to today. Consumer financing, given higher, up front EV costs and raw materials for batteries, will need to be found.

**Green hydrogen,** which is not going to be economical versus other alternatives until 2030, would need a subsidy of $60–80/KW for electrolyser manufacturing and carbon prices (within this decade) to support uptake for its largest use case of green steelmaking. 29 GW of electrolysers may need to be installed by 2030 (relative to the current deployment of about 1.4 GW, globally[16]) and almost 400 GW by 2040.

**Across other industries,** steel would need growth in hydrogen green steel capacity from nil today to 152 Mt by 2040 while blast furnace–basic oxygen furnace (BF-BOF) capacity would need to see an increase from 55 Mt today to 119 Mt by 2030 and then a decrease to 85 Mt by 2040. Coal-based power generation would have to transition from 211 GW today to 120 GW by 2040 and nil by 2050. Refining capacities would need to decrease from 213 Mt per annum today to 114 Mt per annum by 2040 and 105 Mt per annum by 2050.

**Additional land** would be needed to meet India's land requirements. This may be needed for agriculture (12 million ha by 2040), solar plants (5 million ha by 2040), forest densification (4 million ha by 2040), etc. However, sufficient volumes of suitable land will not be readily available unless efficient land use practices are implemented.

**Investment,** currently at $44 billion per annum, will likely need to increase 3.6 times by 2030 and 10 times by 2040. This is doable so long as early action is taken to facilitate the transition within this decade, given that a very large proportion of the decarbonisation levers are in the money.

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[16] https://www.iea.org/reports/electrolysers

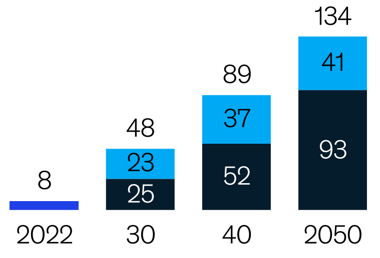
Exhibit E

## Challenges for India's decarbonisation.

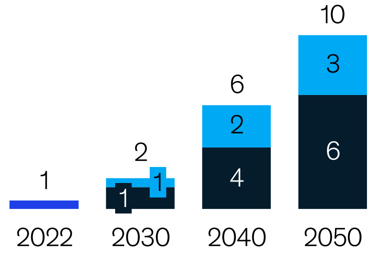
■ LoS scenario
■ Accelerated scenario
■ Current situation

### Power

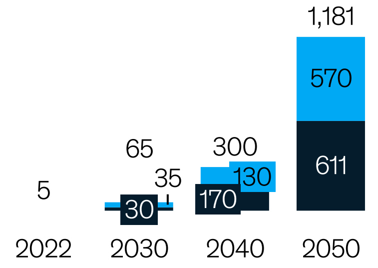
**Average annual solar + wind onshore capacity addition,** GW



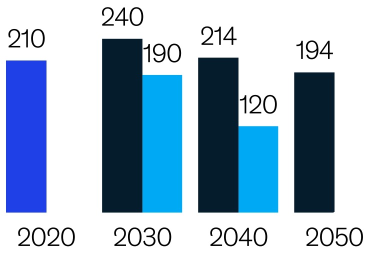
**Land requirement for solar + wind onshore,** Mha



**Storage capacity,** GW

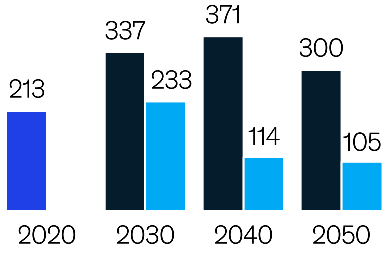


**Coal power generation capacity,** GW

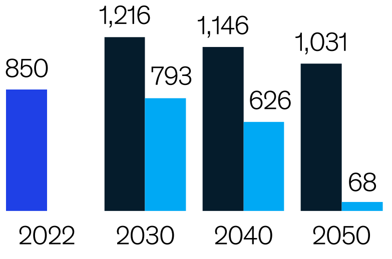


### Energy & hydrogen

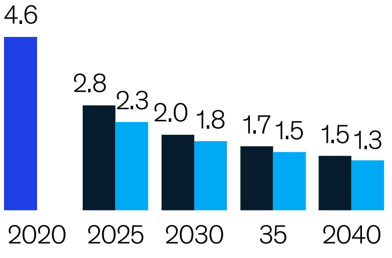
**Refining capacity,** MMTPA



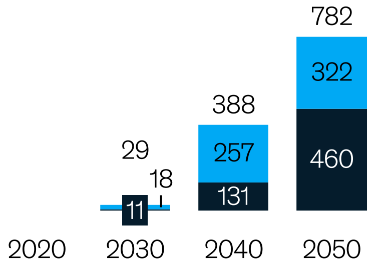
**Coal consumption,** MMTPA



**Cost of green hydrogen,** $/tonne



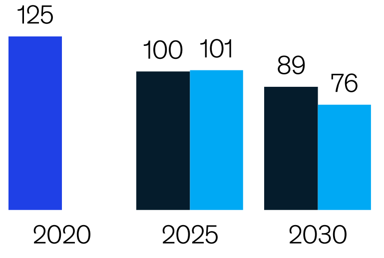
**Electrolyser capacity,** GW



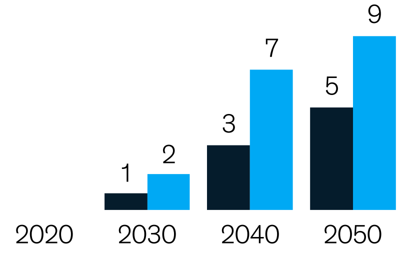
- Subsidy of $60–$80/KW for electrolyser manufacturing

### Automotive

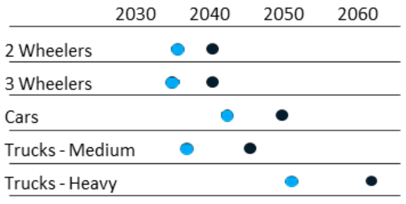
**Battery costs,** $/KWh



**No. of chargers,** millions



**Switchover to 100% EV sales**



- Fame subsidies extended till 2030
- Retail fuel prices maintained
- 2022 battery spot prices hovering around $180/KWh to $195/KWh due to geopolitical issues and Covid impact

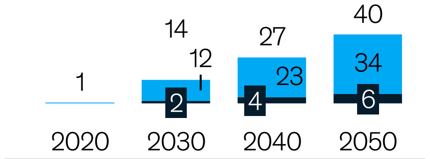
Exhibit E (Continued)

## Challenges for India’s decarbonisation.

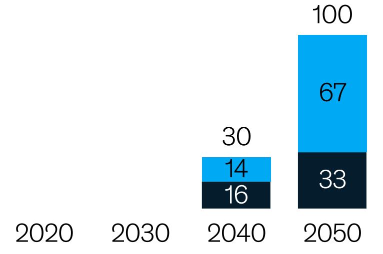
■ LoS scenario
■ Accelerated scenario
■ Current situation

### Agriculture & NCS

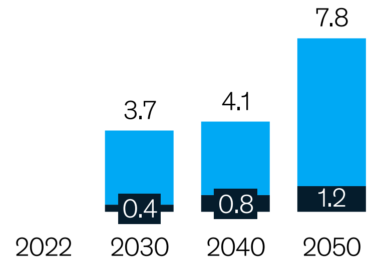
**Improved rice straw management,** %



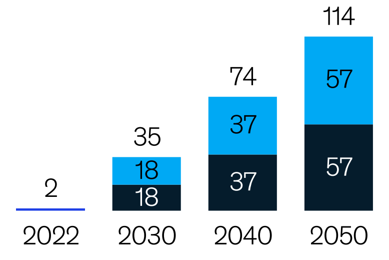
**Electrification of on-farm equipment,** %



**Incremental land required for trees,** Mha

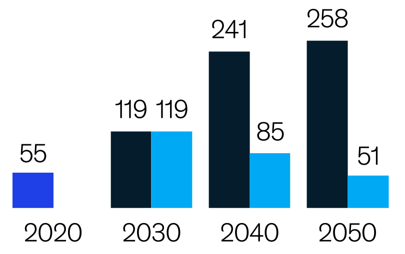


**Incremental land required for regenerative agriculture,** Mha

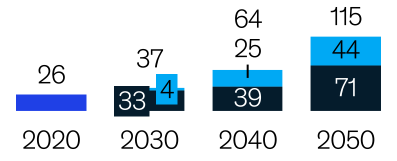


### Steel and cement

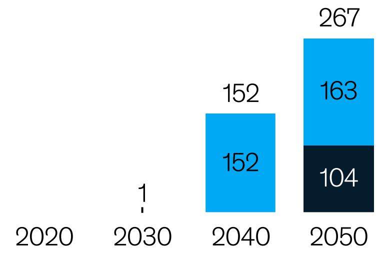
**Steel - BF-BOF capacity,** Mt



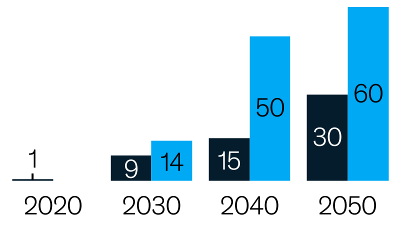
**Steel - scrap based EAF-IF capacity,** Mt



**Steel - hydrogen green steel capacity,** Mt



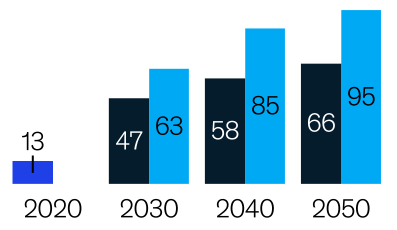
**Cement - heat demand met by green fuels,** %



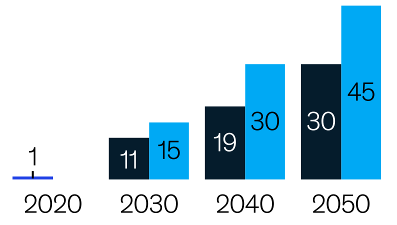
- Carbon price of $50 by 2030
- Clinker to cement ratio reduces to 60% by 2050 in Accelerated scenario (vs 65% for LoS)
- CCUS needed to capture 65% of remaining emissions from cement

### Circularity & financing

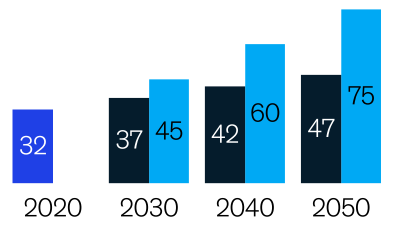
**Recycling rates, plastics,** %



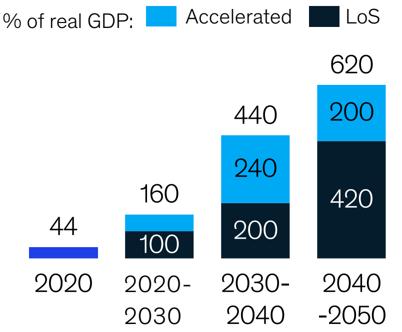
**Recycling rates, construction & demolition,** %



**Recycling rates, municipal solid waste,** %



**Average annual investment,** $ bn



| | | | |
|---|---|---|---|
| 1.6% | 2.6% | 3.1% | 4.1% |
| 1.6% | 4.1% | 6.8% | 6.0% |

Addressing the challenges would need to happen in concert – with stakeholders playing together in harmony. The government would need to create demand signals and the industrial sector would have to bring capacity. Equity and debt funders may have to understand the risk and bring financing at an unprecedented level. Consumers would have to adapt fast.

The risk of a disorderly transition is very high – it has been seen recently in the coal shortages India experienced post-Covid as demand bounced back. Disorderly transitions can occur in many ways. For example – under investment in fossil fuel-based capacities (e.g., coking coal-based steel), even as the demand signals don't build up quickly enough for green steel, leading to import dependence; grid instability and power shortages because of the unbalanced build up of storage capacity or inappropriate use of existing stabilisation sources like hydropower; demand compression due to increased upfront consumer prices for EVs if banks are unable to assess risks and support the higher capital costs; inflation for recycled material if blending mandates are enforced and the recycling infrastructure does not keep pace; new fossil-based capacity build up getting derailed if climate changes force sudden closure.

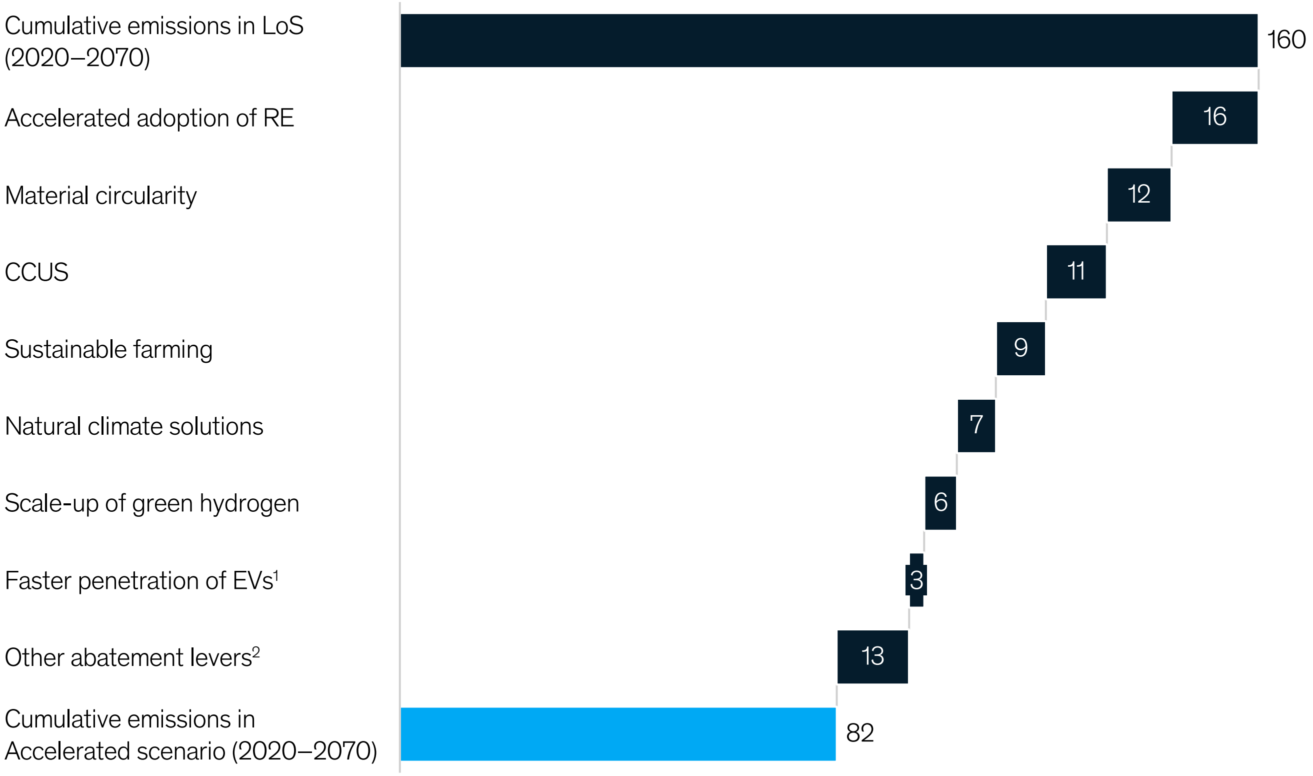
**Major areas of emission reduction need urgent action for an orderly transition**

The Accelerated decarbonisation scenario can cumulatively abate 80 $GtCO_2e$ more than the LoS scenario till 2070. More than 80 percent of this abatement is achievable with seven levers: renewable energy, electrification of mobility, use of hydrogen, implementation of sustainable agriculture practices, material circularity, NCS and CCUS (Exhibit F). Getting these sectors set up for an accelerated transition would need urgent action within this decade.

Exhibit F

## More than 80% of abatement can be achieved through 7 key levers.

**Cumulative emissions reduction between LoS and Accelerated scenarios,** 2020–70, $GtCO_2e$



1. In the LoS scenario, EV penetration reaches 100% only by 2070.
2. Includes other miscellaneous abatement levers such as 100% electrification of cooking, complete treatment of wastewater, improved energy efficiency in industry, and so on.

i. **Expand renewable energy capacity:** 100 percent decarbonisation by 2050 in the Accelerated scenario as opposed to by 2070 in the LoS scenario would result in abating 16 $GtCO_2e$ by 2070. With wind-and solar-generation technologies already available at scale, power would be the quickest sector to decarbonise, potentially reaching net-zero emissions by the mid-2050s.

   India's solar and wind capacity would need to increase from its current 95 GW[17] to 2700 GW by 2050, representing a 95 percent share of generation. This would need an acceleration in the annual build to 40–50 GW from the current 10 GW a year. Ex-bus bar solar tariffs are currently in the range of INR 2.0–2.5/kWh; lower than the marginal generation cost for 60–70 percent of coal power plants.[18] This gap is likely to widen further. Transition to renewable sources of electricity would also decrease power generation costs from the current INR 3.9/kWh to INR 2.9/kWh by 2050, with lower cost renewables and grid-stabilising storage. To accelerate renewable energy production, India would have to quadruple the rate of capacity addition, resolve supply side bottlenecks (land, grid, etc.), accelerate market reforms and storage buildout (1200 GW by 2050) for integration of renewables and grid reliability, foster innovation and localise manufacturing.
   A quarter to two-fifths of the energy supply can be from infirm sources till 2030 in the LoS and Accelerated scenarios, respectively (Exhibit G). The capacity in both scenarios will likely double in the decade of the 2030s and double again in the 2040s. The basics, including capacity-inducing and investment-reducing market reform would need to be put in place now.

---

[17] As of April 2022.

[18] Ex-bus bar tariff excludes the cost of transmission and distribution. Analysis based on the unit-level coal plant variable cost; data from RE navigator and ministry of power annual reports.

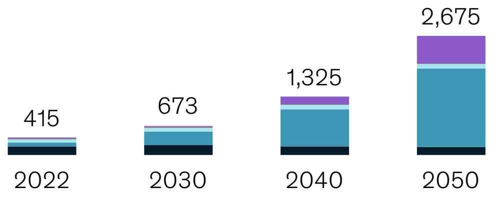
Exhibit G

## Both the LoS and the Accelerated scenarios are realistic—but would likely require substantial investment.

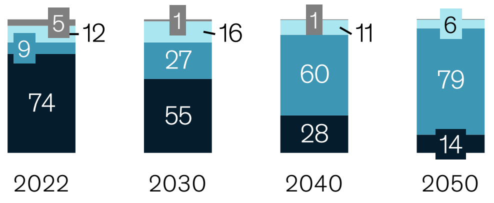
🟥 Transmission & distribution ⬛ Coal ◼ Other fossil[1] 🟦 Solar and wind ◻ Other non-fossil 🟪 Storage[2]

### LoS scenario

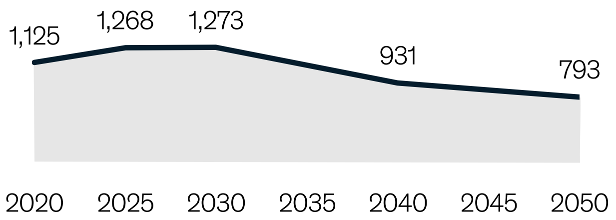
**Non-fossil capacity at 400 GW by 2030**
Capacity evolution until 2050, GW



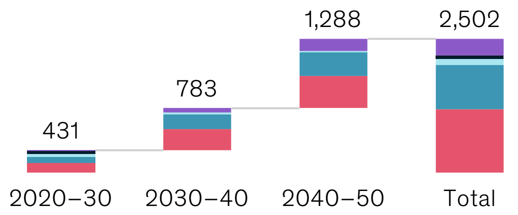
**Coal reaches net zero by 2070**
Generation mix, %



**Emission peaks in the early 2030s**
$CO_2e$ emissions until 2050, Mt



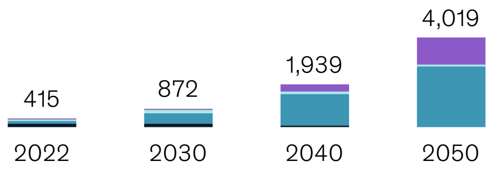
**$2.5 trillion investment required by 2050**
Investments in RE and storage until 2050, $ billions



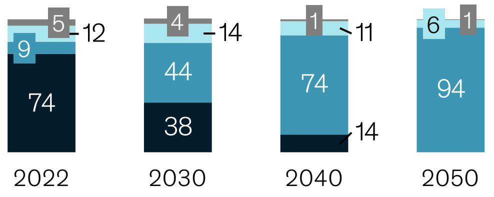
Capacities by 2050: Solar – 1372 GW; Wind onshore – 364 GW; Hydro – 51 GW; Nuclear – 22 GW, Capacities by 2030: Solar – 204 GW; Wind onshore – 86 GW; Hydro – 69 GW; Nuclear – 16 GW.

### Accelerated scenario

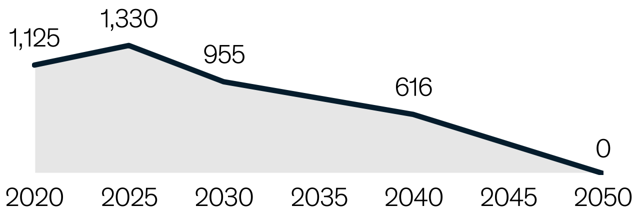
**Non-fossil capacity at 600 GW by 2030**
Capacity evolution until 2050, GW



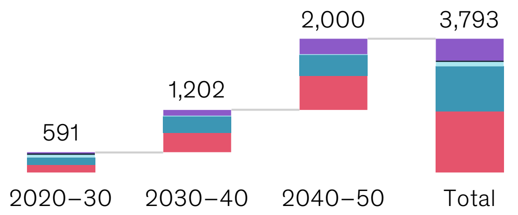
**Coal reaches net zero by 2050**
Generation mix, %



**Emission peaks in mid-2020s**
$CO_2e$ emissions until 2050, Mt



**$3.8 trillion investment required by 2050**
Investments in RE and storage until 2050, $ billions



Capacities by 2030: Solar – 376 GW; Wind onshore – 102 GW; Hydro – 71 GW; Nuclear – 24 GW; Capacities by 2050: Solar – 2172 GW; Wind onshore – 536 GW; Hydro – 54 GW; Nuclear – 22 GW.

1. Other fossil includes gas and oil; other non-fossil includes hydro, biomass and nuclear.
2. Storage includes battery, pumped hydro, LDES 8–24h, LDES 24h+ and hydrogen.

Source: McKinsey Power Model

ii. **Increase penetration of EVs across vehicle types.** Electrification of mobility would likely deliver 7 GtCO$_2$e of cumulative abatement from now till 2070 between the LoS and Accelerated scenarios. This is underway due to advances in battery technology (storage capacity up two times, cost reduction of 17 percent every year over the last 10 years). It enjoys explicit support from the government (GST benefit of five percent for EVs versus 28–51 percent for internal combustion engine {ICE} vehicles; FAME, production-linked incentives {PLI}).[19] Perhaps the most important factor is an implicit carbon tax on transportation fuels of $140 to 240/tCO$_2$e (Exhibit H, I). In the Accelerated scenario, all new vehicle sales are assumed to shift to EVs fully around 2030 for two wheelers, around 2040 for cars and 2040–2050 for CVs. These assumptions are based on total cost of ownership (TCO) parity which needs to be balanced out by market maturity considerations. Typical maturity bottlenecks, which need to be solved, include adequate availability of EV models, charging and swapping infrastructure maturity as well as incentive/dis-incentive schemes as proposed by the government. The infrastructure bottlenecks need decadal Capex investments to the tune of $3 trillion for which the green financing needs to be sorted out. This transition would be enabled by a) further reducing battery costs and fuel cells through at-scale localisation; b) continuing government support through GST and FAME benefits and fossil fuel taxation; c) achieving the target modal mix of 45 percent for rail freight by 2040; and d) targeting affirmative action on select transitions, e.g., commercial fleets, especially heavy commercial vehicles (HCVs).

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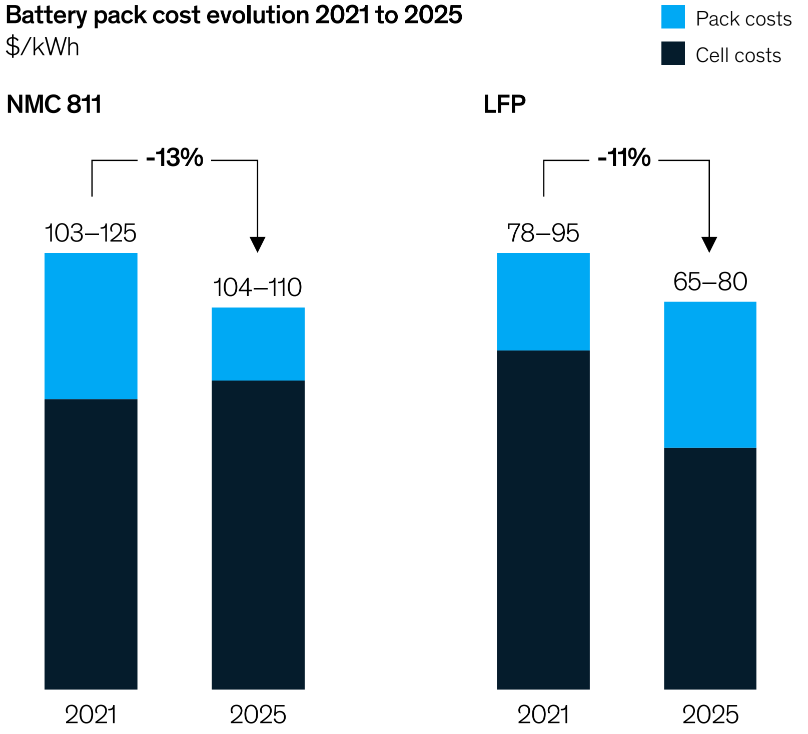
[19] FAME; ministry of heavy industries

Exhibit H

## Battery costs declining rapidly, powering the EV revolution.

**Battery pack cost evolution 2021 to 2025**
$/kWh



**Main drivers of scale effect**

- Increase in EV demand
- Improvement in learning & yield rates
- Increase in average plant size from 9 GWh in 2021 to 18 GWh in 2025
- Spread of direct & indirect cell production costs such as labour, SG&A, logistics, R&D costs and PPE & depreciation

**Main drivers of technology effect**

- Energy density increase (impact on direct material and fixed costs) as well as component technology of cathode, anode and electrolyte
- Gains from next-generation cathode (advanced NMC 811)
- Reduction in the cost of cell components such as separator, copper foil, aluminium foil, etc.

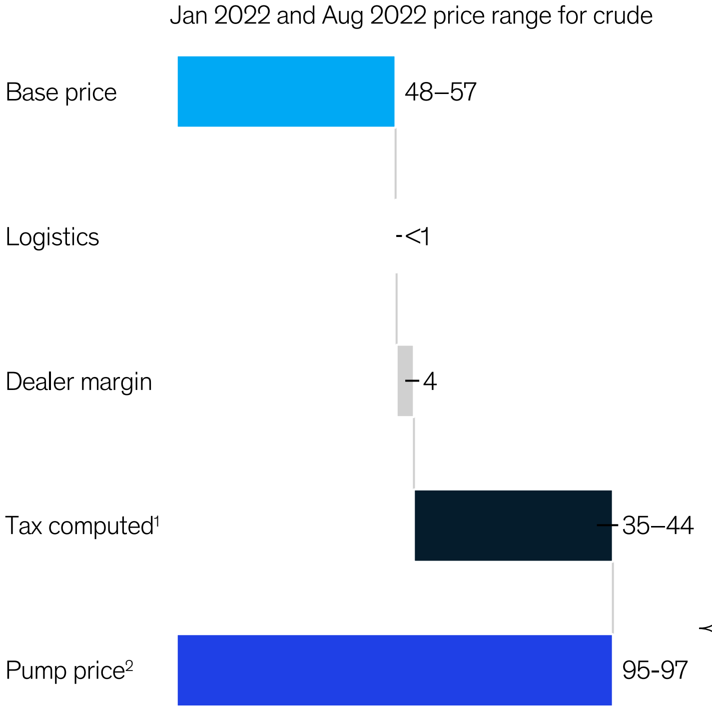
Note: Cost+ at 10 GWh plant in China, excluding the LFP royalties; LFP Export VAT 13%.

Source: McKinsey Battery insights – Battery Cost model

Exhibit I

## Substantial implicit carbon tax on automotive fossil fuels.

**Fuel price breakdown (Delhi example),** INR/lit



| Fair taxation | Implicit carbon tax (INR/lit) | Implicit carbon tax ($USD/tCO_2e$) |
|---|---|---|
| At 5%[3] of product cost[4] | **33–41** | **190–240** |
| At 18% of product cost[4] | **25–34** | **140–200** |

**Assumptions**

1. Includes excise duty and VAT; ignores OMC losses or absorbed costs.
2. Gross sale price at the pump without any fair taxation at Delhi is INR 96.72 in Aug 22, INR 95.41 in Jan 22.
3. Current average electricity tax rate.
4. Product costs are a summation of base price and logistics costs and dealer margins.
5. Per litre consumption of petrol produces 2.3 kg of $CO_2$; i.e., 435 litres of petrol produces 1-ton $CO_2$.

Source: Press, McKinsey analysis

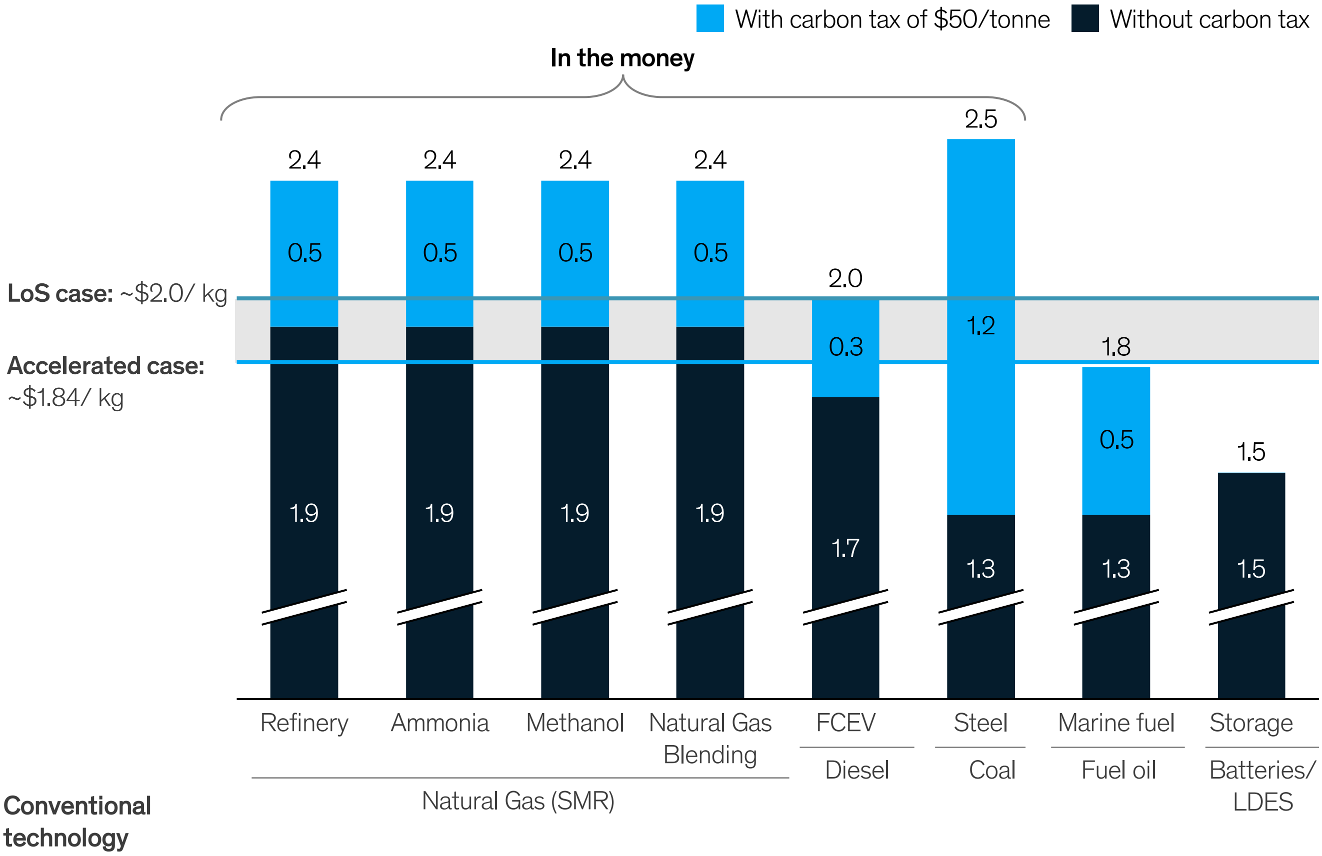
iii. **Ramp up green hydrogen as fuel or feedstock:** Hydrogen is a versatile energy source and chemical reductant. Adoption of green hydrogen could enable an annual abatement of 900 $MtCO_2e$ for India by 2050. This is subject to the evolution of the cost competitiveness of green hydrogen against alternative energy sources, which can be accelerated by faster R&D, adopting technology and ensuring early demand that drives down costs. Green hydrogen demand would first emerge as a replacement for grey hydrogen in use cases like refining, urea, methanol as it becomes more competitive versus grey hydrogen by 2030. In our LoS scenario, hard-to-abate sectors such as steel, automotive and power would drive demand only in the decade of the 2040s. These sectors have the potential to drive a disproportionate portion of the demand for green hydrogen in the decade of the 2030s and 2040s with blending mandates and a carbon price of $50 per tonne (Exhibits J, K).

Exhibit J

## Green hydrogen could become competitive for a majority of the use-cases by 2030.

**Required hydrogen production costs for breakeven against conventional technologies**

$/ kg in 2030

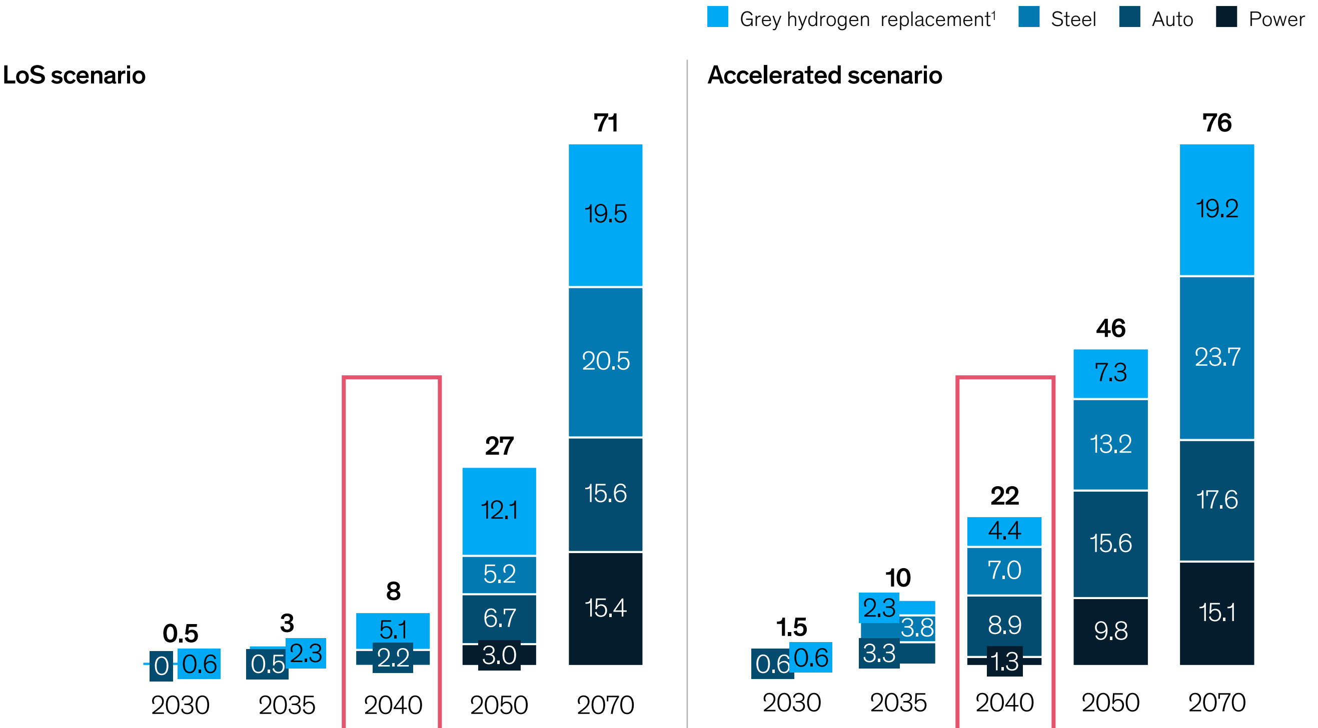


Source: McKinsey Hydrogen Insights: Breakeven Analysis

Exhibit K

## Hard-to-abate sectors drive disproportionate demand for hydrogen in the Accelerated scenario.

**Green H2 Demand,** MMTPA bottom-up sector wise projections



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$CO_2$ abated** MMTPA | 5 | 27 | 71 | 302 | 810 | 20 | 155 | 310 | 535 | 903 |
| **$ billion** | 1.2 | 4.8 | 10.6 | 33.0 | 64.1 | 3.1 | 16.2 | 31.5 | 56.0 | 68.3 |

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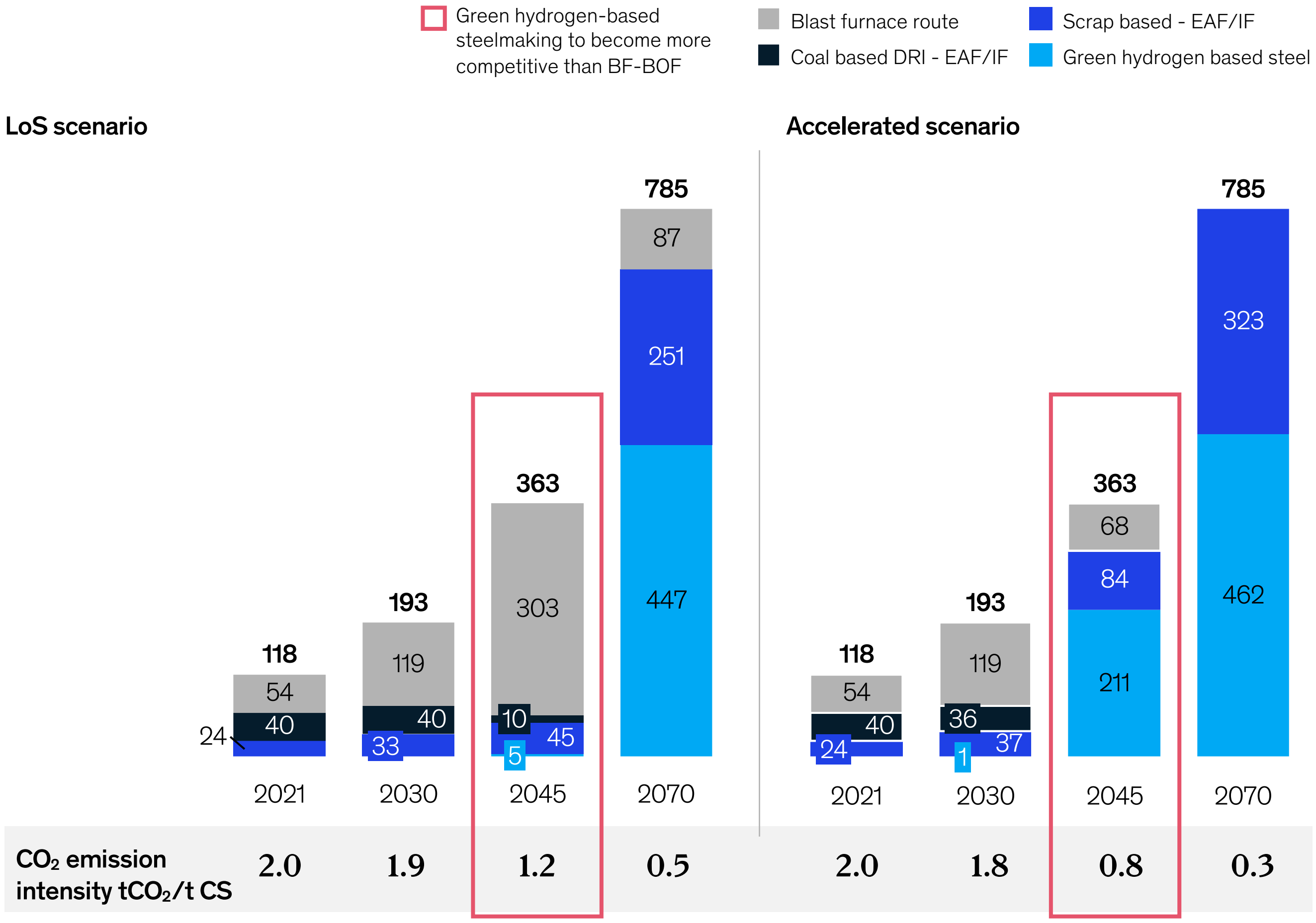
1. Includes refineries, methanol production, fertiliser production and city gas blending.

Exhibit L

## Crude steel production by route.

MMTPA



Note: Assumes scrap rate increasing from 10% currently to 20% in BF-BOF by 2040; scrap rate in green hydrogen-based EAF at 10%; DRI usage in EAF scrap at 10% of total metallic mix.

Source: McKinsey decarbonisation TCO model v14, Metal Bulletin

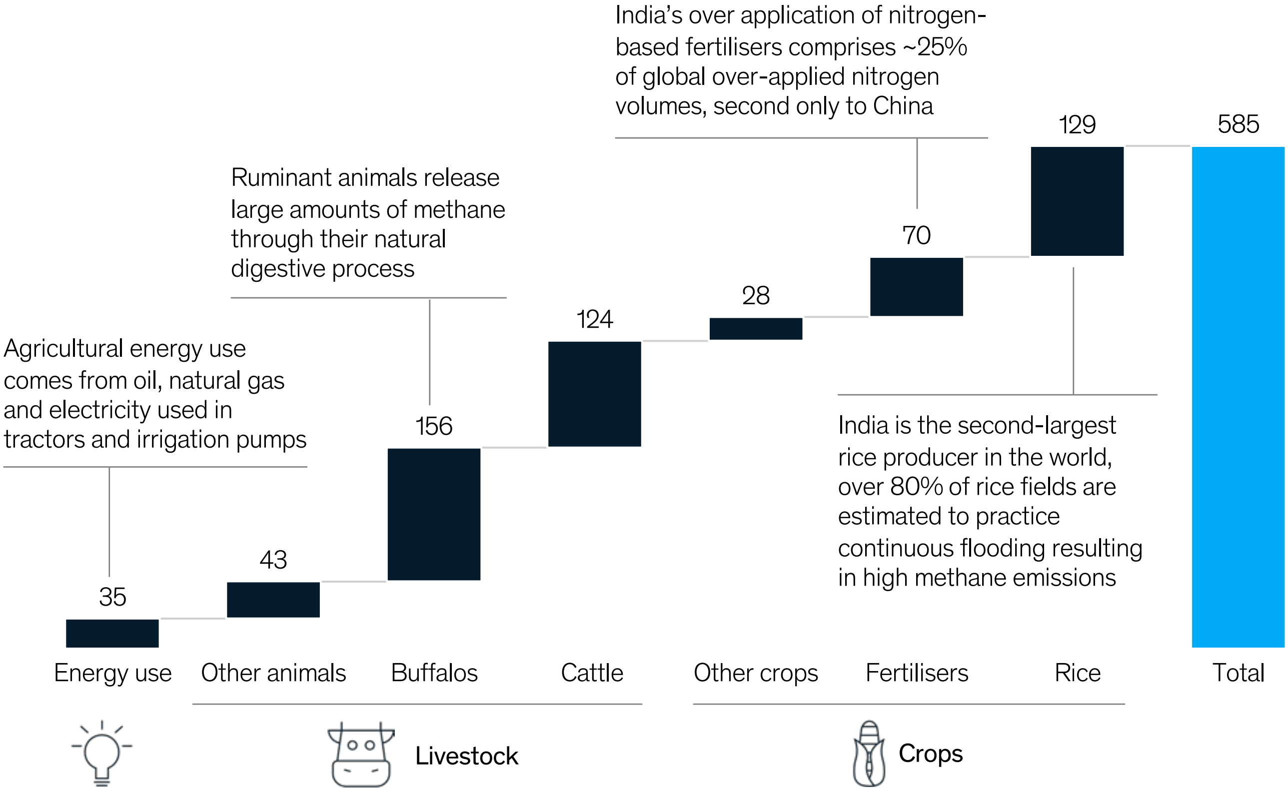
Accelerating hydrogen adoption in steel-making will help India build sustainable assets that could help India in its decarbonisation journey. The steel industry will likely make an investment of about $265 billion over the next 30 years in the new BF-BOF capacity installation, which could run the risk of getting stranded in case of climate shock or early closure, even with India's 2070 net-zero NDC. Indian steelmakers could avoid this risk by investing early in green hydrogen-based steelmaking instead of going down the conventional blast furnace route to the tune of 200 Mt starting from 2030 (Exhibit L). This would need to be enabled by the right policies including a carbon price of $50/t, plans for which would have to be in place within two or three years for steelmakers to plan their investments. This would create additional carbon space of 5.7 $GtCO_2e$, and result in cumulative Forex savings of $280 billion on coking coal imports by 2050. Early adoption of hydrogen also enables Forex savings of $420 billion on oil & gas imports.

iv. **Reform agriculture and dietary systems:** Decarbonisation in the agriculture sector can lead to annual carbon abatement of 292 $MtCO_2e$ by 2050, or nearly half of all expected annual emissions from agriculture. This would mainly be driven by cultivating rice sustainably (20 percent of abatement), reducing nitrate fertilisers (16 percent) and shifting towards sustainable consumer alternatives such as plant-based protein (15 percent) and millets (7 percent).

Exhibit M

## Agriculture is one of the largest emitters of GHG in India.

**GHG emissions from agriculture in 2019 by category**
$MtCO_2e$



India's over application of nitrogen-based fertilisers comprises ~25% of global over-applied nitrogen volumes, second only to China

Ruminant animals release large amounts of methane through their natural digestive process

Agricultural energy use comes from oil, natural gas and electricity used in tractors and irrigation pumps

India is the second-largest rice producer in the world, over 80% of rice fields are estimated to practice continuous flooding resulting in high methane emissions

1. Includes goats, sheep and swine.

Source: Food and Agricultural Organisation; UNFCCC; McKinsey India Decarbonisation Model

Paddy farming and livestock account for 70 percent of agricultural emissions (Exhibit M).[20] Reducing paddy farming emissions by practicing rice-straw upcycling, dry seeding and rice intensification (SRI) over half of India's rice cultivated area and reducing livestock emissions by adopting efficient feeding and manure management practices for half the livestock population would be critical for decarbonising agriculture.

v. **Drive material circularity:** India currently generates 750–800 million tonnes of waste across waste streams with recycling rates of 13 percent for non-agricultural waste streams.[21] Improvement in recycling rates to 80 percent could provide significant recycled raw material and help abate up to 34 $GtCO_2e$ by 2070 in the Accelerated scenario (12 $GtCO_2e$ more than in the LoS scenario which assumes recycling rates increasing to 55 percent). Recycled raw materials help save 50–95 percent emissions in material production across steel (scrap-based electric arc furnace {EAF} steel production), cement (recycled concrete, biomass fuels), plastic (recycled feedstock, recycled plastics), aluminium and other materials.[22] While most technologies for recycling various waste streams already exist, driving material circularity would require investment in recycling infrastructure as well as enforcement of waste management and extended producer responsibility regulations. Demand signals would need to be created through recycled material use mandates.

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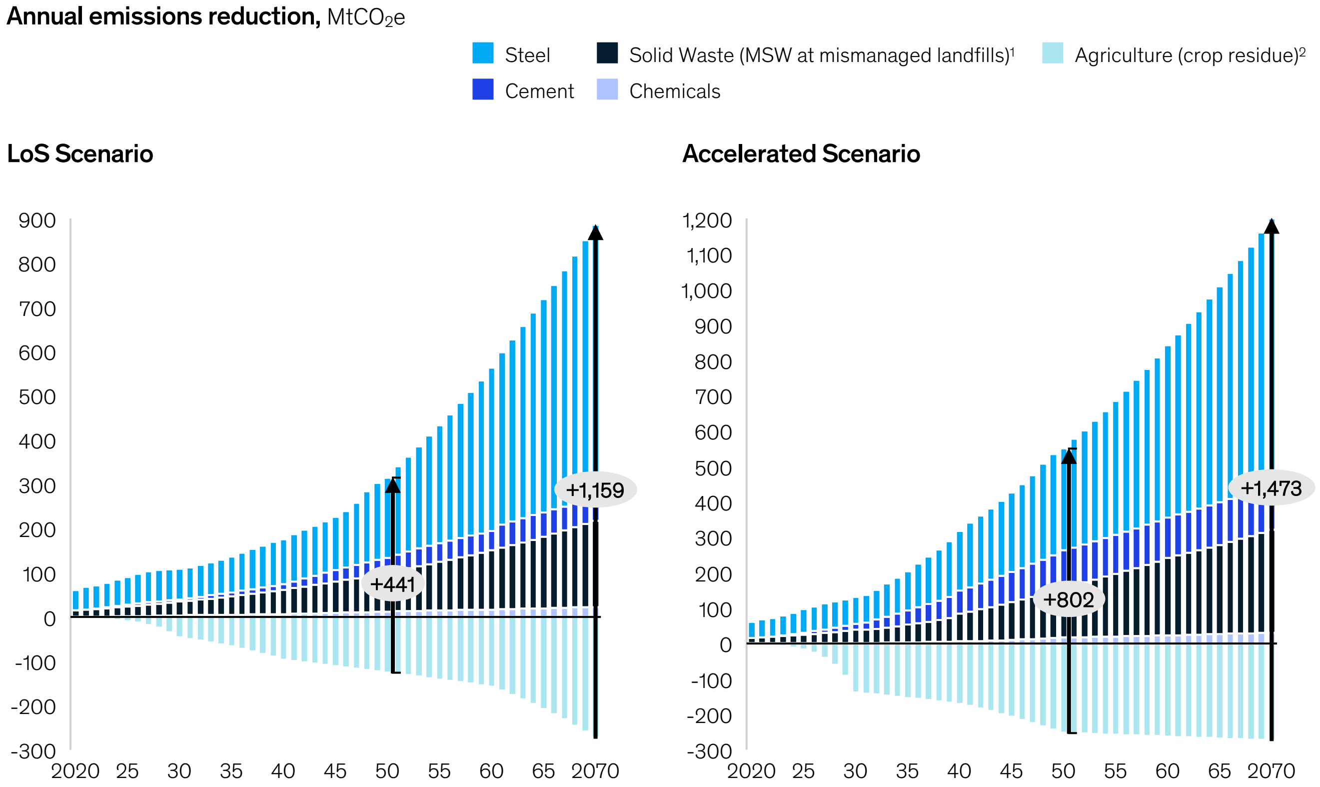
[20] McKinsey analysis on data from FAOSTAT.

[21] World consumer research report; United Nations development programme (UNDP) plastic waste management programme; Central pollution control board (CPCB) solid waste management reports, Indian textile journal; Indian council for agricultural research; ministry of steel; Building material promotion council; FAO; Ministry of Steel – Steel Scrap recycling policy; National Policy on Crop Residue Management by Ministry of Agriculture.

[22] Material economics – the circular economy report.

Exhibit N

## Emissions reduction by driving material circularity across sectors.



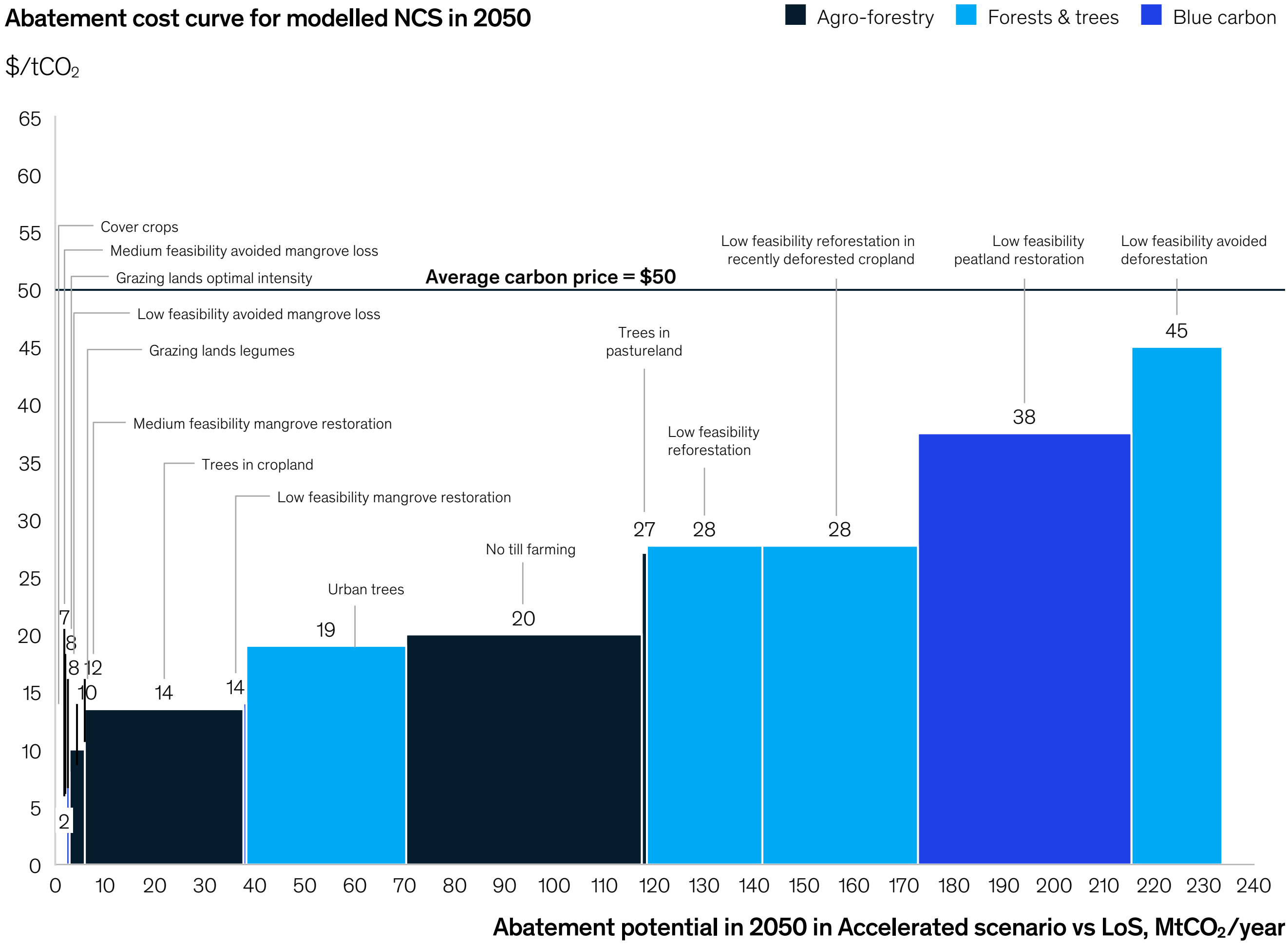
1. Emissions from mismanaged landfills from MSW (Municipal Solid Waste) containing organic and inorganic waste including paper, plastic, textiles among others
2. Sequestration through non-incineration-based uses of crop residue (e.g., paddy straw).

Source: World Consumer research report; UNDP Plastic Waste Management Program, CPCB Solid Waste Management Reports, Indian Textile Journal, Indian Council for Agricultural Research, Ministry of Steel, Building Material Promotion Council, FAO, Steel recycling, Ministry of Steel – Steel Scrap recycling policy, National Policy on Crop Residue Management by Ministry of Agriculture.

vi. **Sequester using natural climate solutions (NCS):** NCS can help remove or sequester emissions through the conservation and restoration of nature. In the Accelerated scenario, India's natural resources can sequester 640 $MtCO_2e$ annually by 2050, nearly 300 $MtCO_2e$ higher than the 2019 levels and 230 $MtCO_2e$ more than the LoS scenario. This translates to additional sequestration of 3 $GtCO_2e$ between 2020 and 2050, and 7 $GtCO_2e$ by 2070 compared to the LoS scenario. Nearly 85 percent of sequestration would come from forests (avoiding deforestation, reforestation), agroforestry (trees in cropland, regenerative agriculture) and urban tree plantation. This would involve restoring an additional eight million hectares of forest (over 10 percent of current forest cover) and practicing regenerative agriculture (such as low-till farming) in at least half of India's croplands, as opposed to 20–25 percent adoption in an LoS scenario. A \$50 per $tCO_2e$ carbon price will enable this sequestration (Exhibit O).

Exhibit O

## $CO_2$ abatement through NCS can be achieved below a carbon price of \$50/$tCO_2e$.



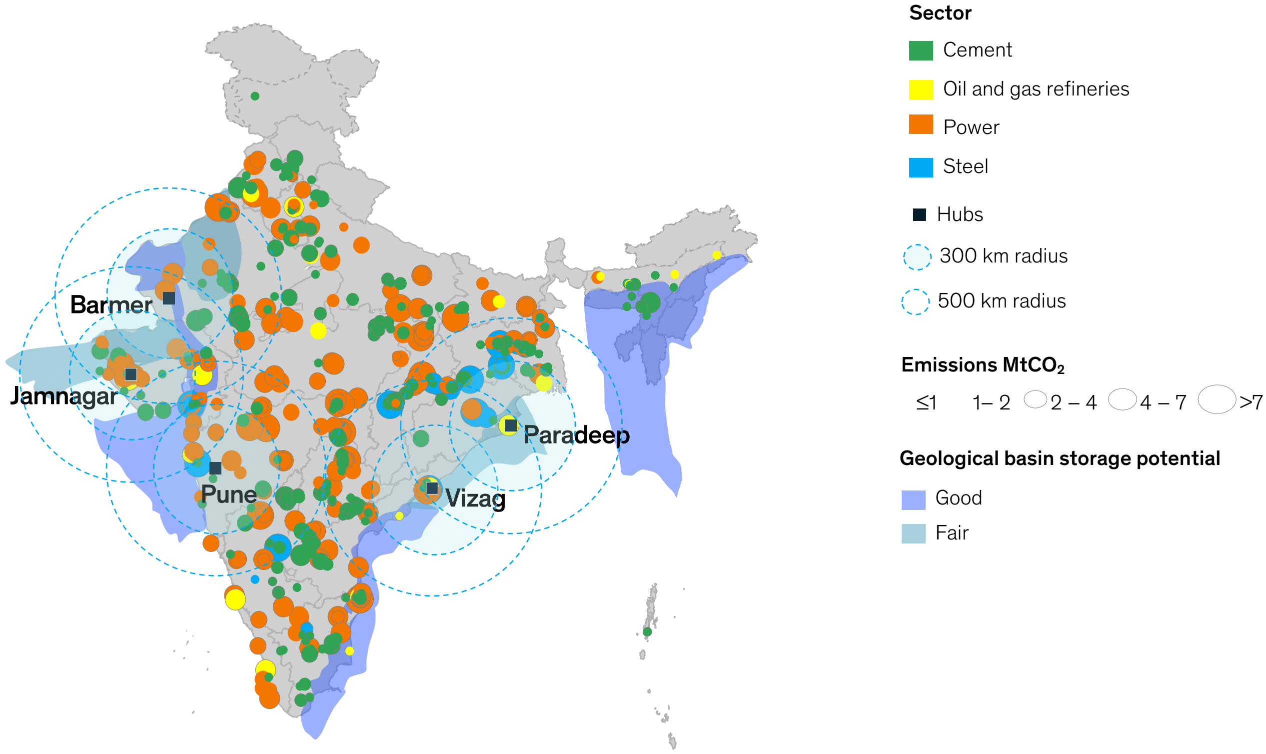
Source: McKinsey Nature Analytics

vii. **Scale CCUS across industries:** Adoption of new carbon-capture technologies could help reduce industrial emissions further, particularly for hard-to-abate sectors like cement, oil and gas and chemicals. CCUS could help capture 11.4 $GtCO_2e$ across these sectors cumulatively by 2070 for utilisation or storage. A hub model set-up for CCUS could be a cost-effective approach and five hubs in India located close to storage could address 70 percent of point source emissions with a transportation radius of up to 500 kilometres (Exhibit P). There could also be a potential for utilising the captured carbon in applications like chemicals production, artificial limestone and construction blocks. CCUS is expensive and would require significant investment and R&D to scale and become cost-effective, and is likely to be a small abatement lever.

Exhibit P

## Around 25–30 percent of point source emissions could be captured within 300 km and 65–70 percent within 500 km of five hubs.

**Possible CCUS hubs in India**



Source: Global Greenhouse Gas Emissions, EDGAR; Joint Research Centre, European Commission; Netherlands Environmental Assessment Agency

## Implications for energy systems

India depends on fossil fuels to meet approximately 75 percent of its current energy demand.[23] This declines rapidly in both the scenarios (Exhibit Q). For example, decarbonisation in the transportation sector would require shifting from petroleum-fuel cars to EVs. The industry sector would shift from a reliance on fossil fuels to a mix of electricity, hydrogen and biomass for its manufacturing processes. In agriculture, farm equipment would become electric. And, as India moves away from coal-based power generation to renewables such as solar and wind, thermal coal demand would reduce drastically. Primary energy demand in the Accelerated scenario would be lower by 18 to 24 percent between 2030 and 2050 driven by higher energy efficiency, circularity and shifts in material use.

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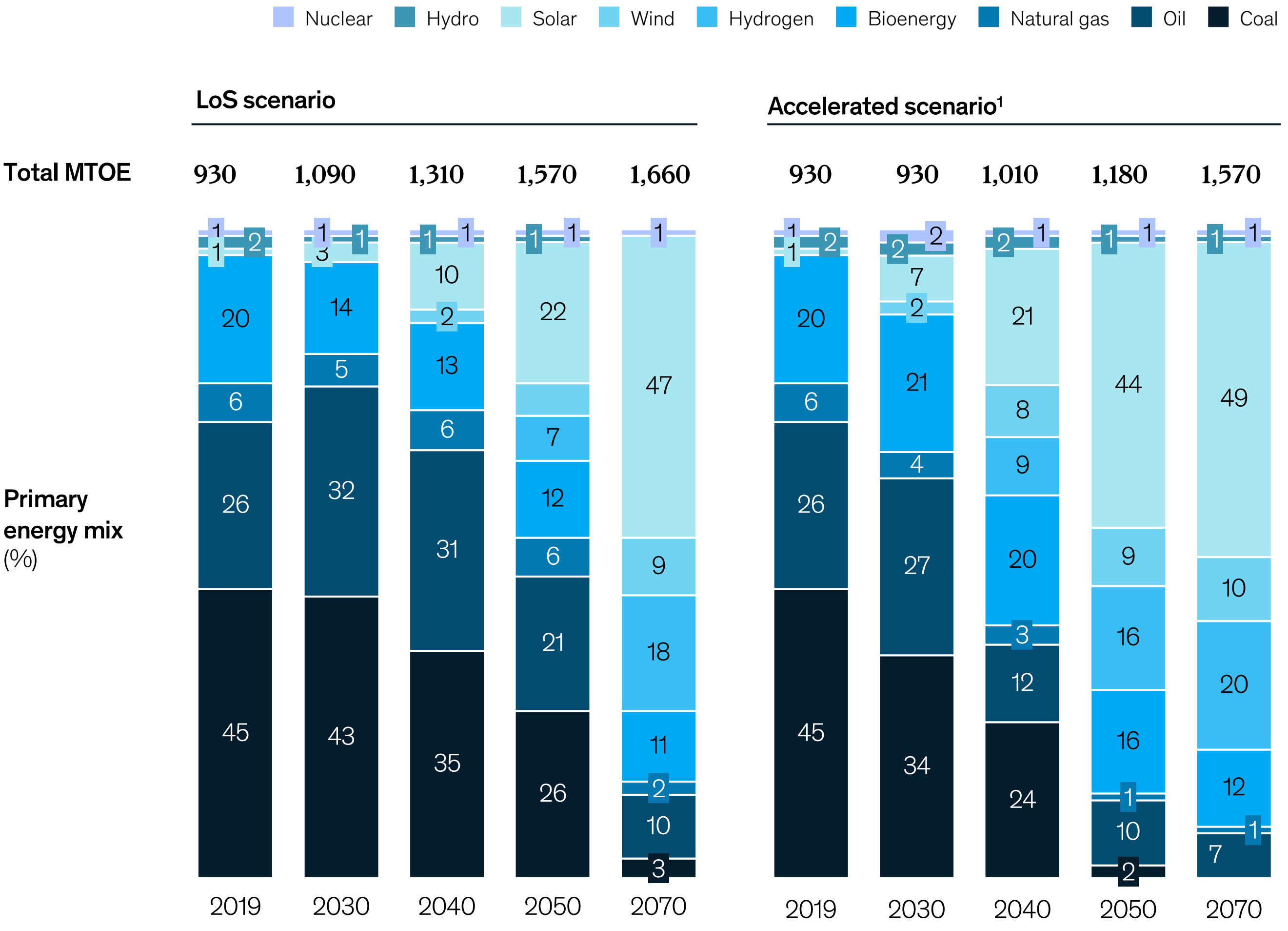
[23] IEA world energy balances

Exhibit Q

## The primary energy mix would likely shift to renewable sources of energy.



1. Total primary energy supply is lower in Accelerated scenario than in LoS scenario because of how renewables are accounted for

**Implications for the Accelerated scenario:**

- **Shrinkage in refining capacity**: The current refining capacity of 250 Mt per annum would increase to 298 Mt per annum by 2030 but then 182 Mt per annum of refining capacity would need to be repurposed or abandoned by 2040. Refiners can repurpose some of the existing refinery assets to produce petrochemicals, green hydrogen, ammonia, synthetic fuels, etc.
- **Reduction in tax revenues:** The total contribution of the petroleum sector to the exchequer is $103 billion, of which $85 billion is tax collection. In the Accelerated scenario, the tax collection may drop to $35 billion by 2050.[24]
- **Reduction in coal mining and closure of coal-based power plants:** By 2050, coal consumption for power would be reduced to a tenth of current consumption and all current coal-based power capacity (211 GW) would need to be decommissioned. Most of this decline would be driven by the power sector's shift to renewable energy sources. The remaining coal used to make steel and generate heat in cement production would also be phased out over time, as the consumption of green fuels such as electricity, hydrogen and bioenergy increased.
- **Corrected use of biomass and agri-based fuels.** Today, the bulk of bioenergy demand is in the form of biomass usage in residential buildings for cooking purposes. The remaining demand, which amounts to less than a quarter of total demand, comes from the power sector. Going forward, scarce feedstock would need to be directed to be used correctly. For example, the biomass currently being used for the power sector and agri-based fuels for the transport sector will need to get directed to the hard-to-abate sectors like cement and aviation, respectively. The bio-fuels usage envisaged for the future could fundamentally transform how agriculture residue will be used in the future versus how it is directly burnt today.

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[24] IEA data for fossil based energy; tax value as per PPAC using INR 75/USD as conversion rate

## Implications for land use

India has a total land area of 329 million hectare, out of which 21 million ha consists of inland waters, leaving a total of 308 million ha of available land. Today, 23 percent of this available land is forest area, 59 percent is agricultural land and the remaining 18 percent is used for non-agricultural purposes, grazing pastures and barren land.[25] As India grows in a sustainable fashion in the Accelerated scenario, it will need land not only for urbanisation, industrial capacity and increasing agricultural output but also for renewable power, carbon sinks and biomass feedstock for decarbonisation.

Based on current land usage practices, we estimate that the total increased land area requirement would be 45 million ha in 2050 versus today (Exhibit R). However, this land is not readily available, and India will have to implement efficient land use practices to ensure that necessary land can be made available. These measures would need to be innovative and could include increasing agricultural productivity by adopting sustainable and higher-yield farming practices, using barren land for installing solar and wind power plants, increasing the density of forests to meet carbon sink goals and using vertical urbanisation to create higher population densities in towns and cities, instead of increasing the overall built-up area. However, these measures will likely free up only 34 million ha, leaving a further 11 million ha unsolved for.

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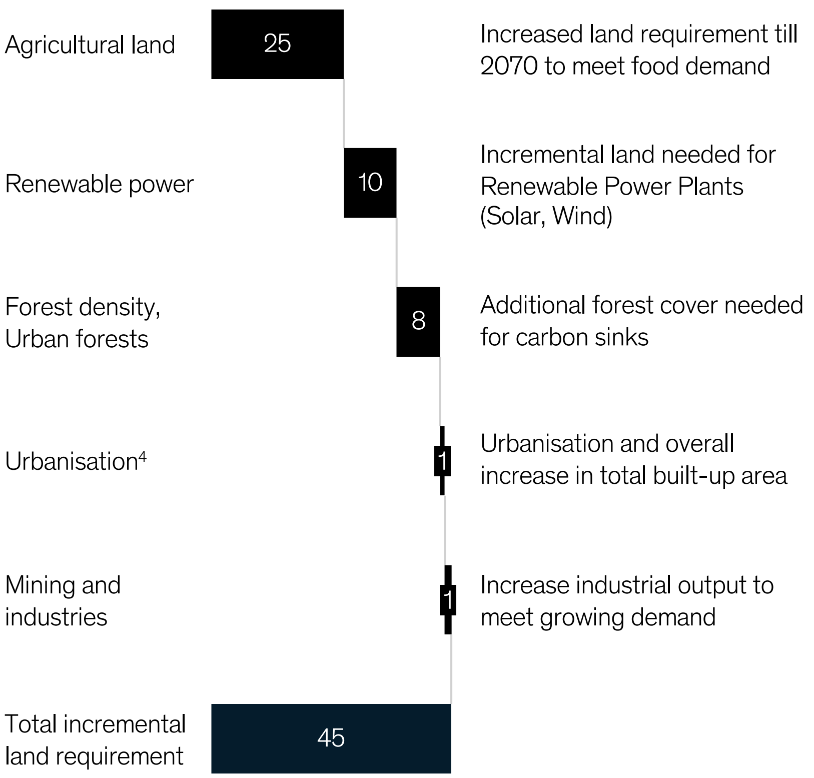
[25] Land use statistics at a glance, Government of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture & Farmers Welfare, Directorate of Economics & Statistics, November 2021

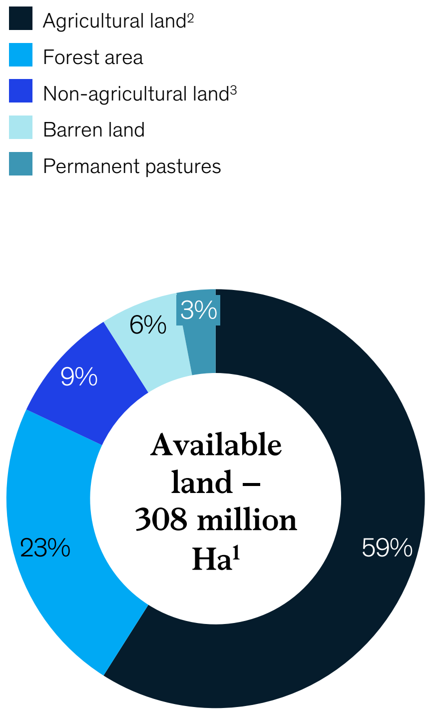
Exhibit R

## 45 million ha incremental land would likely be required in the Accelerated scenario by 2070.

**Incremental land requirement in 2070 versus today**
Mn Hectares



**India's current land use, Percentage of available land**



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1. Total land 329 mn ha less Inland waters of 21 mn ha.
2. Agricultural land includes croplands, culturable wastelands, land under miscellaneous tree crops and fallow lands.
3. Non-agricultural land includes built up urban and rural areas, mining land and land used for other industrial purposes like railways, irrigation, etc.
4. Urbanisation requirement includes a need to increase built up urban area by 3.7 mn ha, which is offset by a decrease in rural built-up area by 2.8 mn ha.

## Impact on people – spending and jobs

A critical consideration for accelerated decarbonisation is the impact it will have on the average Indian household's spending. Our estimate suggests that there will be minimal inflationary impact on households below the Empowerment Line[26] by 2040 (Exhibit S). Food spending sees no major impact (expenditure in agriculture may be offset by cost savings from sustainable practices and improved productivity), whereas energy and transport spending are reduced due to lower power generation costs with renewables and operational savings due to the shift from ICE vehicles to EVs. Housing could become somewhat more expensive due to the increase in steel and cement prices. This is a preliminary viewing that could bear more precise analysis. Also, this assumes that higher upfront costs of EVs would be addressed by financing, paid for by operating cost savings. If the financing does not come, this would impact affordability and demand.

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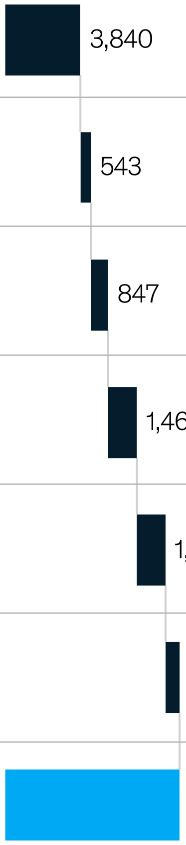
[26] https://www.mckinsey.com/featured-insights/asia-pacific/indias-path-from-poverty-to-empowerment

Exhibit S

### Decarbonisation-driven household spending impact for households on the Empowerment Line[1] (in year 2040).

↔ No major impact ↓ Decrease in spending ↑ Increase in spending



| | **Normative spend for household FY20** (INR/month) | | **Impact in Accelerated scenario in 2040** | **Factors not considered** |
|---|---|---|---|---|
| Food | 3,840 | ↔ | Incremental agri capex offset by savings from sustainable practices, improved productivity, and income from crop residue and agroforestry (carbon credits) | Climate impact on agriculture yields and hence food prices |
| Housing | 543 | ↑ | Increase in cost of cement (impact of 1-1.5%) and steel (impact of 0.5–1%) increases housing costs | Land price increases caused by land demand for decarbonisation |
| Energy | 847 | ↔ | Decrease in average supply cost from 6.15 kWh to 5.4 kWh. Increase in T&D costs offset by decrease in generation costs due to shift to RE and reduction in AT&C losses | Land driven increases, increase in raw material prices |
| Transport and others[2] | 1,463 | ↓ | ICE to EV shift leads to reduced costs | Financing assumed to be available for higher upfront cost of EVs; fuel related tax losses not compensated for through auto and power taxes |
| Health and social security[3] | 1,450 | ↔ | Increased cost of building infrastructure, lower spends on transportation and power costs, not impacting the overall spend | Adaptation costs |
| Education[4] | 702 | ↔ | No major impact | |
| **Total** | **8,845** | ↔ | | |

1. MGI 2014 Report: From poverty to empowerment. Data adjusted for inflation and household of four people assumed.
2. Includes clothing, footwear, entertainment, communication and domestic appliances.
3. Adjustment for value of subsidies in sanitation and drinking water is included under health.
4. Includes elementary and secondary education.

Source: McKinsey Global Institute analysis

The accelerated decarbonisation is expected to impact jobs and skills requirements across sectors as they decarbonise. India's coal mines are estimated to employ around 0.35 million workers currently. Additionally, more than 1.7 million people are indirectly dependent on the coal sector.[27] The phasing out of coal as India decarbonises would need to be supported by new businesses that support the transition for this workforce. Similarly, as two-thirds of the 2030 refining capacity could be closed by 2050 in the Accelerated scenario, the workforce in this sector would also be impacted. However, the power sector would likely see an uptick in employment with jobs moving from non-renewable energy plants to jobs in solar and wind projects. The automobile industry would see a restructuring from ICE manufacturing to EV manufacturing roles. The steel and cement sectors would also see restructuring from BF-BOF to hydrogen-based green steel and adoption of new raw materials for clinker development, respectively.

Overall, the Accelerated decarbonisation of India could transform more than 30 million jobs (24 million new jobs could be created while six million existing jobs could be lost) by 2050.[28] While important, the scale of workforce reallocation may be smaller than that from other macro trends (e.g., 60 million new workers entering the workforce by 2030). Displaced workers will nonetheless need support, training and reskilling through the transition.[29]

## Reduced energy import dependence and opportunity to build export competitive new industries

While the primary benefit of decarbonisation would be the ability to arrest climate change, this transition offers other benefits, too. It would result in localising India's energy requirement with the shift from coking coal, oil and gas to renewable energy, green hydrogen and biomass strengthening energy security. This could result in Forex savings of $2.4–3.0 trillion by 2070. Further, India could also aspire to becoming a global manufacturing hub for green hydrogen, solar panels electrolysers and batteries.

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[27] TERI.

[28] McKinsey Global Institute: The net-zero transition - what it would cost, what it would bring.

[29] McKinsey Global Institute – India's turning point.

## Accelerating decarbonisation would require investments to be scaled up

Our bottom-up models estimate that financing this decarbonisation would need an estimated $7.2 trillion in green investments until 2050 to decarbonise in the LoS scenario and an additional $4.9 trillion (Exhibit T) for the Accelerated scenario (about 3.5 percent and an additional 2.4 percent of India's GDP through this period, respectively). This would translate to an average annual investment of $240 billion in LoS, with an additional $160 billion in the Accelerated scenario.

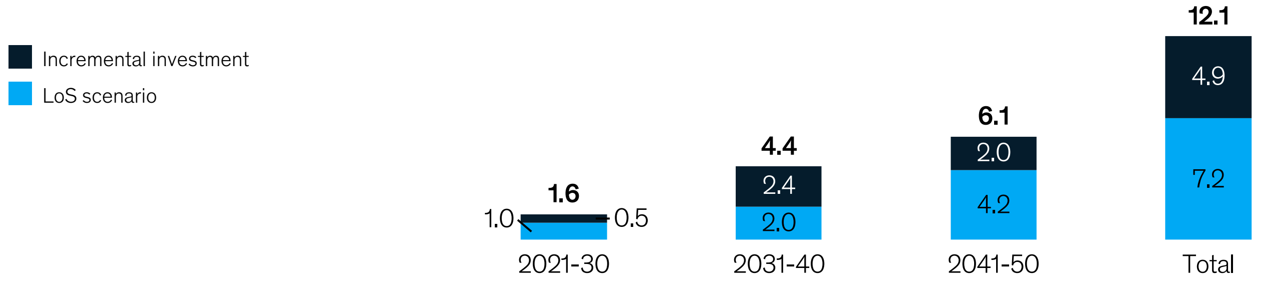
About 70 percent of the funding would be needed for Capex investment in the power and automotive sectors in both the scenarios, primarily driving an expansion of RE capacity and electrification of the automotive sector (Exhibit U).

Exhibit T

### Investment is required for India's decarbonisation in the LoS scenario; and to accelerate the transition.

**Decade-wise investment**[2]
($ trillion)

| | | | | Cumulative |
|---|---|---|---|---|
| **Total investments as % age of real GDP (LoS)** | 2.6% | 3.1% | 4.1% | 3.5% |
| **Total investments as % age of real GDP (Acc.)** | 4.1% | 6.8% | 6.0% | 5.9% |



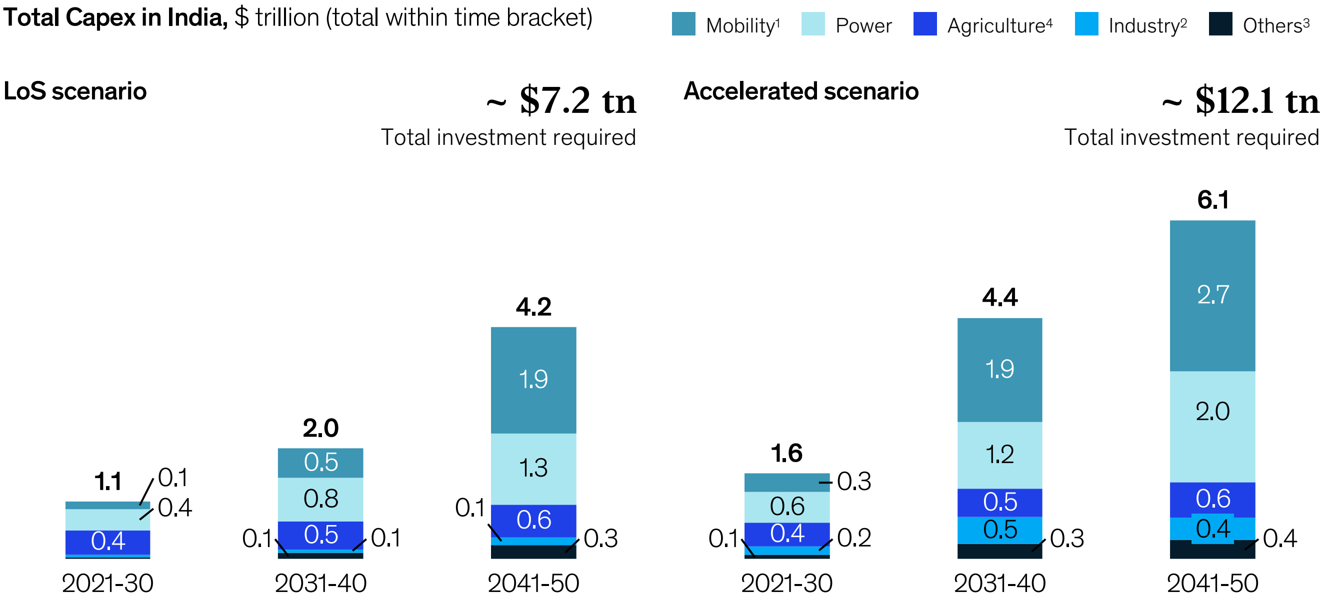
| | | | | |
|---|---|---|---|---|
| **Average annual investment** | LoS, $ trillion | 0.10 | 0.20 | 0.42 |
| | Accelerated, $ trillion | 0.16 | 0.44 | 0.61 |

1. EUI data used for GDP forecast.
2. The investment numbers are based on bottom-up investment analysis for abatement and supporting infrastructure, built granular, sector by sector. High-emission ongoing capex has not been considered; Capex calculations derived from bottom-up models for power, steel, cement, other industries, transport, agriculture, NBS, CCUS, hydrogen and material circularity.
3. Estimated cumulative GDP: 2021–30: $38.7 tn; 2031–40: $64.6 tn; 2041–50: $101.6 tn.

Exhibit U

### 70% of total investment would likely be required to decarbonise the power and mobility sectors.

**Total Capex in India,** $ trillion (total within time bracket)



1. Automotive and aviation sectors combined under mobility header.
2. Industry includes steel ($113 bn), cement ($81 bn), aluminium, ammonia and waste management in LoS, includes CCUS in Accelerated scenario ($325 bn).
3. Others includes cross-cutting themes, i.e., hydrogen ($189 bn) and circular economy ($185 bn) in LoS.
4. Total production capex involved in agriculture, including factor costs and green levers.

Source: Bottom-up models for sectors

Accelerated decarbonisation will likely create operational cost savings, such as lowering the cost of power generation due to the increased penetration of renewables. As a result, some portion of the additional investment could be recuperated through operating cost savings. The investments required are front-loaded; India would have a runway till 2040 to orchestrate half of the total $12.1 trillion requirement. The balance half of investments would be required from 2040–2050. From now until 2050, operating costs would lead to overall savings of $2.1 trillion, offsetting about 45 percent of the capital investment required over the same period (Exhibit V).

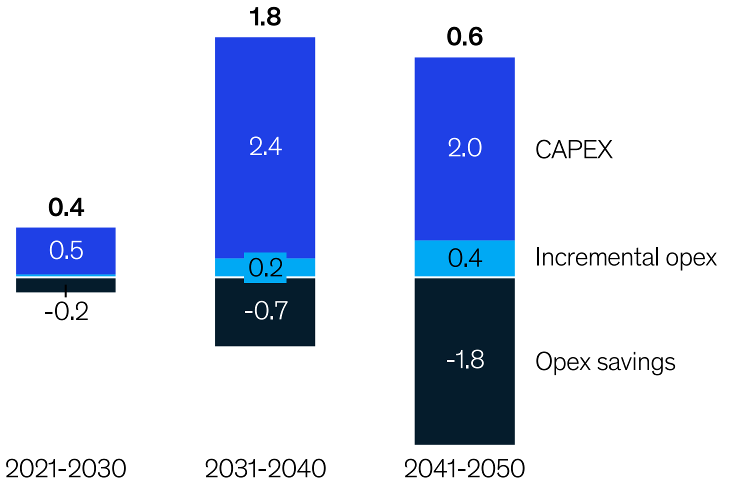
However, the cost savings are not balanced across sectors. The domestic transportation, power and agriculture sectors would derive most of the operating cost savings, while sectors like steel and cement would see an increase in operating costs, in addition to the capital investments.

Exhibit V

## In the Accelerated scenario, decarbonisation could offset 45% of incremental capital investments.

**Incremental[1] decade wise spend[2] for accelerating Decarbonisation,** $ trillion

**$50 tn**
**(25 % of GDP)**
total spending on physical assets over 30 years in Accelerated



**$4.9 tn**
incremental spending on green physical assets over 30 years

**$2.1[4] tn**
incremental operating cost savings over 30 years

| | 2021-2030 | 2031-2040 | 2041-2050 | Cumulative[3] |
|---|---|---|---|---|
| Net incremental spend[5], percent of cumulative GDP in period | 1.02% | 2.90% | 0.55% | 1.37% |

1. Spending on physical assets in accelerated scenario, minus those in LoS scenario for capex and vice versa for opex; excluding opex reduction in refining sector (which is mainly due to reduction of the refining activity).
2. Estimation of capex includes spending on physical assets in power, mobility, steel, cement, agriculture, CCUS, hydrogen, circular economy and other industries. Estimation of opex includes spend for physical assets across various forms of energy supply (e.g., power systems, hydrogen, and fuel supply), energy demand (e.g., for vehicles, alternate methods of steel and cement production), and various forms of land use (e.g., GHG-efficient farming practices).
3. Calculated as spending on physical assets net of operating costs in that period, divided by GDP in the period. GDP is for the cumulative GDP from 2021–2050 is taken directly from IHS-Markit.
4. Savings from one sector may not directly compensate for capex requirement of other sectors and numbers shown present a macro-economic view for the nation.
5. Potential revenue from levers has not been captured.

Current annual investments toward decarbonisation and other green projects are about $44 billion (heavily skewed toward the power sector), accounting for 10–12 percent of the future investment required.[30] The Accelerated scenario optimises net system-level costs at country level. However, most businesses and consumers are unlikely to take decisions based on total cost of ownership. Without intervention, these stakeholders may well make decisions different from those laid out here, basing their spending decisions on factors like upfront capital costs. Thus, financing the transition will require targeted demand- and supply-side interventions.

The cost of decarbonisation is expected to decline as technologies mature – even in a high growth economy, as innovation and economies of scale lower technology costs over time. As a result, between the Accelerated and LoS scenarios, two-thirds of the emissions could be abated at negative or low cost (<$10/$tCO_2e$) and 50 percent of the emissions could be abated through in-the-money levers (Exhibit W). Solar energy, wind power and EVs, comprising the first quintile of the abatement potential, present a positive investment case. The levers in the last quintile are the high-cost ones, comprising some advanced agriculture practices, offshore wind, CCUS, etc. which would cost more than $60/$tCO_2e$. Hydrogen-based steel would cost $47/$tCO_2e$ till 2040. From 2040–2070, it would cost $9.6/$tCO_2e$. An estimated carbon price of $40–50 /$tCO_2e$ could potentially drive domestic carbon credits generation by making all sequestration levers cost competitive.

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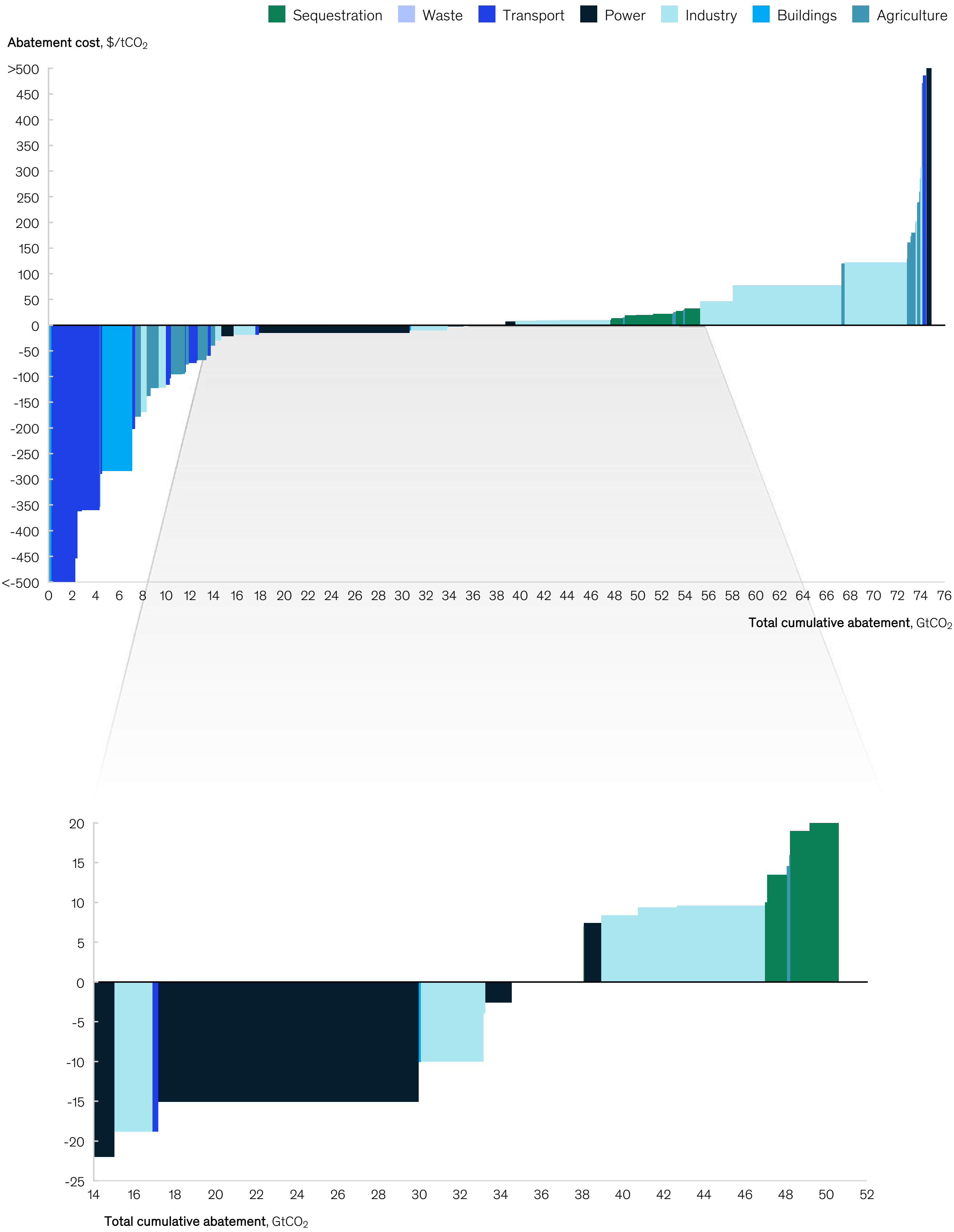
[30] Landscape of green finance in India, Climate Policy initiative

Exhibit W

## Two-thirds of the emissions can be abated at a low or negative cost (<10 \$/tCO$_2$).

### Cost curve displays the cumulative abated emissions wrt LoS scenario



## Ten urgent actions could accelerate India's decarbonisation and ensure it is orderly

From our analysis, it appears that benefits to India could outweigh the downsides of a well-planned, orderly, accelerated transition given its growth outlook. But it requires that India take action within this decade to set things up. If it does so, India can use its growth momentum to build itself right in the decades thereafter.

It is vital for all stakeholders — government, corporates, consumers, civil society — to come together and act now and in concert to accelerate India's decarbonisation and ensure it is orderly. The government can provide policy and regulatory support to make projects across sectors economically viable. These could include but are not limited to incentivising the usage of EVs and fuel cell electric vehicles (FCEVs) by balancing taxation schemes, simplifying regulations for authorising and installing new power and grid installations, creating demand signals for higher-cost green materials like steel and generating support for localising electrolyser manufacturing. Support would also be required to ensure a just transition that minimises impact on low-income households. These actions would need to work together and happen in the right sequence otherwise they would result in shortages, price rise and will be at risk of disorderliness.

Achieving the necessary technological breakthroughs to reduce emissions in hard-to-abate sectors, and accelerating their progress to market, would require consistent public and private investment. It would also require greater willingness among business leaders and policy makers to adopt new technologies. These would include longer duration storage technologies to capture the seasonality of renewable sources, advancement in fuel cell technology, improvements in recycling technologies.

This report proposes ten actions needed today within the context highlighted to accelerate India's decarbonisation:

1. **Lay out a detailed, medium-term (5 - 15 - 25-year) decarbonisation plan** with sector-specific priorities and policy frameworks that provides demand signals and guides corporates to invest. The plan will need to be implemented through an accountable nodal agency so as to ensure coordination across ministries and external stakeholders in delivering net-zero. The governance mechanism employed must include compensating mechanisms to address socioeconomic impact. Delays in doing this or quality gaps (e.g., inconsistent policies across sectors, too many changes) would lead to the wrong investment decisions worth several hundreds of billions of dollars, or reduced investment, thus leading to a less than ideal transition.

2. **Accelerate implementation of a compliance carbon market (within three years)**. This would also require the creation of demand signals to accelerate decarbonisation, especially in the hard-to-abate sectors, and incentivise investments in the newer technologies like CCUS. Policy makers could take a strategic (as opposed to a compliance-oriented) view of this and work across ministries. Getting this right, fast, can enable both domestic and foreign investment.

3. **Enabling banks to support the transition, catalysed by a green transition bank.** Banks could be asked to come up with their investment glide paths within a year or two and build the necessary capability for assessing risks in these new spaces. The regulator could assist with the necessary taxonomy, disclosure guidelines, actions to reduce risks. A green transition bank with a clearly defined set of green financing norms can act as the catalyst for change.

4. **Accelerate renewable adoption in the power sector** to scale up capacity addition 4X, and to deepen market reforms with a 30-year outlook in a manner that ensures a stable grid fed predominantly by infirm power. These market reforms can reduce the investment requirements by $150–200 billion by 2050.

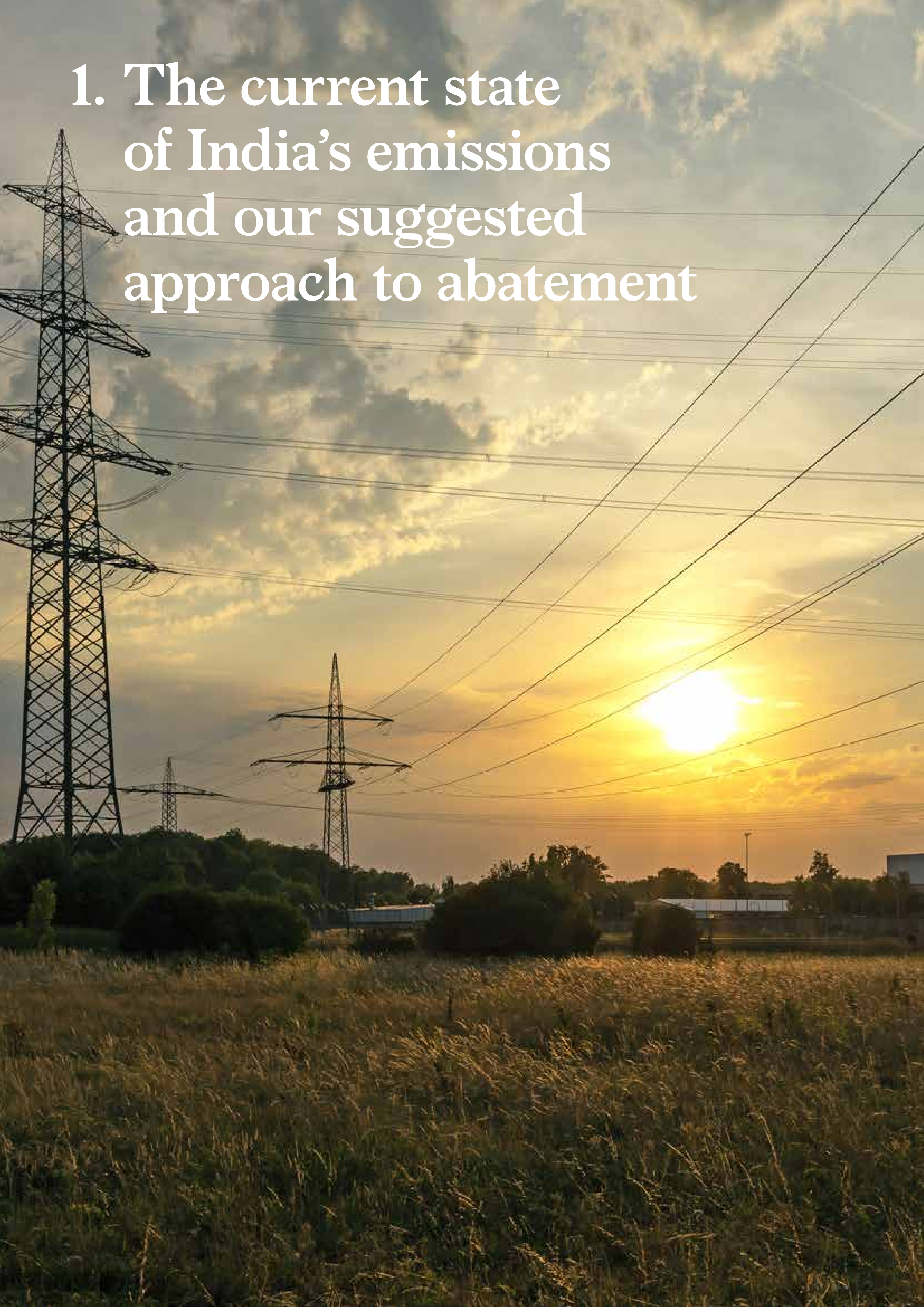
5. **Empower a nodal authority to define a national land use plan,** lay clear land-use guidelines and mandates for optimised use across urbanisation, industrial needs, carbon sinks, agriculture and renewables.

6. **Create a resilient indigenous manufacturing capability and increase investment in cleantech R&D.** Efforts would be needed to develop local raw material resources (e.g., rare earths), secure materials from elsewhere in the world and produce equipment locally through mechanisms like the PLI. This would need to be supported by a green innovation mission which increases the investments in R&D across a number of the technologies that will drive decarbonisation.
7. **Evaluate five CCS hubs** in Gujarat (Jamnagar), Odisha (Paradeep), Rajasthan (Barmer), Maharashtra (Pune) and Andhra Pradesh (Vizag) potentially in public-private partnership for utilisation and storage of captured carbon.
8. **Create a national circularity mission** with recycling hubs in the top 20 Indian cities (contributing 35 percent of municipal solid waste), mandated targets on recycling rates, recycled raw material use (e.g., blending norms) and landfill levies.
9. **Enhance the National Hydrogen Mission,** where government could play a key role in accelerating demand through blending mandates, boosting cost competitiveness via capital subsidies and R&D investments and enabling export opportunities via international trade agreements.
10. **Companies can aim to play on the front foot,** evaluating investment opportunities that this green trend would unlock, aligned with India's national plans or opportunities opened up by decarbonisation of other countries (e.g., green hydrogen derivative exports). Heavy emitters could immediately set five- to-ten-year decarbonisation targets, and use these to mobilise their organisations, looking for the value-creating opportunities, in addition to investing right for the future.

These actions would need to be supported wholeheartedly by consumers such that we see a behavioural shift in their approach. The government has announced the Accelerate Lifestyle for Environment (LiFE) mission at CoP26. This would be a crucial component for India's transition.

In closing, India needs thoughtful action now for setting itself up for an accelerated and orderly transition. Looking beyond the short term and laying the foundation for this transformation within this next decade is absolutely imperative.

# 1. The current state of India's emissions and our suggested approach to abatement



## Context

India is the third-largest emitter of GHG after China and the US with 2.9 $GtCO_2e$ of net emissions per year;[31] yet its per capita emissions of 1.96 $tCO_2e$ are less than a third of the global average of 6.55 $tCO_2e$ (9 percent of global GHG emissions with a 17 percent share of the global population). Therefore, despite its low per capita emissions, India would need to play an outsized role in the battle for decarbonisation if the world needs to win the war on climate change.

India is already seeing the impact of climate change – in 2019, about 12 million people were affected by intense rainfall and floods with the damage done estimated at $10 billion.[32] The country also faced eight tropical cyclones that year with six being categorised as 'very severe'.[33] At this rate, by 2050, India could experience a fourfold increase in people exposed to severe hazards under a two-degree Celsius warming scenario.

In 2021, at COP-26, India announced its ambition to achieve net-zero emissions by 2070 and presented the Panchamrit plan which included NDC targets such as 50 percent cumulative electric power capacity to be non-fossil fuel-based by 2030 and 45 percent reduction in the emission intensity of GDP by 2030 (over 2005 levels).[34] This has come on the back of a series of steps taken by India over the past few years toward decarbonisation. Over the past two decades, India has announced policies like FAME, ACC PLI[35], the Green Hydrogen Mission, a vehicle scrappage policy and single-use plastic ban. Additionally, it established the Perform, Achieve and Trade (PAT) mechanism to improve industrial energy efficiency, saving 60 $MtCO_2$ between 2016 and 2019;[36] the LIFE mission plans to use social networks to promote environmentally friendly lifestyles; and the Energy Conservation bill introduced in Lok Sabha that mandates buildings with a minimum connected load of 100 KW to use renewable sources, empowers the government to specify a carbon-credit trading scheme and a minimum share of energy consumption from non-fossil sources for designated consumers.

There is no better time than now for India to push for an accelerated decarbonisation trajectory. Much of the India of 2050 is yet to be built, with India's GDP estimated to grow four times[37] over this period. If India builds it right, it has the unique opportunity to decarbonise without slowing the economy down. This can also serve as an inspiration to other high growth economies.

## Situation today

India's current net GHG emissions are 2.9 $GtCO_2e$ every year (after accounting for 0.3 $GtCO_2e$ negative emissions). The bulk of these emissions (70 percent) are driven by five sectors – power, steel, automotive, cement and agriculture (Exhibit 1). India has reduced its emission intensity at 1.3 percent per annum over the last decade (Exhibit 2) and has successfully decoupled emissions from GDP growth. As a result, there was a 24 percent decline in economic emissions in 2016 versus its 2005 levels (excluding agricultural emissions).[38]

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[31] CAIT data from Climate watch; about 14 percent of gross emissions are methane, based on 2016 UNFCCC data

[32] Global climate risk index, Germanwatch

[33] The weather channel, IBM

[34] India's NDC

[35] FAME – Faster Adoption and Manufacturing of Electric Vehicles Scheme, ACC PLI – Production Linked Incentive (PLI) Scheme 'National Programme on Advanced Chemistry Cell (ACC) Battery Storage'

[36] India's third biennial update report to the UNFCCC

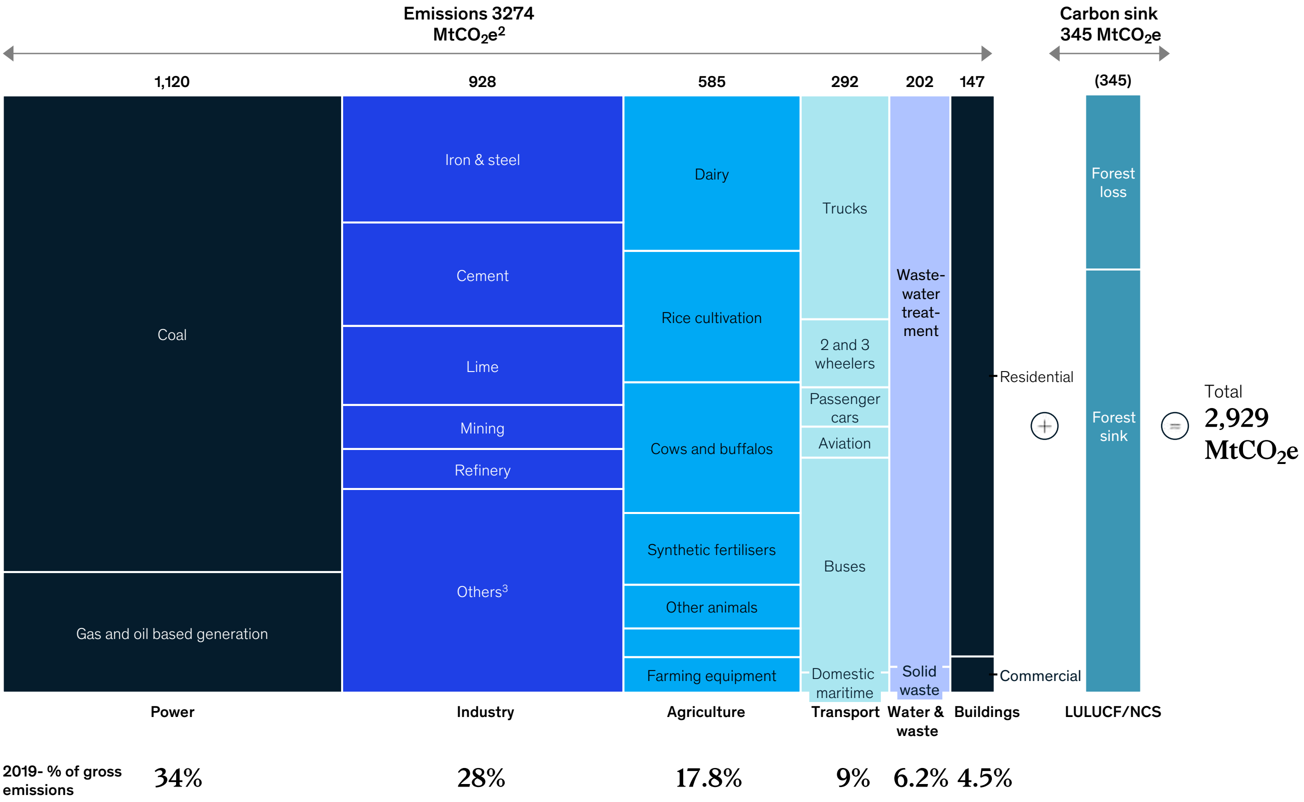
[37] Based on Economist Intelligence Unit projections of $12.12 trillion by 2050 (Real GDP - USD at 2010 prices); This GDP forecast represents a more conservative estimate compared to other estimates - we have considered the lower range of growth in our analyses to build a more robust decarbonisation pathway.

[38] UNFCCC, Climate action tracker, EIU, India's biennial update report 3

Exhibit 1

## India's current carbon emission mix.

**Baseline emissions,** $MtCO_2e^1$, 2019

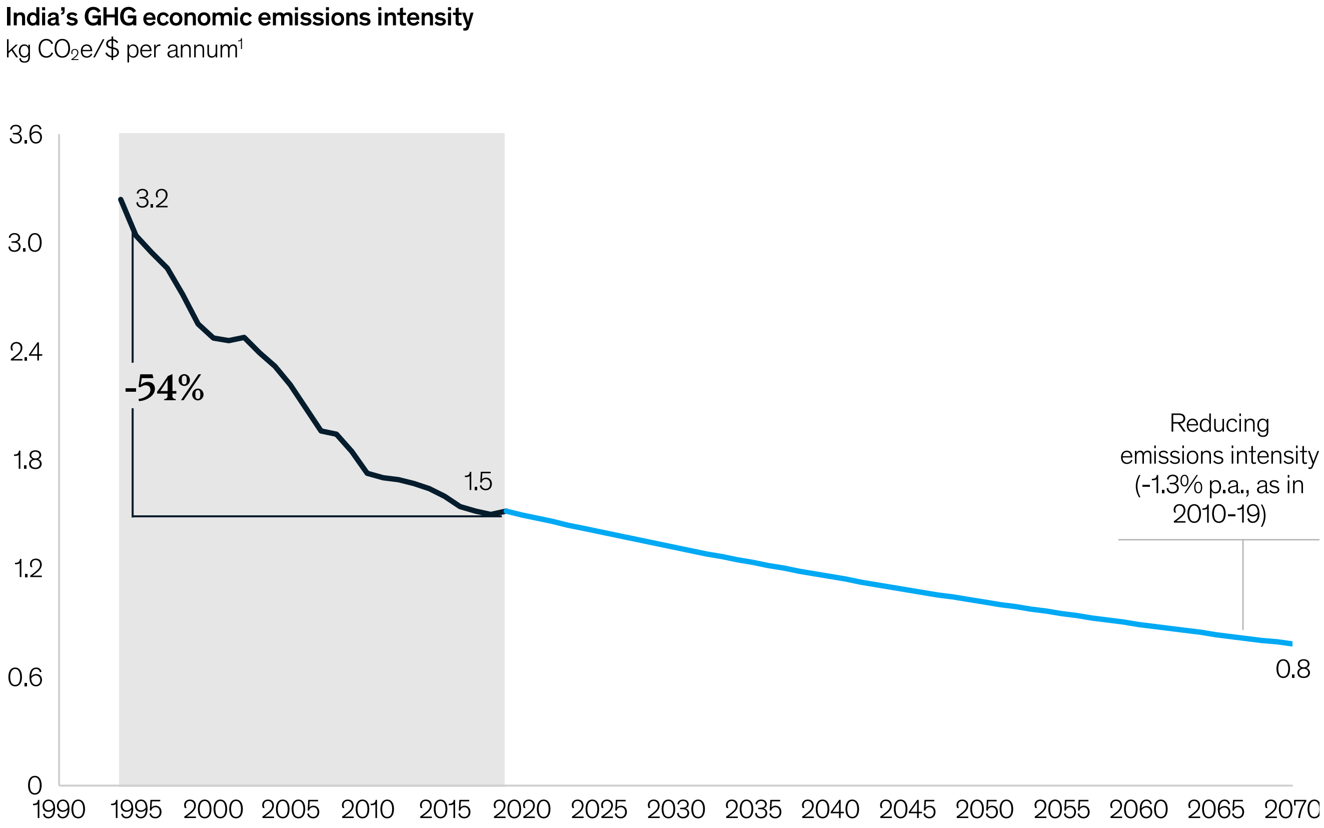


1. Converting GHGs into $CO_2e$ assuming GWP-100 and AR5 methodology with India's BUR-3 reported emissions for 2016 as baseline.
2. Gross and net emissions for 2019 based on Climate Action Tracker overall emissions for India.
3. Others include: other industry oil & coal use, ammonia, aluminium, F-gases and ethylene.

Source: McKinsey India Decarbonisation Scenario Explorer

Exhibit 2

## Economic emissions intensity reduction for India.



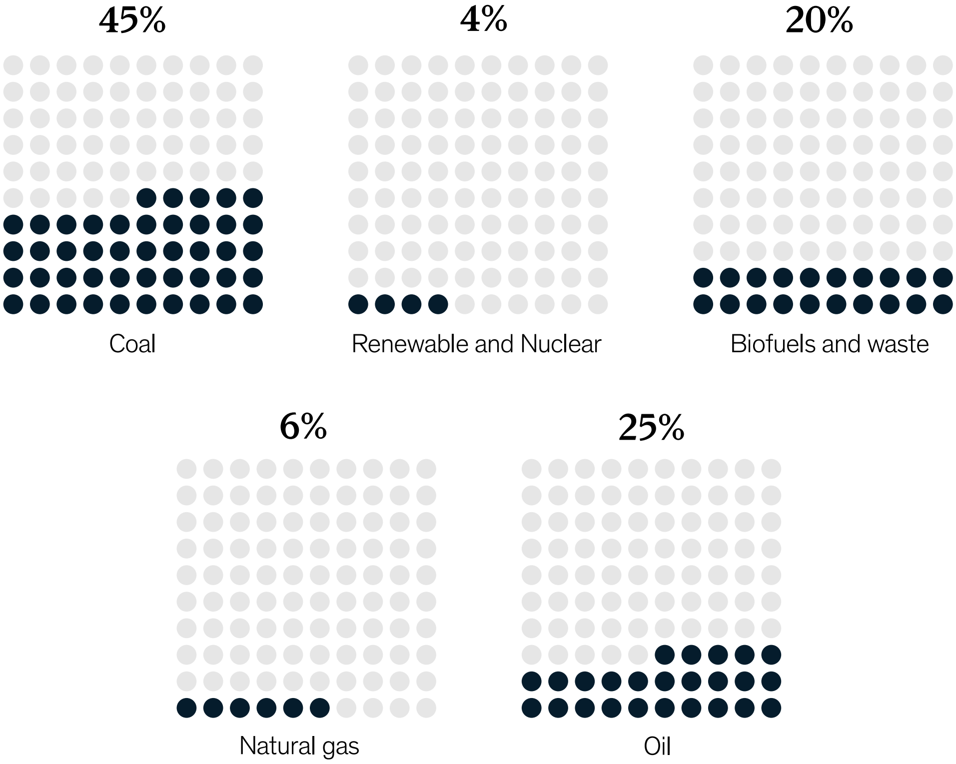
1. Including LULUCF emissions and offset.
2. Economic emission intensity from annexed and non-annexed countries in UNFCCC.

Source: UNFCCC, climate action tracker, McKinsey India DSE, EIU , India's biennial update report 3

India's current energy system depends on fossil fuels to meet approximately 75 percent of its energy demand (Exhibit 3). Power relies mostly on coal; transport consumes mostly oil; biomass is used predominantly in the buildings segment mainly for cooking (besides the power consumption required for building) and industry uses a mix of fossil fuels (Exhibit 4).

Exhibit 3

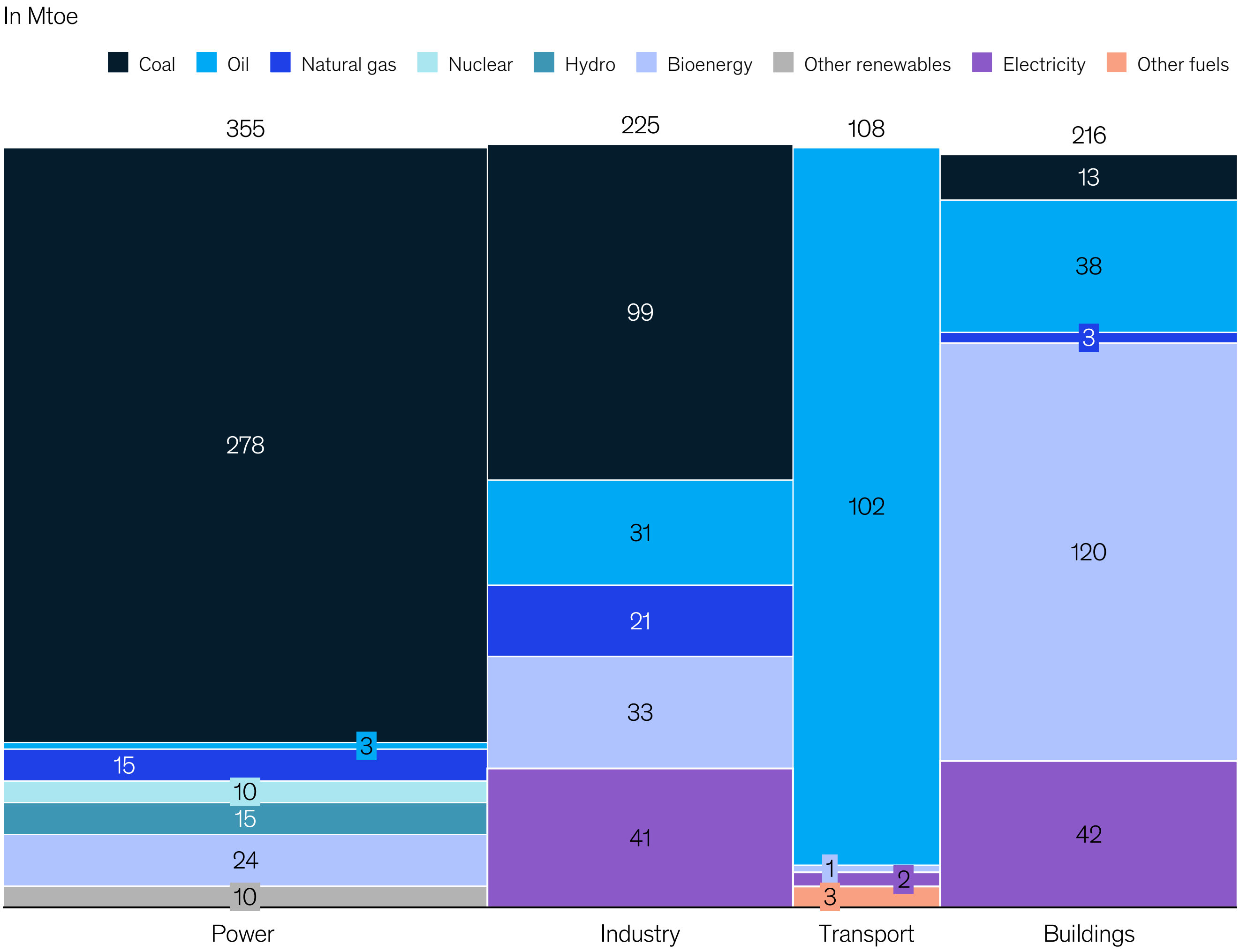
## India's current energy mix.



Source: IEA World Energy Balances https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances

Exhibit 4

## Primary energy demand by sector as of 2019.[1]



1. Only for power, transport, building and other industries. Agriculture excluded.

Source: IEA

Over the past 20 years, India's total primary energy demand has been growing at four percent per annum, compared to an annual GDP growth of six and a half percent because of energy efficiency improvements and growth in the services' share of the economy.[39]

India's energy mix and hence emissions are different from the global mix (e.g., the EU and Japan) as nuclear and renewable energy currently form only four percent of India's energy mix versus 20 percent in the EU and eight percent in Japan (Exhibit 5).

India's transport sector has a big carbon footprint across multiple modes – road, rail, air, water – and spans passenger and goods transport. While passenger transport is split more or less equally between intra-city and inter-city, the long-haul inter-city segments dominate goods transport (Exhibit 6).

Accordingly, surface transport is responsible for the bulk of the emissions (over 70–75 percent) and a large part of that comes from the commercial vehicles used for goods transportation (190 $MtCO_2e$ per year for FY21, comprising about 75 percent of total tailpipe emissions) (Exhibit 7).

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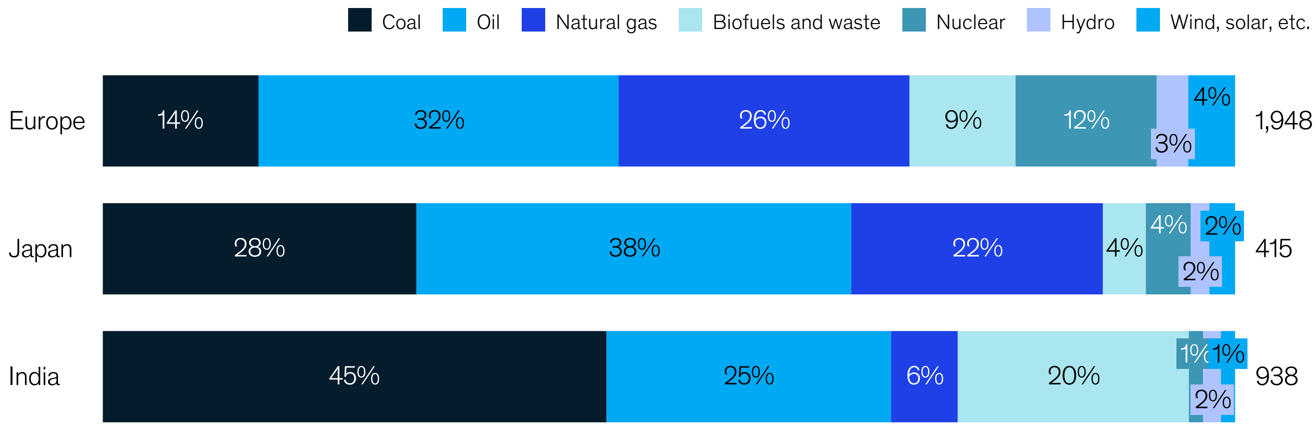
[39] McKinsey analysis based on data from EIU and IEA.

Exhibit 5

## Comparison of the current energy mix across Europe, Japan and India for 2019.

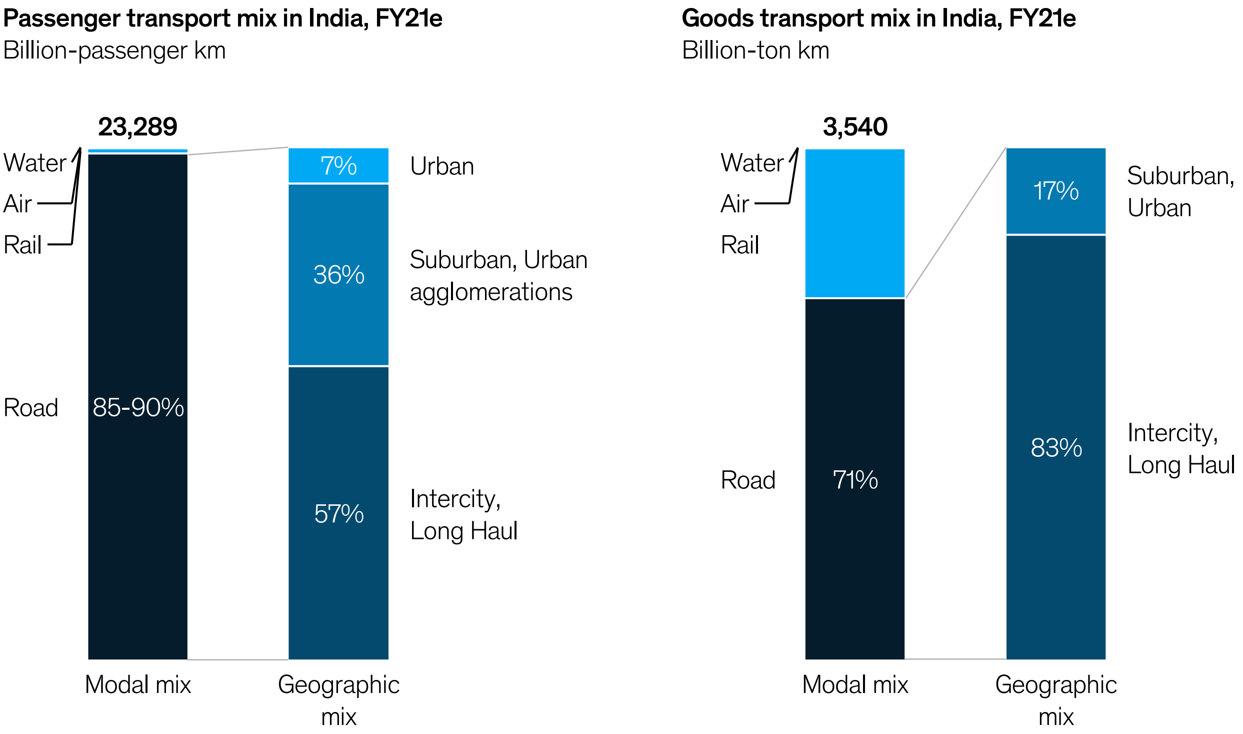
**Percentage contribution of total energy demand**
MTOE



Source: IEA World Energy Balances https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances

Exhibit 6

## Transportation mix in India: varied for passengers and goods.

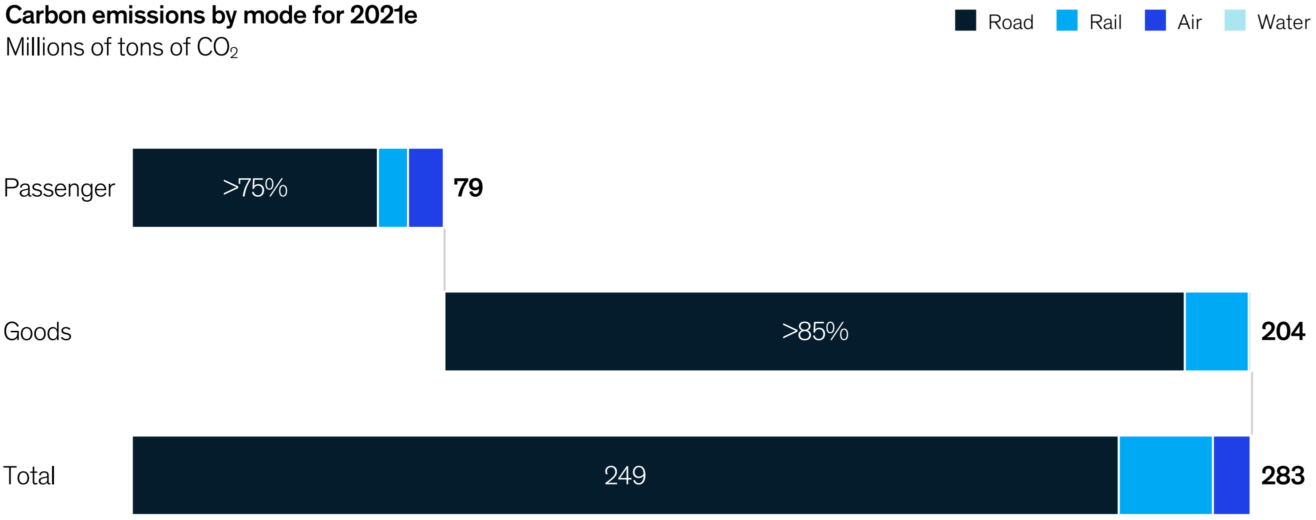


Source: MORTH, Niti Aayog, Ministry of Ports, Shipping, and Waterways, Ministry of Railways, World Bank, IBEF, TERI, Rocky Mountain, Technical University of Denmark, Statista, McKinsey Analysis

Exhibit 7

## Road transportation is responsible for a majority of the carbon emissions.

**Carbon emissions by mode for 2021e**
Millions of tons of $CO_2$



Source: McKinsey Analysis

Automotive tailpipe emissions account for seven to eight percent of India's total GHG emissions. Hence the road-mobility segment has been discussed in detail in this report. In addition, we explore the hard-to-abate aviation sector. Aviation is a significant contributor to India's emissions, accounting for 5 percent of total emissions from the transport sector, with rapid growth expected going forward. Also, emissions from the aviation sector have a two to four times greater impact on the environment than road transport due to the additional non-$CO_2$ pollutants directly released into the atmosphere.[40]

In addition to the power and mobility sectors, this report takes an in-depth look at three other high-emitting sectors: steel, cement and agriculture.

## Actions taken by India so far

India has already taken many positive steps towards decarbonisation. As per the updated NDCs to the United Nations Framework Convention on Climate Change (UNFCCC) in August 2022, India has committed to reducing the emissions intensity of its GDP by 45 percent by 2030, from its 2005 levels. In comparison, the 2015 NDC committed to a 33–35 percent reduction target by 2030.[41]

**Renewable energy:** India has committed to achieving about 50 percent cumulative electric power installed capacity from non-fossil fuel-based resources by 2030.[41] Earlier, a target of 175 GW of installed electricity capacity from renewables by 2022, and 500 GW by 2030 had been set.[42] By June 2022, India's renewable energy capacity (excluding large hydro) stood at 114 GW, with 60 GW of projects under various stages of development.[43] The latest Energy Conservation (Amendment) Bill, 2022, also specifies obligations for designated consumers[44] to use non-fossil sources of energy, which is expected to spur on demand for renewable energy.

**Transport:** India's 2030 vision of e-mobility sets EV sales penetration targets of 70 percent for commercial cars, 30 percent for private cars, 40 percent for buses and 80 percent for two-wheelers and three-wheelers by 2030.[45] This translates to 102 million EVs on-road. In keeping with these targets, multiple fiscal and funding measures have been announced for the promotion of EVs, such as the reduction of GST on EVs from 12 to five percent and from 18 to five percent for EV chargers. The FAME scheme was also extended until 2022 with an outlay of INR 10,000 crores to incentivise EV uptake.[46]

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[40] World Economic Forum's Clean Skies for Tomorrow; Transport & Environment.
[41] India's NDC; UNFCCC.
[42] Press information bureau.
[43] SAUR energy international.
[44] Designated consumers include: (i) industries such as mining, steel, cement, textile, chemicals and petrochemicals; (ii) transport sector including Railways; and (iii) commercial buildings.
[45] CEEW.
[46] Ministry of heavy industries.

**Energy efficiency:** The National Mission for Enhanced Energy Efficiency (NMEEE) specifies energy consumption reduction in large, energy-consuming industries, with a system for companies to trade energy-savings certificates. The adoption of energy efficiency schemes led to overall energy savings of 24 Mtoe for the year 2018–19.[47] The PAT scheme for improved energy efficiency in industry under the NMEEE saved 31 $MtCO_2$ of emissions in PAT-I (2012–15) and 61 $MtCO_2$ of emissions in PAT-II (2016–19).[48]

**Agriculture:** The Pradhan Mantri Krishi Sinchayee Yojana (Prime Minister's Agricultural Irrigation Scheme) aimed at convergence of investments in irrigation at field level, expansion of cultivable area and improvement of water use efficiency, resulted in an emissions reduction of 12 $MtCO_2$ from the period 2017–18 to 2018–19.[49] Other schemes in crop production, such as crop diversification from paddy, direct seeding of rice and systems of rice intensification, and other agricultural sectors such as livestock, horticulture and fisheries also contributed to the lowering of emissions.

**Material circularity:** Extended producer responsibility (EPR) regulations with the intent to drive circularity and improve waste management have been in place for e-waste since 2016. In 2022, guidelines for an EPR programme for plastics and tyres were also added to these. The EPR guidelines also include targets on use of recycled content in plastic packaging. Efforts to drive circularity have also been taken in the automotive and steel sectors. While the ministry of steel has indicated clear demand signals for use of scrap steel, the new vehicle scrappage policy is targeted at recovery of old vehicles with the intent of material recovery and reducing the number of high-emission vehicles on-road as well as further enabling the transition to EVs.[50]

**Carbon markets:** The recent Energy Conservation (Amendment) Bill also empowers the central government to specify a carbon-credit trading scheme. According to the provisions, the central government or any authorised agency may issue carbon-credit certificates to entities compliant with the scheme. Any other person may also purchase a carbon-credit certificate on a voluntary basis.[51]

**Hydrogen:** The Green Hydrogen Policy 2022 puts in place several measures aimed at promoting a smooth transition to green hydrogen and green ammonia, both as energy carriers and chemical feedstock. This includes waiving interstate transmission charges for green hydrogen producers, providing land for renewable energy parks and setting up manufacturing zones.[52]

**Biofuels:** India has also taken steps to promote biofuels and biomass. The renewable energy capacity target of 175 GW by 2022, for instance, mandates 10 GW from bio-power.[53] Further, the National Policy on Biofuels 2018 allows for the use of more feedstock in biofuel production and advances an ethanol blending target of 20 percent in petrol to Ethanol Supply Year (ESY) 2025–26 from 2030 compared to the current blending rates of 10.2 percent blending in ESY 2021–22.[54]

While these are encouraging steps, there is still a long way to go for India to achieve the announced net-zero goal and a significant effort will be needed from all stakeholders.

## The road ahead

Across various estimates[55], India's real GDP is expected to grow at about five percent annually till 2050 (Table 1). This would mean fourfold GDP growth for India over the next 30 years. With this, demand growth across all sectors could multiply: power (quadruple), steel (quadruple), cement (triple), automotive (triple) and agricultural food production (double) (Exhibit 8). Based on the reduction in carbon intensity of GDP seen over the last decade, India's annual GHG emissions will likely grow substantially from their current 2.9 $GtCO_2e$ to 11.8 $GtCO_2e$ by 2070.[56] With 75 percent of India yet to be developed by 2050, we are uniquely positioned among our global peers to build more sustainably (Exhibit 9).[57] From our analysis, it appears that benefits to India of a well-planned, orderly, accelerated transition would outweigh the downsides given India's growth outlook. This would need that India take action within this decade to set things up. If it does so, India can use its growth momentum and build India right in the decades thereafter.

| Year | Annual real GDP[58] growth rate |
|---|---|
| 2020–2030 | 5.8% |
| 2030–2040 | 5.1% |
| 2040–2050 | 4.7% |
| 2050–2060 | 3% |
| 2060–2070 | 3% |

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[47] Impact of energy efficiency measures, Bureau of energy efficiency.

[48] Brief note on PAT scheme, Bureau of energy efficiency.

[49] https://www.forests.tn.gov.in/app/webroot/img/document/gov-india-publication/18India_3_Bur-20.pdf

[50] CPCB, Press search.

[51] Press information bureau, Ministry of Power.

[52] Niti Aayog – Harnessing green hydrogen – Opportunities for deep decarbonisation in India@.

[53] Press information bureau.

[54] National policy on biofuels, Ministry of new and renewable energy; press information bureau.

[55] OECD, IHS markit and EIU.

[56] UNFCCC, climate action tracker, India's biennial update report 3.

[57] Analysis based on GDP data from EIU.

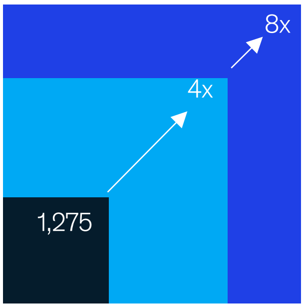
[58] Gross domestic product (GDP) at constant market prices, rebased to 2010 constant prices and translated into US$ using the LCU:$ exchange rate in 2010 – from The Economist Intelligence Unit for 2020–50. Assumed 3% annual real GDP growth from 2050–70.

Exhibit 8

## As a majority of India is yet to be built, demand is expected to rise multifold and so are the emissions.

**Power**

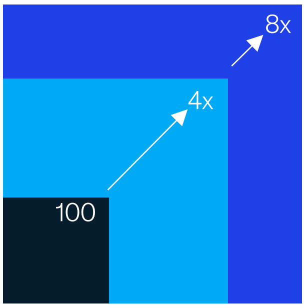
Consumption, TWh



India's power generation is expected to grow over 9,000 TWh by 2070

**Steel**

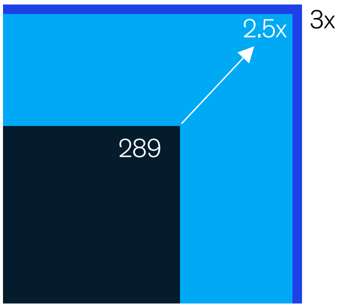
Demand, Mt



Steel is in use in the form of buildings, cars, appliances, pipelines and industrial plants likely to rise 8x driven by high urbanisation and industrial expansion

**Cement**

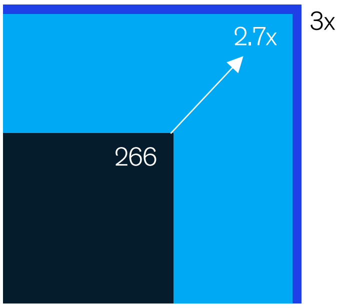
Demand, Mt



Cement demand grows marginally ahead of GDP until 2035 post which it decouples from GDP and follows population growth rates to a per capita consumption of 350-370 kg/year

**Automotive**

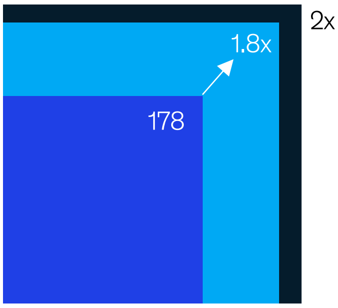
Total vehicle PARC, Millions



Medium and heavy truck sales at over 2% CAGR until 2070. Passenger vehicles at 1-1.5% CAGR

**Agriculture**

Rice production, Mt

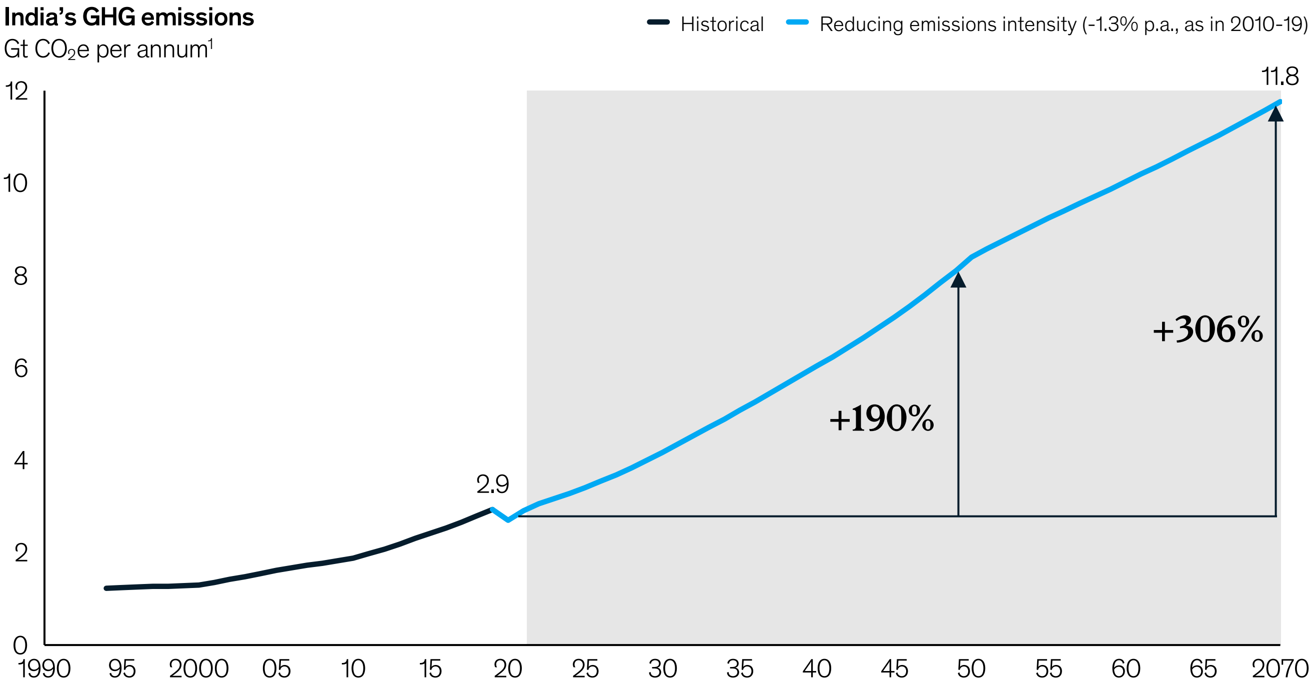


While rice production nearly doubles, area under rice cultivation decreases at a CAGR of 0.03% due to increased mechanisation and thereby yield/hectare

Source: McKinsey India Decarbonisation model

Exhibit 9

## India's emissions could triple over the next 50 years even at the current pace of emission intensity reduction.



1. Including LULUCF emissions and offset.

Source: UNFCCC, Climate Action Tracker, McKinsey India DSE, India's biennial update report 3

## Our Methodology: what this report is and what it is not

This report is a synthesis of a year-long effort that included bottom-up modelling across six sectors (power, automotive, aviation, cement, steel and agriculture) and four cross-cutting enablers. We took a four-step approach for each sector:

— **Creating the baseline:** 2019 was taken as the baseline year. We modelled emissions bottom-up based on India's activity levels across sectors and corresponding emission intensities. Our findings were refined and syndicated to align with India's submission to the UNFCCC.

— **Granular forecasting of demand:** We used sector-specific sources and expert inputs to arrive at demand projections for each of the six sectors. Forecasts were aligned with expected GDP and population outlooks up to 2070.

— **Identifying optimal production and technology mix:** We leveraged McKinsey's decarbonisation lever repository and the Decarbonisation Scenario Explorer (DSE) tool to identify and model technological levers for production. Assumptions were modified for India based on inputs from industry experts as well as secondary sources.

— **Defining enablers and estimating implications** of decarbonisation, including potential costs and benefits through bottom-up modelling for the six sectors using local and industry data. Assumptions were tested through 50+ Indian and global expert interviews. The data points mentioned in the report are based on McKinsey's Sustainability modelling framework unless mentioned otherwise.

In this report, we have assumed two potential pathway scenarios – LoS and Accelerated. The LoS scenario considers a phased adoption of decarbonisation levers, implementation of current policy announcements and predicted reduction of technology costs. Our Accelerated scenario considers faster adoption of decarbonisation levers and quicker reduction in technology costs. More importantly, it considers new regulations (like carbon price through an emission-trading scheme) and faster maturing of new technologies (e.g., CCS). Both these scenarios consider that India's growth can happen along with progress on broader development imperatives while pursuing actions for emission abatement. Further, these scenarios have largely been estimated with currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture). More detailed assumptions made in each scenario are elaborated on next:

**The LoS scenario** assumes continued demand and economic growth, with penetration of low-carbon technologies continuing at presently predicted rates. We consider a phased adoption of abatement levers in line with India's net-zero 2070 goal, current policy announcements and currently estimated technology cost outlooks. The major assumptions in this scenario include:

- **Demand:** Industrial production and consumer demand increase in line with GDP (five percent per annum from 2020–2050 and three percent per annum from 2050–2070) and population (0.5-one percent per annum) until 2070.[59] Sustainable alternatives are adopted as per current policies and market outlook, e.g., continued uptake of renewable energy, steady increase in demand for EVs. The LoS scenario does not assume any externalities or interventions that shift or disrupt expected demand.
- **Technologies:** Only currently available and feasible green interventions and technologies are assumed in this scenario. This includes renewable energy sources such as solar and onshore wind, battery electric vehicles (BEVs) for transport, and organic and nano-fertilisers in agriculture. Green fuels are used partially in industries like cement. A majority of steel production is assumed to continue with blast furnaces in the near future, with electric arc furnaces being adopted in line with scrap availability. Next-horizon or less-economically-viable technologies like CCUS are not incorporated into this scenario. Other currently less feasible technologies, such as hydrogen in steelmaking or technologies to improve productivity in livestock, are assumed to be delayed and come into play only when they become economic.
- **Policies:** Current policies, targets and planned policies are assumed to continue in this scenario. Existing policies on renewable energy capacity additions, coal phase-out targets and so on are assumed. Current EV policies and funding schemes such as FAME are incorporated. Government actions on sustainable farming, such as incentives on nano-fertilisers and forest conservation efforts are also expected to continue at historical rates. This scenario does not have any structural interventions aimed at creating green demand signals. For example, carbon pricing or premiums, domestic carbon markets, further blending or recycling mandates are not assumed in the LoS scenario.

**The Accelerated scenario** assumes adoption of decarbonisation levers at a much faster pace. It also takes into account the adoption of newer low-carbon technologies across sectors and cross-cutting themes, investments in nascent technologies (e.g., CCUS) and new policy interventions aimed at accelerating decarbonisation (e.g., carbon markets).

- **Demand:** Economy and population grow at the same rates as LoS. In this scenario, however, there are also shifts in expected demand to decarbonised alternatives. 20 percent of demand for cement, for example, is expected to shift to alternative construction materials by 2070.[60] Likewise, consumption of rice is assumed to decline by 30–40 percent and instead shift to alternative coarse cereals.
- **Technologies:** Currently available technologies are assumed to be adopted at a much faster pace. Penetration of EVs, for example, reaches 95–100 percent by 2050 instead of 2070 as in the LoS pathway. Renewable energy contributes to 95 percent of power generation by 2050. Green hydrogen uptake is also accelerated, leading to faster adoption of green hydrogen-based steel-making technology and FCEVs in commercial vehicles by 2050. This Accelerated scenario also assumes the adoption of future technologies that are not yet commercially viable, for example, CCS in industry.
- **Policies**: In addition to current and planned policies, the Accelerated scenario also assumes certain big policy moves that enable faster adoption of decarbonisation technologies including demand side signals such as extension of GST benefits and FAME subsidies for EVs until 2030, prioritisation of carbon neutral biomass as industrial fuel (e.g., for use in cement kilns), and mandated recycling and blending rates (50 percent recycled plastics in packaging, 100 percent use of bio-decomposer in paddy-straw residue and 20 percent recycled concrete used as clinker substitute in cement). This scenario also assumes a carbon pricing of \$50 / $tCO_2$ by 2030 in industries such as steel, which progressively increases. The establishment of a domestic carbon market is also assumed to enable the financing of green technologies and development of NCS that can generate carbon credits.

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[59] GDP data from EIU and population data from UN

[60] GCCA - concrete future roadmap - efficiency in design and construction

### Resources leveraged from McKinsey's sectors and solutions teams

**50+** McKinsey global leaders, industry experts and sustainability experts were consulted for their expertise and inputs. This report also leveraged **10+ proprietary tools** for various analyses and modelling. This includes sector- and theme-specific tools such as the Global Energy Perspective model, McKinsey Power model, Battery Insights, Nature Analytics, Hydrogen Insights, Chemical Insights (CI), CI Circular and Carbon Capture, Utilisation and Storage model.

McKinsey's specialised teams including McKinsey Global Institute (MGI), Vivid Economics, Sustainability Insights, Energy Insights, Chemical Insights, Basic Materials Insights and Power Solutions have been fully leveraged. Experts from various sectors and functions (e.g., Advanced Industries, Basic Materials, Chemicals & Agriculture, Electric Power & Natural Gas, Oil & Gas, Banking, Sustainability and Strategy & Corporate Finance) have driven the work directly.

### Limitations

While this report includes a thorough bottom-up analysis of key sectors and cross-cutting themes, it does have the following limitations:

- The different sectoral and topic-wise analyses do not take into account future technological breakthroughs (e.g., Direct Air Capture) or structural shifts (e.g., complete overhaul of food systems to vertical farming) that are not currently foreseen to be in the conversation.
- The modelling assumes tax structures, tariffs, subsidies as they are currently (e.g., on transportation fuels). It does not account for positive or negative social impact, transaction costs associated with switching to new technology, communication costs and administrative costs. All the analyses have been done in real dollars and rupees.
- The report focuses only on emissions generated within the domestic borders of India. It does not look at indirect emissions from imports, or the emissions from international shipping and aviation.
- It also covers briefly but does not carry out a detailed analysis on the potential impact of transition and demand shifts on jobs and employment. Likewise, it covers the costs of the green transition on the poor at a high level only. The report does not provide any policy recommendations or microeconomic analyses on these important issues.
- This report does not address physical risks and adaptation topics. It also does not take into consideration the societal and economic impact of the COVID-19 pandemic in its analysis. Long-term energy consumption trends and challenges that government and businesses face in getting to net zero have been assumed to be the same as pre-pandemic. Further, the war in Ukraine is changing the energy landscape and while it may make a clean-energy transition more complicated in the short term, this report doesn't include any impact of this conflict on India's decarbonisation pathways.
- The pathways assumed in this report are scenarios and not a projection or forecast of what is to come. We have also not assessed the impact of transition on individual companies or major stakeholders. The decisions that individual stakeholders may take in the absence of any changes in regulations and incentive structures may differ owing to a number of factors such as the differing costs of capital and payback expectations they may apply to investment decisions.
- Finally, this report does not consider any non-economic benefits of reducing carbon emissions, such as improvements in society's overall health and social life due to reduced pollution and better quality of environment.

Nonetheless, we hope that our scenario-based analysis will help readers gain an understanding of the scale of response needed to achieve sustainable growth over the next few decades. Furthermore, we hope that this report assists public and private sector leaders in setting and meeting their carbon emission reduction goals.

### How to read this report

The overall summary of our pathway modelling, from the primary abatement measures to the required redesign of the energy system, are discussed in this chapter (Chapter 1).

Each sector has a different starting point and faces unique challenges in its decarbonisation journey. We present the cost-optimal pathways for each sector in sector deep dives in Chapter 2, and discuss the roles of hydrogen, CCUS, NCS and material circularity as cross-sector enablers in Chapter 3.

Accelerated decarbonisation by 2050 would have significant socio-economic implications such as shifting land use, changes in energy mix, reskilling of the workforce, stranded assets and inflation impact on the poor. We discuss these implications in Chapter 4.

Financing the transition is a challenge for countries around the world and India is no different. We discuss the short- and long-term financing challenges and implications in Financing India's decarbonisation in Chapter 5 and conclude with a proposed list of ten actions in Chapter 6. Finally, the appendix carries more details on our modelling approach, lists references and includes a glossary of terms.

# 2. Sector deepdives

# 2.1 Power sector

## Key takeaways

**The power generation sector accounts for 35 percent of India's total emissions**, which have grown at a CAGR of two percent in the last decade, in line with the demand growth of electricity. While India has taken steps toward decarbonising the sector by accelerating build-out of RE capacity over the past decade, challenges remain.

**India could get to net-zero emissions by 2070 in our LoS scenario,** supported by favourable economics (of RE and RE-storage hybrids vis-à-vis coal), industry action, conducive policies and increasing investment (including from major global investors). We do not envisage accelerated retirement of coal-fired power plants in our scenarios—incremental demand for power would largely be met with non-fossil sources of generation while the existing fleet of hyphenate plants would continue to operate (depending on their position in the merit order curve) until the end of their economic life.

**India's power sector could achieve net zero by 2050 in the Accelerated scenario** by accelerating investment and undertaking market reforms. This will require around 1000 GW additional renewable capacity by 2050 and can result in avoiding a cumulative 16 $GtCO_2e$ of emissions by 2070. Sector emissions would peak by the mid- to late-2020s in this scenario.

**This transition will likely need an investment** of $2.5 trillion until 2050 in the LoS scenario and an additional $1.3 trillion in the Accelerated scenario. Importantly, most of this investment is NPV positive and could get India's power-generation cost from its current INR 4/kWh to INR 3/kWh by 2050. The total average system cost of supply which was 6.15 INR/kWh in 2020 can also come down by 0.7–0.9 INR/kWh as increases in per unit transmission and distribution cost could be offset by decreases in generation cost and aggregate, technical and commercial (AT&C) loss reduction.[61] However, India would have to be mindful not to compromise on energy security through import localisation and power-mix diversification.

**Critical challenges that India would face to achieve net-zero in the power sector** are a) 5x and 9x RE capacity addition in 2030 and 2040, respectively relative to its current 10–12 GW per year RE addition; b) RE supply chain and raw material manufacturing given 80–90 percent of solar modules are currently imported; c) land availability and grid connectivity; d) integration of intermittent RE while ensuring grid stability and avoiding power outages.

**Key actions that India could take to enable the transition** would be a) increase RE and storage capacity additions; b) initiate market reforms, leverage innovative flexibility sources for RE-integration to ensure grid reliability; c) improve the financial health of power distribution companies (DISCOMs); and d) localise manufacturing in key technology areas such as solar, storage and hydrogen electrolysers. Besides the transition, decarbonisation could also help accelerate job creation and provide India with an opportunity to become a global leader of energy transition and a possible exporter of green technologies. However, India will have to be mindful not to compromise on energy security through import localisation and power-mix diversification.

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[61] Full system cost of power including costs (factoring reasonable returns and system losses) for generation, transmission and distribution. The corresponding cost of power generation Is INR 3.9/KwH.

## The power sector today

The power sector currently accounts for around 35 percent of India's total carbon emissions. Between 2011 and 2019, emissions increased from 930 $MtCO_2e$ to 1100 $MtCO_2e$—a CAGR of two percent,[62] roughly half the electricity demand growth in the period.[63] Demand for power is set to rise further as industry and transport electrify, increasing per capita consumption from the current relatively low levels of around 1,200 kWh, just one-seventh of the Organisation for Economic Co-operation and Development (OECD) average.[64]

**Renewables are increasingly competitive against coal:** Most of the emissions in the sector are from coal-based thermal power plants, which currently meet three-quarters of India's power demand.[65] However, the share of coal generation in the power generation mix peaked in 2015 at 78 percent and has been declining since.[66] This decline is driven primarily by exponential capacity growth in RE and its cost competitiveness (Exhibit 10). India is a global leader in RE development. In 2021, it had the world's fifth-highest global solar-power capacity and fourth-largest global solar and wind capacity.[67] Rapid cost declines in solar photovoltaic (PV) and wind power have led to the RE annual capacity addition outpacing coal since 2017.[68] Government initiatives over the past decade—such as holding reverse auctions, creating solar parks and de-risking evacuation and offtake—have also attracted significant investment and enabled this shift.

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[62] Historical emissions—UNFCCC

[63] Climate action tracker (India); "Third biennial update report to the United Nations Framework Convention on Climate Change," Ministry of Environment, Forest and Climate Change, Government of India, 2021.

[64] "Per capita electricity generation," Our World in Data.

[65] India's current capacity mix, Ministry of Power annual report, 2021–22

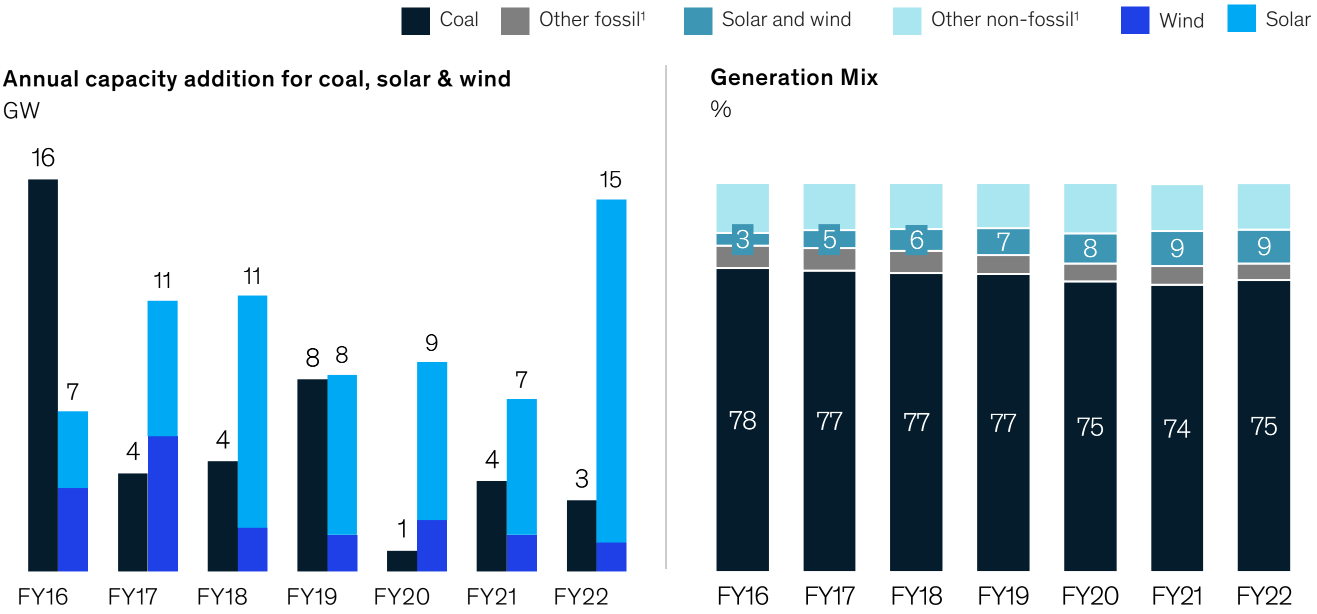
[66] "India energy outlook," IEA, 2021.

[67] Country rankings, International Renewable Energy Agency (IRENA).

[68] Ministry of Power and Ministry of New and Renewable energy annual reports

Exhibit 10

### The share of coal generation in the power mix has been declining due to capacity growth in renewable energy.



Source: India RE Navigator, Ministry of Power annual reports; Ministry of new and renewable energy; Government of India

Solar tariffs in the range of INR 2–2.5/kWh are cheaper than the marginal cost of 60–70 percent of coal power plants.[69] Solar-wind-storage hybrid plants that provide 85 percent round-the-clock power on an annual basis—a common definition of baseload RE in India—have ex-bus bar tariffs between INR 4–5/kWh. These RE-storage hybrids have reached parity with new-build coal plants, and it is expected that they will be cheaper on a marginal cost basis than 30–50 percent of operating coal plants by 2030 and 60–75 percent by 2040 (Exhibit 11).[70]

**Net zero is possible, but challenges remain:** Reaching net zero is possible in India only if the power sector builds on and accelerates its energy-transition momentum. We examine two scenarios for getting to net zero in the sector: the LoS scenario and the Accelerated scenario (Exhibit 12). Both are realistic and would bring great benefits. However, both scenarios would require substantial investment, and major challenges remain to be addressed—primarily through market and policy reform.

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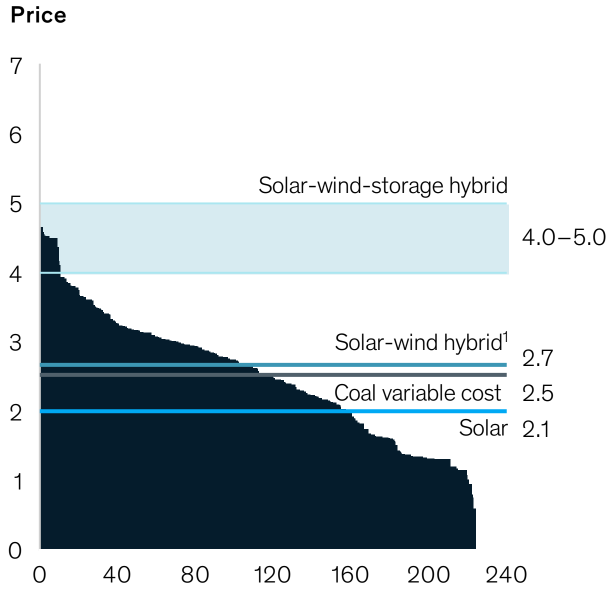
[69] Ex-bus bar tariff excludes the cost of transmission and distribution. Analysis based on the unit-level coal plant variable cost; Data from RE navigator and Merit India

[70] Analysis based on unit-level coal plant variable cost.

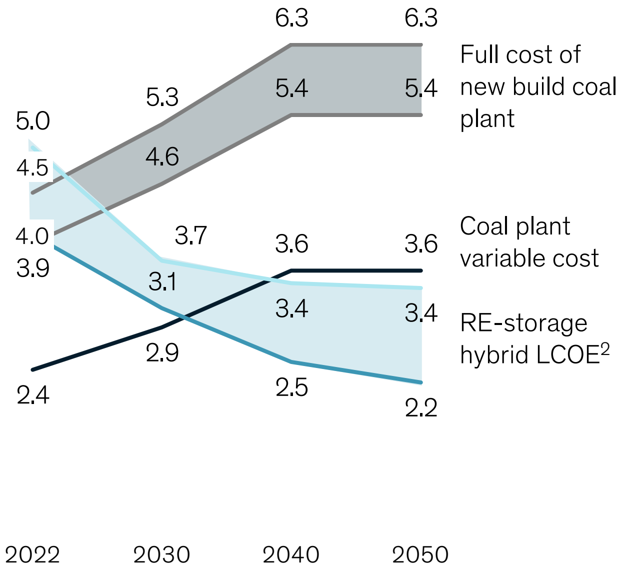
Exhibit 11

## Cost of power from solar-wind-storage hybrids has reached parity with the full-cost of new-build coal plants.

**Comparison of coal plant variable cost curve with RE tariffs in 2021,** INR/kWh



**LCOE comparison of baseload RE and coal based generation,** INR/kWh



1. Adani Hybrid Energy Jaisalmer commissioned a 390 MW solar-wind hybrid plant. The plant has a PPA with SECI at a tariff of ₹2.69/kWh.
2. The upper limit is hybrid levelised cost of energy (LCOE) with average capex and opex costs for solar, wind and storage; lower limit is hybrid LCOE with best-in-class 85% fulfilment.

Source: India RE Navigator, Merit India, McKinsey Power Model

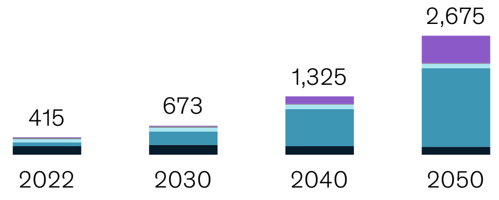
Exhibit 12

## Both the LoS and the Accelerated scenarios are realistic—but would likely require substantial investment.

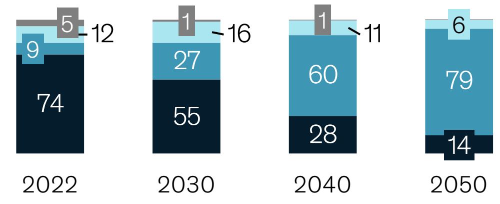
🟥 Transmission & distribution ⬛ Coal ⬛ Other fossil[1] 🟦 Solar and wind 🟦 Other non-fossil 🟪 Storage[2]

### LoS scenario

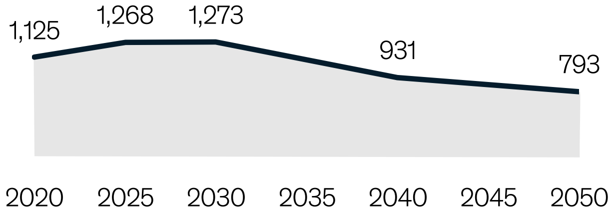
**Non-fossil capacity at 400 GW by 2030**
Capacity evolution until 2050, GW



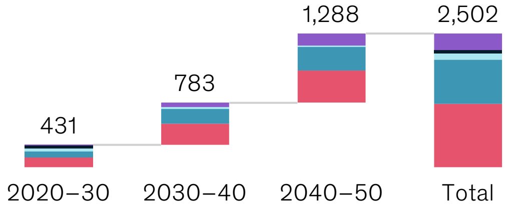
**Coal reaches net zero by 2070**
Generation mix, %



**Emission peaks in the early 2030s**
$CO_2e$ emissions until 2050, Mt



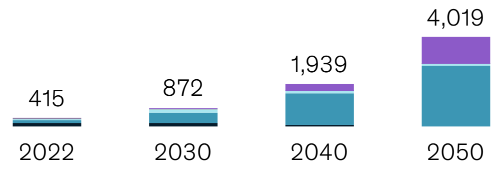
**$2.5 trillion investment required by 2050**
Investments in RE and storage until 2050, $ billions



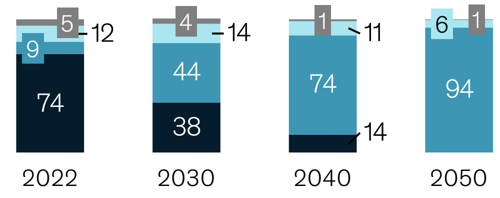
Capacities by 2050: Solar – 1372 GW; Wind onshore – 364 GW; Hydro – 51 GW; Nuclear – 22 GW, Capacities by 2030: Solar – 204 GW; Wind onshore – 86 GW; Hydro – 69 GW; Nuclear – 16 GW.

### Accelerated scenario

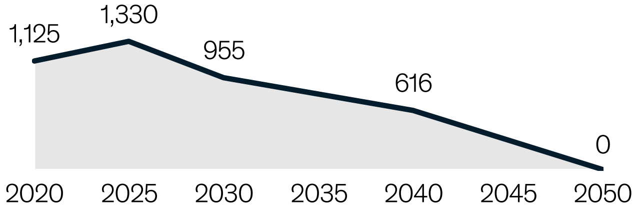
**Non-fossil capacity at 600 GW by 2030**
Capacity evolution until 2050, GW



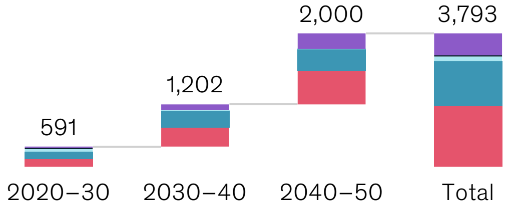
**Coal reaches net zero by 2050**
Generation mix, %



**Emission peaks in mid-2020s**
$CO_2e$ emissions until 2050, Mt



**$3.8 trillion investment required by 2050**
Investments in RE and storage until 2050, $ billions



Capacities by 2030: Solar – 376 GW; Wind onshore – 102 GW; Hydro – 71 GW; Nuclear – 24 GW; Capacities by 2050: Solar – 2172 GW; Wind onshore – 536 GW; Hydro – 54 GW; Nuclear – 22 GW.

1. Other fossil includes gas and oil; other non-fossil includes hydro, biomass and nuclear.
2. Storage includes battery, pumped hydro, LDES 8–24h, LDES 24h+ and hydrogen.

Source: McKinsey Power Model

These challenges include but are not limited to the poor financial health of DISCOMs, power infrastructure upgrades to deal with infirm power, constraints in the RE supply chain and barriers to RE access for industrial consumers. The absence of ancillary and capacity markets in India shows that India's market structures are still not ready to integrate large amounts of RE.[71] The fact of a relatively young coal fleet (the average age of coal-powered plants is 14 years) will need to be kept in mind while developing India's road map to net-zero emissions.

## The LoS scenario

It is feasible for India to achieve net-zero emissions by 2070 in an LoS scenario. Several factors put India's power sector on a strong footing to reach its decarbonisation goals: favourable economics; strong policy backing, including the waiver of inter-state transmission charges and ambitious decarbonisation targets; a well-developed, mature power and RE industry; the presence of large global investors; and a growing trend among industrial consumers to decarbonise their power.

In this scenario, emissions may rise for another decade, as coal generation is expected to increase modestly to provide continuous power and balance the grid till RE-storage hybrid ramps up. Correspondingly, emissions would peak in the early 2030s at 1.3 $GtCO_2e$. Emission intensity would, however, gradually decrease from 0.77 $kgCO_2e$/kWh in 2020 to 0.52 $kgCO_2e$/kWh by 2030. This transition would be enabled by:

— **Coal capacity:** This is estimated to increase from its current 210 GW to peak at 240 GW by 2030, driven by the completion of major projects currently under construction or in advanced planning (Exhibit 14).[72] The LoS scenario assumes that there would be minimal to nil coal capacity addition after 2030—but also no forced plant retirements, as cheaper coal capacity could be maintained at an average plant load factor (PLF) of 60 percent.

— **Solar and wind capacity:** This is expected to increase from the current 95 GW in 2021 to 300 GW by 2030, with 20–25 GW built annually. This is achievable, considering India has succeeded in adding 10–12 GW per year over the past five years (excluding some periods affected by the COVID-19 pandemic)[73] and is further scaling its renewable capacity.

Exhibit 13

### Key assumptions made in the LoS and Accelerated scenarios for power sector analysis.

**LoS scenario**

- Demand growth of 5% till 2050 (including hydrogen demand); without hydrogen demand growth at 4% till 2050
- Coal capacity increases from 210 GW currently to peak at 240 GW by 2030 driven by completion of plants which are under-construction and in advanced planning stage
- No accelerated decommissioning of coal plants, coal plants are retired when they reach their end of life (40-50 years)
- Wind and solar capacity addition assumed not to be constrained by land availability, equipment and other factors
- Nuclear capacity is assumed to increase from 7 GW in 2021 to minimum 15 GW by 2030 and 20 GW by 2040. Wind Offshore is assumed to reach 5 GW by 2030, 15 GW by 2040 and 30 GW by 2050

**Accelerated scenario**

- Higher demand growth rate of 6% till 2050 due to faster electrification of industry and transport
- No new coal plants built other than plants already under construction. Coal capacity peaks in mid-2020s, and is 190 GW in 2030
- Most coal plants become uneconomical by mid-2040s and are retired. End of life for coal plants assumed to be 10 years less (30-40 years)
- Wind and solar capacity addition assumed not to be constrained by land availability, equipment and other factors
- Nuclear capacity is assumed to increase from 7 GW in 2021 to minimum 15 GW by 2030 and 20 GW by 2040. Wind Offshore is assumed to reach 5 GW by 2030, 15 GW by 2040 and 30 GW by 2050

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[71] 90 percent of power in India is still provided via long-term power purchase agreements (PPAs), the majority of which are for baseload. The share of wholesale or traded power, peak PPAs and shaped PPAs is very low. Time-of-day pricing, which is needed to achieve demand-side flexibility, is also not dynamic or adequate in many places.

[72] Based on the McKinsey power model (detailed in the Box 1). Currently, 29 GW of coal power plant capacity is under construction and 20 GW of capacity is planned. By 2030, it is expected that 18 GW of coal power plants will be retired, which entails a net increase of 30 GW by 2030.

[73] Solar energy, Ministry of New and Renewable Energy, Government of India.

- **Enhanced storage and flexibility,** where total storage could increase from its current operational capacity of 3.3 GW to 30 GW by 2030, reaching 600 GW by 2050:[74] Until the mid-2030s, pumped hydro (6–24 hours of capacity) would continue to be the dominant storage technology as lithium-ion batteries (less than six hours of capacity) continue to scale. These existing storage technologies with technological improvements that could reduce Capex and increase efficiency would be sufficient to meet the sector's needs for the next two decades. From 2040, as the RE share increases beyond 60 percent, intermittent RE sources may require longer-duration storage technologies, such as hydrogen, for seasonal storage.
- **Nuclear power**: To maintain grid reliability as coal is phased out, we have assumed that nuclear will increase from its current levels of around 7 GW to at least 15 GW by 2030 and around 20 GW by 2050; and offshore wind will increase to a minimum of 5 GW in 2030, 15 GW in 2040 and 30 GW by 2050. India's huge thorium reserves and long coastline mean that nuclear and offshore-wind power-generation technologies both have great potential to enhance grid reliability. If initial support is provided by the government in the form of feed-in tariffs or viability gap funding, offshore wind and new nuclear technology could become cost competitive and help India decarbonise even sooner.

The above capacity mix projection for the LoS scenario is also in line with India's NDC commitment of achieving 50 percent of installed power capacity from non-fossil fuel by 2030.

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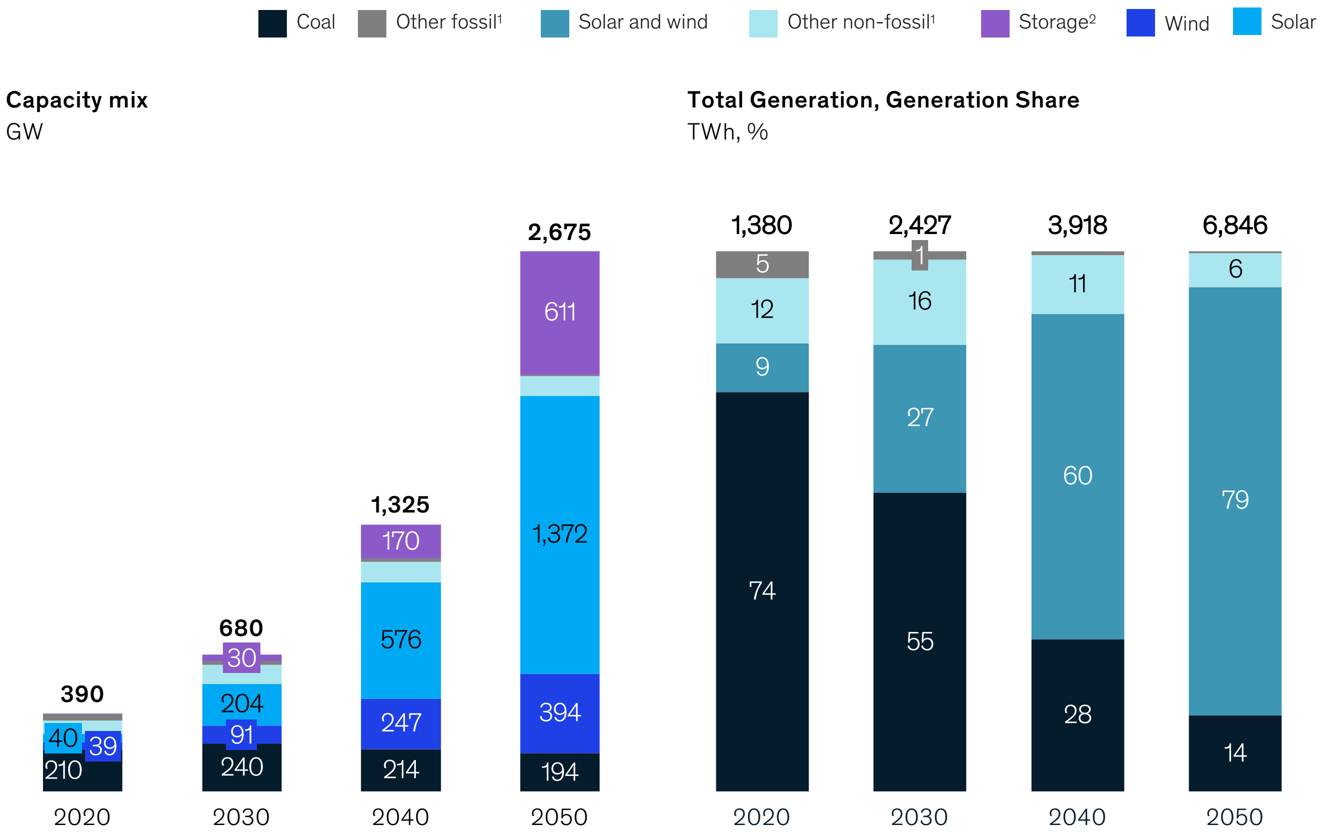
[74] CEA, Mecromindia.

Exhibit 14

## In the LoS scenario, non-fossil capacity is expected to reach 400 GW by 2030 with a 40–45% share in generation mix.



1. Other fossil includes gas and oil; other non-fossil includes hydro, biomass and nuclear
2. Storage includes battery, pumped hydro, LDES 8–24h, LDES 24h+ and hydrogen

Source: McKinsey Power Model

## The Accelerated scenario

Given the rapid innovations in RE and acceleration in capital deployment, India has a unique opportunity to achieve net-zero emissions by 2050. This could be made possible by accelerating interventions to address industry challenges and instituting key market reforms to encourage further investment. Relative to the LoS scenario, net-zero emissions by 2050 could prevent about 16 $GtCO_2e$ of cumulative emissions by 2070, while only marginally increasing generation costs.[75] In the Accelerated scenario, emissions could peak in the mid-2020s at 1.3 $GtCO_2e$, following the coal-generation trajectory. Emission intensity would rapidly decrease to 0.37 $kgCO_2e/kWh$ by 2030. This would be enabled by:

— High-cost coal capacity becoming increasingly uneconomical in comparison to the declining costs of solar or wind hybrids. Assuming no new coal plant would come online beyond current capacity, existing efficient low-cost coal plants may continue to generate power (PLFs of 60–65 percent) into the mid-2040s. By 2050, the entire current coal fleet could expect to be retired.

— Solar and wind capacity increasing to 480 GW by 2030—a 45 percent share of all power generation (Exhibit 15). This would need an acceleration in the annual build-out to 40–50 GW (compared to 10–12 GW per year over the past five years) till 2030. By 2050, India may likely need 2,700 GW of solar and wind, representing a 95 percent share of the generation mix.

— Enhanced storage, which, along with hydro and coal reutilised as flexible generation sources, would be needed to balance the higher RE share. The amount of required storage would be 65 GW by 2030 and 1,200 GW by 2050. Until mid-2030, pumped hydro would be the key storage technology (for short- to medium-term storage) supported by lithium-ion batteries to provide baseload power—but from the late 2030s onward, long-duration energy storage technologies (including hydrogen) would be needed as seasonal storage.

— Generation from nuclear, which is assumed to increase to around 25 GW by 2030, remaining at this level until 2050. As with the LoS scenario, the share of offshore wind is assumed to gradually increase to reach 30 GW by 2050.

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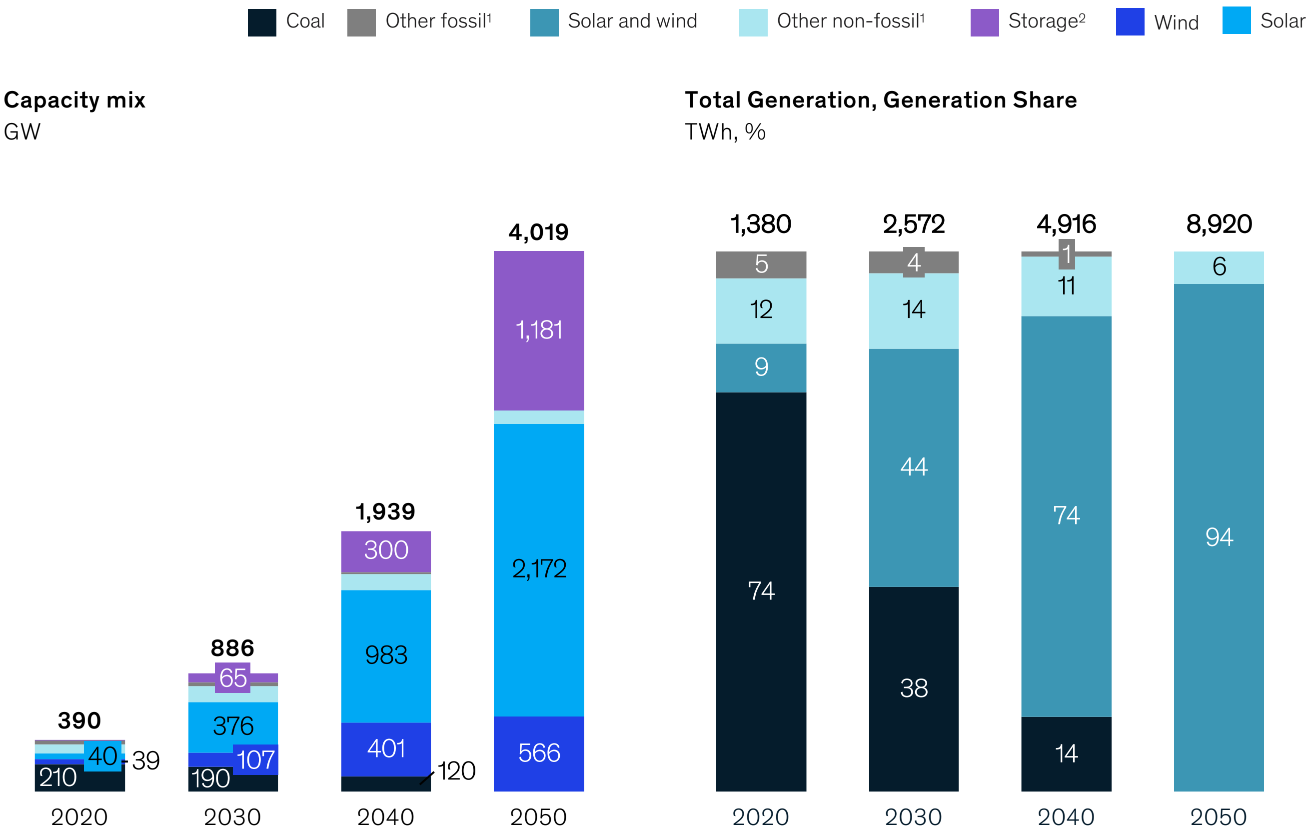
[75] McKinsey power model and analysis.

Exhibit 15

## In the Accelerated scenario, non-fossil capacity is expected to reach 600 GW by 2030 with 50–60% share in the generation mix.



1. Other fossil includes gas and oil; other non-fossil includes hydro, biomass and nuclear
2. Storage includes battery, pumped hydro, LDES 8–24h, LDES 24h+ and hydrogen

Source: McKinsey Power Model

Achieving this scenario would require more intense and rapid efforts across four areas:

1. **Accelerating India's RE capacity:** India would need to add 40–50 GW of RE annually over the next decade and 130–140 GW annually from 2040 to 2050.[76] Associated challenges involving land acquisition, grid connectivity and counterparty risks (such as problems with PPA adoption, renegotiation and payment) would also have to be addressed. These issues are expected to multiply as RE scales up. For example, the 2050 solar capacity of 2,000 GW is expected to require 1.3 percent of India's land surface (about a quarter of India's wasteland).
2. **Ensuring grid reliability and market reforms:** India has limited flexible generation capacity compared to many other countries. Already, RE integration issues are emerging, leading to solar power curtailment and a slowing down in terms of signing new PPAs. For grid reliability with 90 percent RE, massive reforms are required in the power market. Currently, the wholesale market share is under ten percent; there is no ancillary services market; incentives for peak-load plants are inadequate; and time-of-day tariffs are limited.[77] As most of this RE capacity is likely to be in the south and west, the country will likely need to increase interconnection capacity. Finally, RE addition must be complemented by either 60–65 GW of storage (short and long duration) by 2030 and 1,200 GW by 2050 or alternative flexibility mechanisms will need to be found.

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[76] McKinsey power model and analysis.

[77] "Report on the short-term power market in India: 2020–21", Economics Division, Central Electricity Regulatory Commission, Government of India.

3. **Ensuring financial viability of the distribution sector:** Most public DISCOMs in India are lossmaking, leading to increased financial stress on power generators and reluctance to promote open access RE for commercial and industrial (C&I) customers. The financial health of DISCOMs would need to improve to be able to attract low-cost capital for the transition.
4. **Streamlining governance, policy making and planning:** Multiple ministries are needed to enable the transition, and they may need to be aligned fully with this transition. Furthermore, coordination and policy cohesion between federal and state governments would be needed.

## Implications of the transition to net zero for the power sector

**Emissions:** In the LoS scenario, power-sector emissions are expected to peak by the early 2030s. In the Accelerated scenario, the peak could be reached by the mid-2020s (Exhibit 16). If India's power-sector targets the Accelerated scenario instead of the LoS scenario, it could abate around 10 $GtCO_2e$ emissions by 2050 and around 16 $GtCO_2e$ by 2070.[78]

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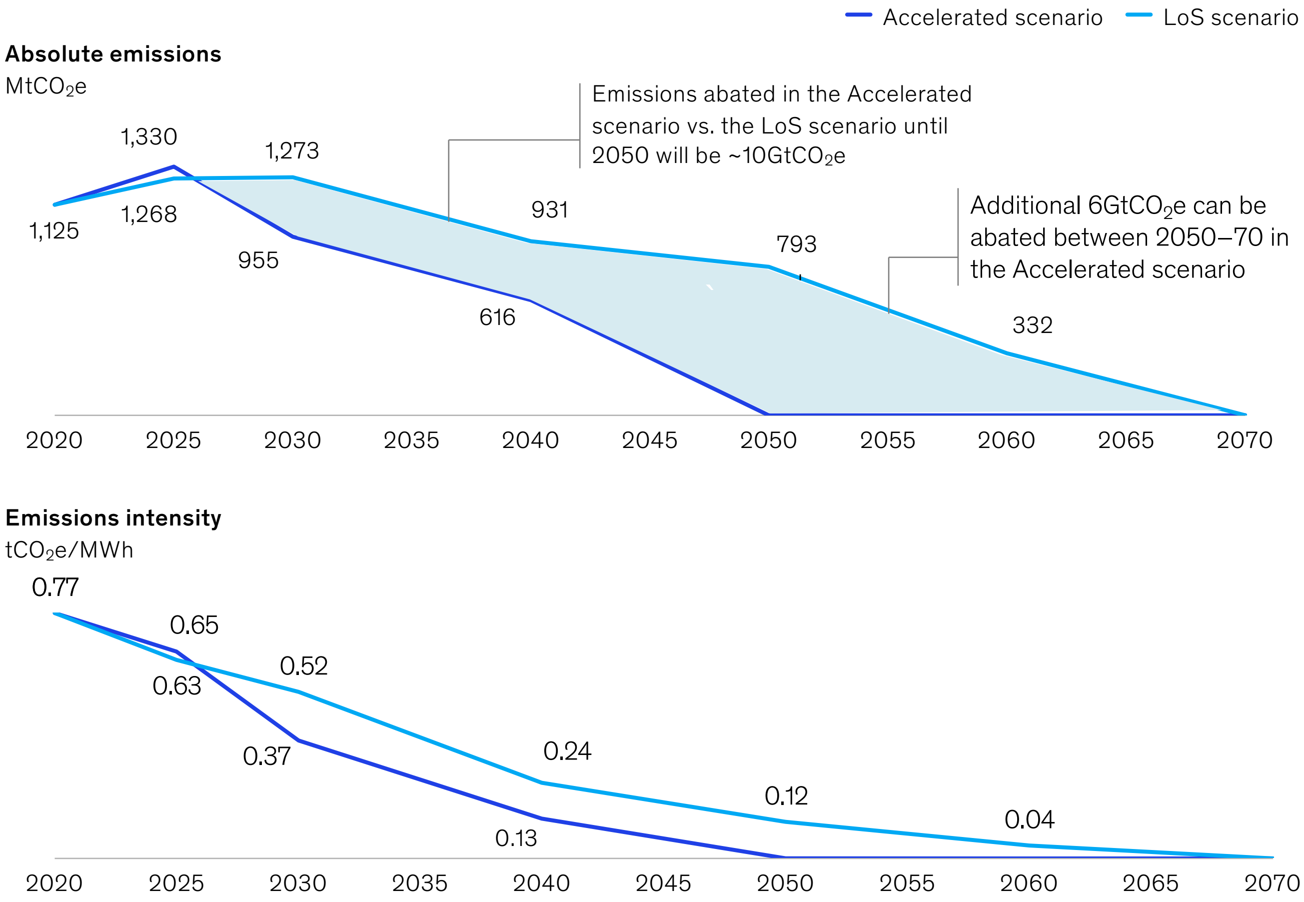
[78] McKinsey power model and analysis.

Exhibit 16

### In the Accelerated scenario, power emissions could peak a decade sooner than in the LoS scenario.



Source: McKinsey Power Model

**Investments:** An investment of $1.3 trillion through to 2050 would be required for the LoS scenario to build RE, storage and distribution capacity. This represents an annual investment between $12 and $14 billion through to 2030, rising thereafter to between $70 and $80 billion per annum. This is realistic but challenging, considering that in 2021 India's RE sector attracted $12–$15 billion in investment.[79]

In addition, expanding and upgrading the transmission and distribution (T&D) infrastructure would need another $1.2 trillion.

For the Accelerated scenario, an additional cumulative Capex investment of $750 billion would be needed for RE and storage capacity, and $550 billion for the transmission and distribution infrastructure through 2050 vis-à-vis the LoS scenario. The investments in RE and storage factor in reasonable improvements in the cost and efficiency expected over the next few years.

Storage considers multiple technologies – lithium-ion, pumped hydro storage, other long duration energy storage technologies and hydrogen – based on the duration needed for storage. Investments in T&D infrastructure have been estimated based on their correlation with capacity additions and peak demand growth. These numbers have also been triangulated with forecasts by other agencies.[80]

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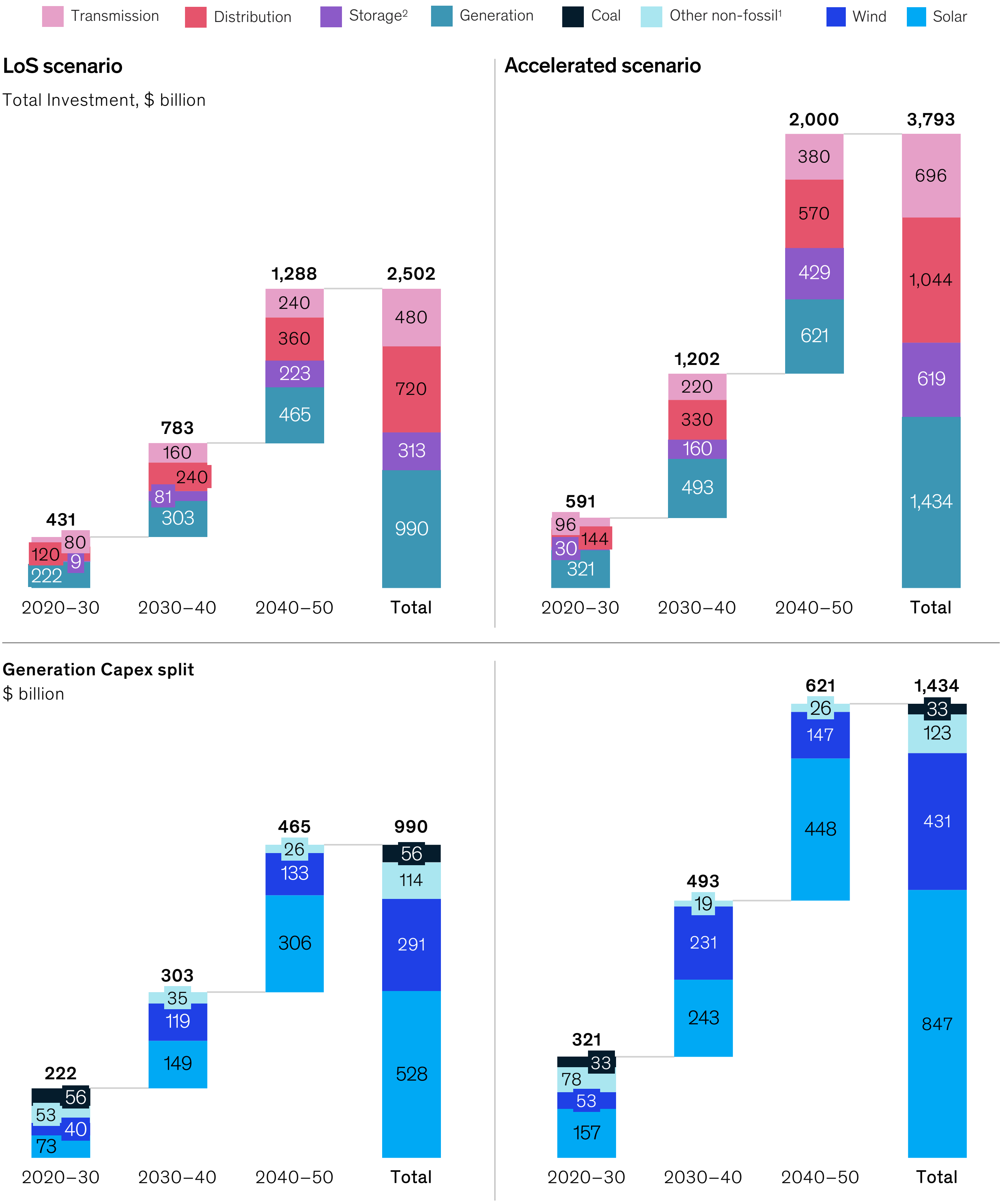
[79] Vibhuti Garg, "India saw record investment in renewables last financial year—so what next for green power in the country?" Institute for Energy Economics and Financial Analysis, July 15, 2022.

[80] Agencies include Postdam Institute For Climate Impact Research, IEA and NGFS

Exhibit 17

## An additional investment of $1.3 trillion would be needed to move from the LoS to the Accelerated scenario.



**LoS scenario**

**Accelerated scenario**

**Generation Capex split**

1. Other non-fossil includes hydro, biomass and nuclear
2. Storage includes battery, pumped hydro, LDES 8–24h, LDES 24h+ and hydrogen
3. Average Annual T&D capex for past 5 years is $20-25 Billion

Source: McKinsey Team Analysis, McKinsey Power Model; Cost Assumptions (Capex) for technologies from CEA - India Technology Catalogue 2022 and Expert Interviews

**Generation cost:** In both scenarios, the shift from thermal power to renewables is expected to decrease the average cost of generation, given the decreasing cost of RE and storage technologies (Exhibit 18). Even though a huge sum of investment is required for this transition, most of this investment would be NPV, reducing India's power-generation costs from the current INR 4/kWh to INR 2.5–3/kWh by 2050 (without considering transmission and distribution costs).[81] When T&D costs are added to the generation cost to get the total system cost, the overall power costs will still decline, but not as steeply as the power generation cost by itself.

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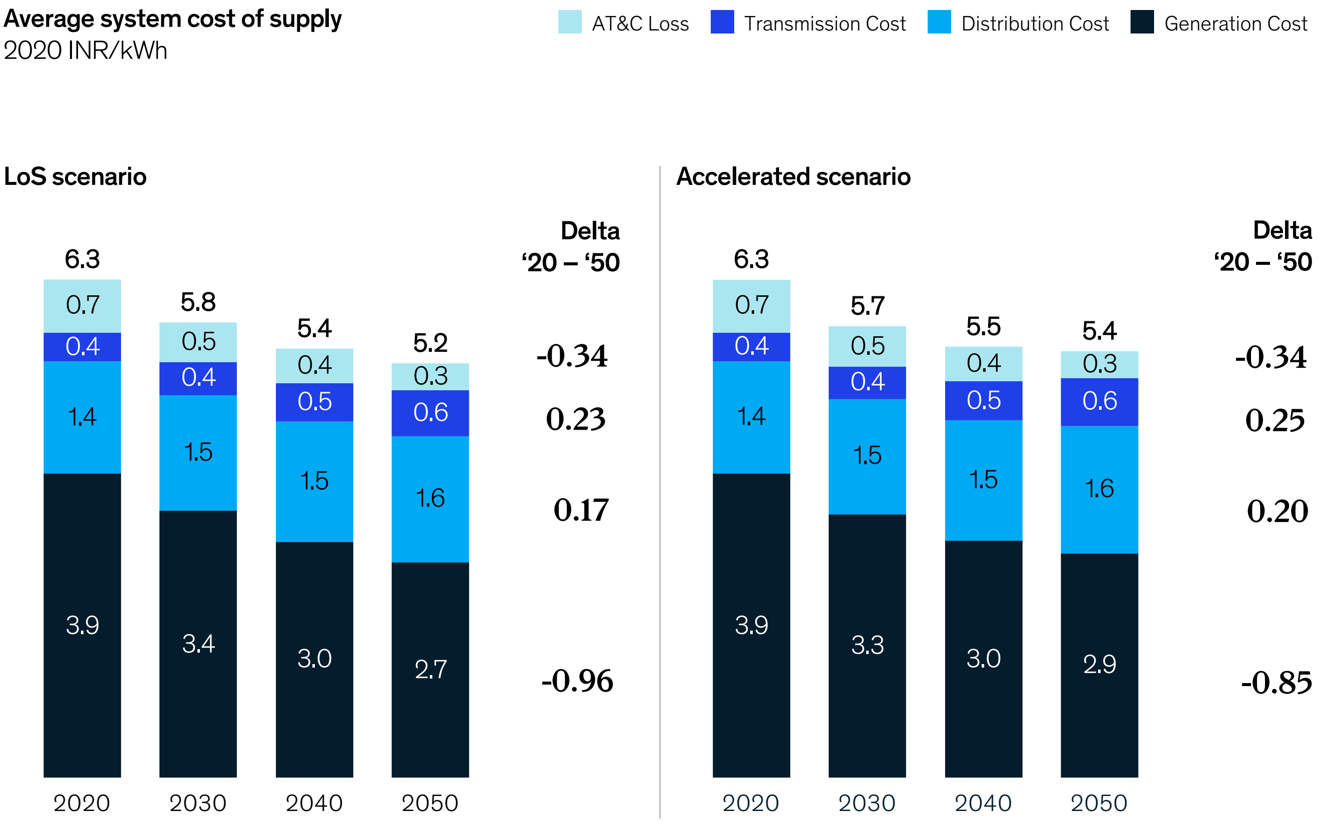
[81] McKinsey power model and analysis.

Exhibit 18

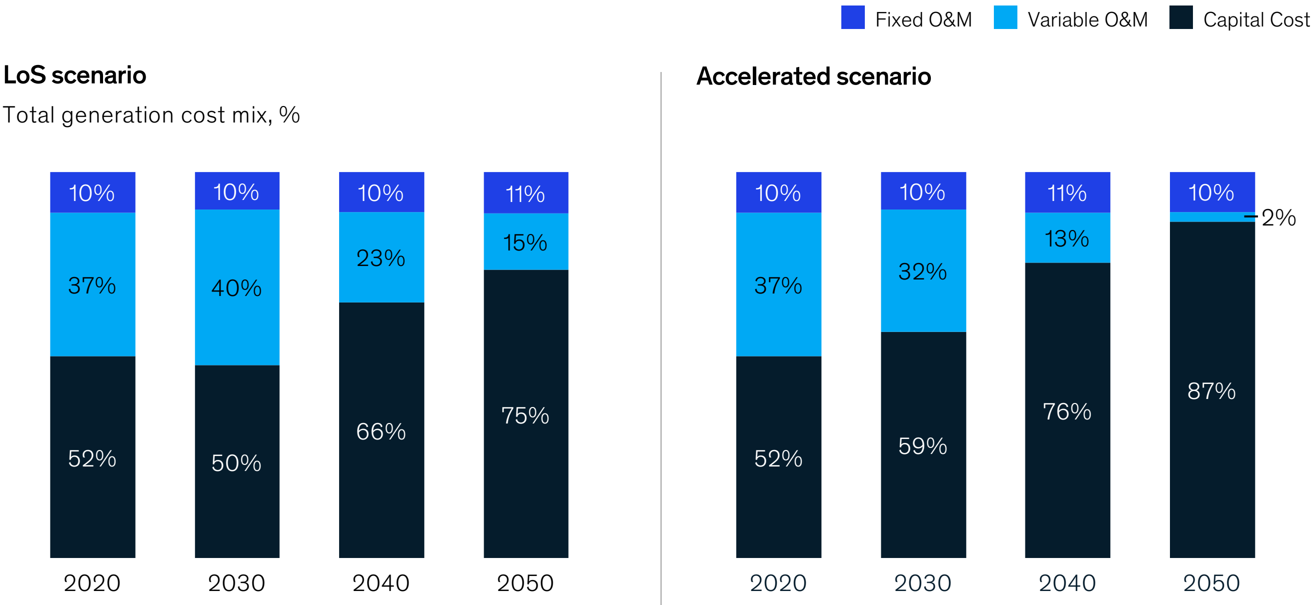
**Energy generation cost is expected to decline due to the increasing share of renewables in the capacity mix; average system cost will also decline but not as steeply.**



Source: McKinsey Power Model & Team Analysis

Exhibit 19

## As the mix moves away from coal, variable O&M share in the total system cost would decline and the capex share would increase as RE has low O&M.



Source: McKinsey Power Model

**Imported equipment**: India currently imports 80–90 percent of its solar modules, leading to an annual import bill of $5 billion to $10 billion (in 2021).[82] This could increase to $50 billion by 2030 and $300 billion by 2050 in the LoS scenario, and increase to $120 billion by 2030 and $450 billion by 2050 in the Accelerated scenario. There is an ongoing race for raw materials for solar PV and storage (e.g., cobalt, rare earth metals). India has historically under-invested in R&D and innovation on alternative material science applications for technologies like solar PV and battery. To secure the future energy mix and make India a global green-energy hub, it will be vital to localise manufacturing.

## Proposed enablers for power decarbonisation

Three enablers to be considered for the transition to net zero in India's power sector:

1. **Reducing land and grid bottlenecks for RE projects:** A central RE infrastructure planning and project monitoring agency could be responsible for resolving the supply-side bottlenecks for RE projects. This agency could identify land pockets (especially wastelands) through geospatial analysis and satellite imaging; maintain a databank on available land with resource potential (which could also lower financing cost and promote insurance products); coordinate with bodies, such as the National Land Monetisation Corporation, the Department of Land Resources and state governments, to either aggregate land in a solar-park model or facilitate acquisition by private players. It would also coordinate with transmission companies to inform their capacity planning.
2. **Accelerating power market reforms and DISCOM reforms to integrate RE and de-risk the sector:** Such reforms would include deepening power markets with the introduction of derivatives and futures for risk mitigation, launching ancillary services and capacity markets, leveraging demand-side flexibility by speeding the adoption of consumer time-of-day tariffs and EV charging. It would also include creating supply-side flexibility by enabling existing coal and hydro plants to blend RE into existing PPAs, and incentivising underutilised plants to participate in the capacity market. Market reform could save $150 billion to $200 billion in investments through 2050, which have been built into our investment estimates.[83]

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[82] Trade statistics, Department of Commerce, Ministry of Commerce and Industry, Government of India.

[83] These savings have been estimated assuming supply- and demand-side flexibility—for demand-side flexibility, McKinsey assumed that 15 percent of EV demand would shift to solar hours and 5 percent of residential demand would shift to solar hours through demand response. For supply-side flexibility, the higher ramp rates and lower technical minimum of coal plants, along with repurposing some hydro plants as flexibility providers, were considered.

On the DISCOM side, India has already undertaken multiple efforts to reform the power-distribution sector. It can ensure strict monitoring and adherence to the recent revamped distribution sector scheme reforms, make lending to DISCOMs more stringent (including from private banks and financial institutions), strengthen the performance of regulators (for example, by ensuring timely and adequate tariffs) and encourage DISCOMs to create a roadmap for business transformation amenable to improving last mile delivery (quality/ reliability), customer service and competition.

Furthermore, India could unlock latent C&I demand by removing barriers to open access (for example, through banking, net metering, inter-state open access and extension of the interstate transmission system {ISTS} charges waiver); promoting innovative contracting mechanisms (like virtual PPAs) to enable RE procurement for smaller C&I customers (less than 100kW); reducing the financial impact on DISCOMs; improving the bankability of RE projects; and encouraging DISCOMs to launch green tariffs. It could also develop inter-country transmission networks in South Asia, Southeast Asia and eventually the Middle East to deepen the grid.

3. **Localising manufacturing and key technologies could be leveraged to further enable the transition by** i) incentivising end-to-end manufacturing for PV modules, storage, electrolysers; ii) acquiring or developing upstream assets (such as lithium mines or polysilicon processing plants) to secure critical supply chains; iii) creating green innovation clusters consisting of academia, start-ups, incubators/ investors and industry players to lead R&D, prototyping and the scale-up of future energy technologies (e.g., off-river pumped storage, fuel cells, novel chemistries for storage, perovskite solar cells, thorium based nuclear, electrolysers) enabled by higher R&D spend by government and industry; iv) leveraging data stack, democratising data access and incentivising tech players to build AI/ ML solutions across the value chain (e.g., weather and generation forecasting, integrated resource planning and prescriptive models, predictive maintenance); v) training and reskilling power-sector employees for RE; and vi) enabling a circular economy by recycling and promoting second-life usage of batteries and PV modules for sustainability.

Net zero in power is achievable if India acts fast.[84] With policymakers, industry and companies facilitating RE integration into the grid (by building a flexible, robust grid and ensuring that conventional and storage technologies operate together), India could become a global energy-transition leader and an exporter of green technologies. Favourable RE economics can play a supportive role in this transition, attracting investments from the growing global pool of sustainability-themed capital. Decarbonising India's power sector would need significant investments, but can bring with it considerable opportunities, including that of global green energy leadership.

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[84] See Box 1 for details on modelling methodology, levelised cost of electricity (LCOE) and levelised cost of system (LCOS), the evolution of different generation and storage technologies and the evolution of generation cost and emissions in both scenarios.

## Box 1

## Modelling methodology:

For the power sector, the capacity and generation mix outlook has been prepared using a robust McKinsey proprietary power model. The least cost optimisation model is designed to develop an outlook on the capacity and generation mix such that the total system cost is minimised while reliably meeting constraints such as demand and emissions constraints. The model accounts for grid stability through matching demand and supply at hourly intervals for sampled days using a mix of 10+ generation and flexibility sources. 1000s of inputs are fed into the model, ranging from technological inputs such as choice of technology for generation and flexibility, capital and operating cost assumptions, generation profiles, efficiency and WACC for each technology along with inputs on demand outlook for each year, load profiles, current capacity mix with unit level details of existing power generation plants.

## The analysis is carried out through a model which provides valuable insights for understanding the future supply/demand dynamics at a very granular level.

### Data inputs

**Standard inputs**

- Electric load and growth
- Current capacity mix
- Fuel price outlook
- Technology cost outlook
- Policy target
- Future hydrogen demand

**Generation sources considered**

Fossil

- Coal, Natural gas & Oil

Clean sources

- Nuclear, Hydro, Biomass, Wind (onshore & offshore) & Solar

Flexible resources

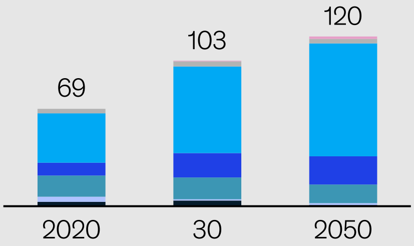
- Hydrogen (Electrolyser & turbine), Battery, PHES1 & LDES[2]

### Process

- The model takes an economic optimisation approach informed by policy and cross-sector inputs
- The model balances supply/demand by hour across the market, optimising both capacity expansion and dispatch decisions such that the total system cost is minimised while meeting all the constraints
- Cost optimisation makes the model sensitive to cost assumptions (capex, opex) for each technology hence the accrual capacity mix can vary due to deviation in assumptions and policy interventions
- An average solar and wind generation is assumed, and any extreme/unusual weather events are not modelled

### Outputs

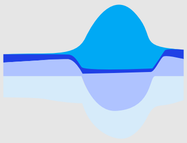
**Long term planning,** e.g., capacity installed by technology



Other outputs include: generation mix, emissions, total cost of system, etc.

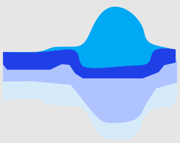
**Short term (hourly) market results,** e.g., hourly profiles for different days

'Average' day



Average day; does not exist in practice; Indicative of solar/storage activity

March 16



High RE production day High charging of storage with some curtailment

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[1] PHES – Pumped Hydro Energy Storage
[2] LDES – Long Duration Energy Storage

## 2.2 Automotive sector

## Key takeaways

**Automotive tailpipe emissions** account for 280 $MtCO_2e$ per annum (seven-eight percent of India's total emissions), increasing at about six-eight percent per annum[85] due to a growing vehicle parc, increasing size of vehicle engines and also increasing average usage per vehicle.

**In the LoS scenario, the automotive sector could get to net-zero tailpipe emissions by 2070.** Electrification of mobility is fast-accelerating due to advances in battery technology (storage capacity per kg up two times, average cost reduction of 17 percent every year over the last ten years). The sector benefits from government support (GST benefit of five percent on EVs versus 28–51 percent on ICE vehicles; dedicated FAME and PLI schemes).[86] Perhaps the most important factor is an implicit carbon tax on transportation fuels of $140–240/$tCO_2e$. As a result, India can achieve almost net-zero tail pipe emissions by 2070 in the LoS scenario.

**In the Accelerated scenario, the sector could get to near net zero by 2050.** In the Accelerated scenario, India can abate 95 percent of tail pipe emissions by 2050. This acceleration would come from a) reducing battery and fuel cell costs more quickly through at-scale localisation; b) providing continued government support through GST and FAME benefits till 2030; c) maintaining fossil fuel taxation at current levels; d) achieving the targeted modal mix of 45 percent for rail freight by 2040; and e) providing pointed affirmative action for transitioning to EVs for select 'late-transition' vehicle categories like HCVs.

**The Accelerated scenario would result in an additional cumulative abatement of around ~7 $GtCO_2e$ till 2070** versus the LoS scenario. This would also save Forex on crude import of $900 billion till 2050 (net of battery material import), versus the LoS scenario. An accelerated transition presents India with an opportunity to become a global manufacturing base for select vehicle categories, e.g., e-two wheelers, e-three wheelers, e-SCVs.

**The Accelerated scenario needs an incremental investment** of $1.3 trillion till 2070, in addition to the $1.9 trillion needed for the LoS scenario. This would be for the higher upfront EVs cost for the customer, while automotive, battery makers and charging providers will need to invest less than they would for the equivalent ICE manufacturing capacity. Additionally, the government would need to re-balance its finances as fuel taxes, which currently amount to 14 percent of central government receipts at $50 billion (two percent of GDP), and will decline with faster EV penetration.[87]

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[85] Toyota industries.

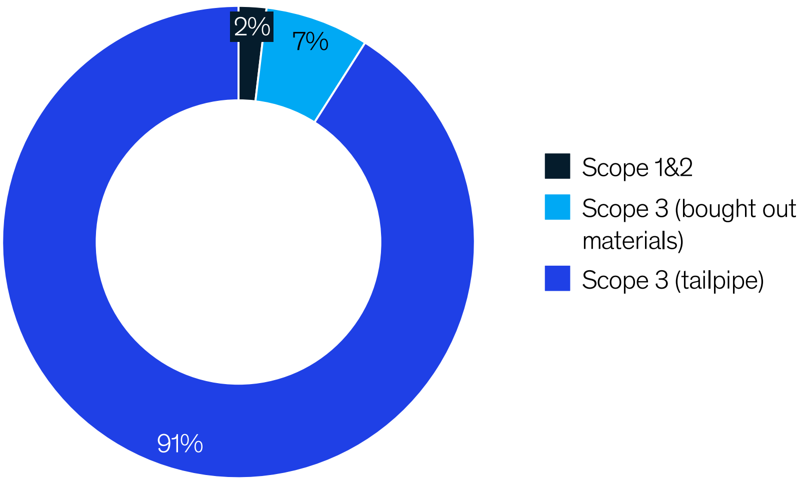
[86] FAME, Ministry of heavy industries.

[87] MOSPI.

Exhibit 21

## Automotive sector emissions dominated by tailpipe emissions.

**Automotive emissions mix** (%)



**Scope 1**
All energy used in manufacturing the car – by OEMs and suppliers

**Scope 2**
Emissions created to make the final fuel available for the customer to use, i.e., pumping, refining, logistics of crude, petrol, diesel and others

**Scope 3**
Tailpipe emissions, bought out materials

Source: Toyota Industries, McKinsey Analysis

## The automotive sector today

Automotive tailpipe emissions, at 280 $MtCO_2e$ per annum, comprise seven to eight percent of the total carbon footprint of India, growing at six to eight percent annually, with scope 3 (tailpipe emissions) far higher than scope 3 (upstream materials used in the car), scope 2 (fuel value chain) and scope 1 (vehicle manufacturing) emissions (Exhibit 21).

The sector has been on the path of energy and carbon efficiency through measures like light-weighting (ten percent weight reduction improves mileage by six to eight percent), advanced combustion technologies and engine hybridisation. The government has also put in place regulations that reduce emissions by bringing in Corporate Average Fuel Economy (CAFE) norms that started with passenger cars and are extending to CVs and other categories.[88] Yet, these interventions provide only marginal improvements.

The shifting demand to larger cars and, hence, engines (e.g., share of entry-level hatchbacks has dropped from over 60 to 40 percent over the last eight-nine years)[89] and the growing parc (from 290 million today to over 700 million by 2050)[90] will lead to emission growth. In the internal combustion engine world, tailpipe emissions could rise to 800 $MtCO_2e$ annually by 2050.

As with the rest of our analysis, this chapter examines two scenarios for getting to net-zero tailpipe emissions — the LoS scenario and the Accelerated scenario.

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[88] Press Information Bureau.
[89] SIAM.
[90] MORTH, Vahan, SIAM.

## The LoS scenario

Electrification is changing the face of mobility globally, with EV share gains accelerating in early adopter markets like China, the EU and US. These regions expect complete electrification of new car sales by 2030–2035 (Exhibit 22).

These trends are playing out in India as well, leading to the increasing competitiveness of EVs vis-à-vis ICE vehicles.

1. **Battery and fuel cell technology** advancements and the associated cost decrease (Exhibit 23), which is making EVs competitive on a lifetime cost basis (TCO).
2. **Implicit carbon taxes on transportation fuels** in the form of central and state VAT and excise duties. For example, these amount to 35–45 percent of the petrol retail price in Delhi and translate to an implicit carbon tax of \$140–240/$tCO_2e$ for usage of petrol, depending on the crude oil price and prevailing rates of taxes (Exhibit 24).
3. **Upfront fiscal support** being provided by the government in the form of GST benefits (five percent for EVs versus 28–51 percent for ICE vehicles) and FAME benefits (e.g., for two-wheelers, at the rate of INR 15,000/kWh of battery pack).[91]

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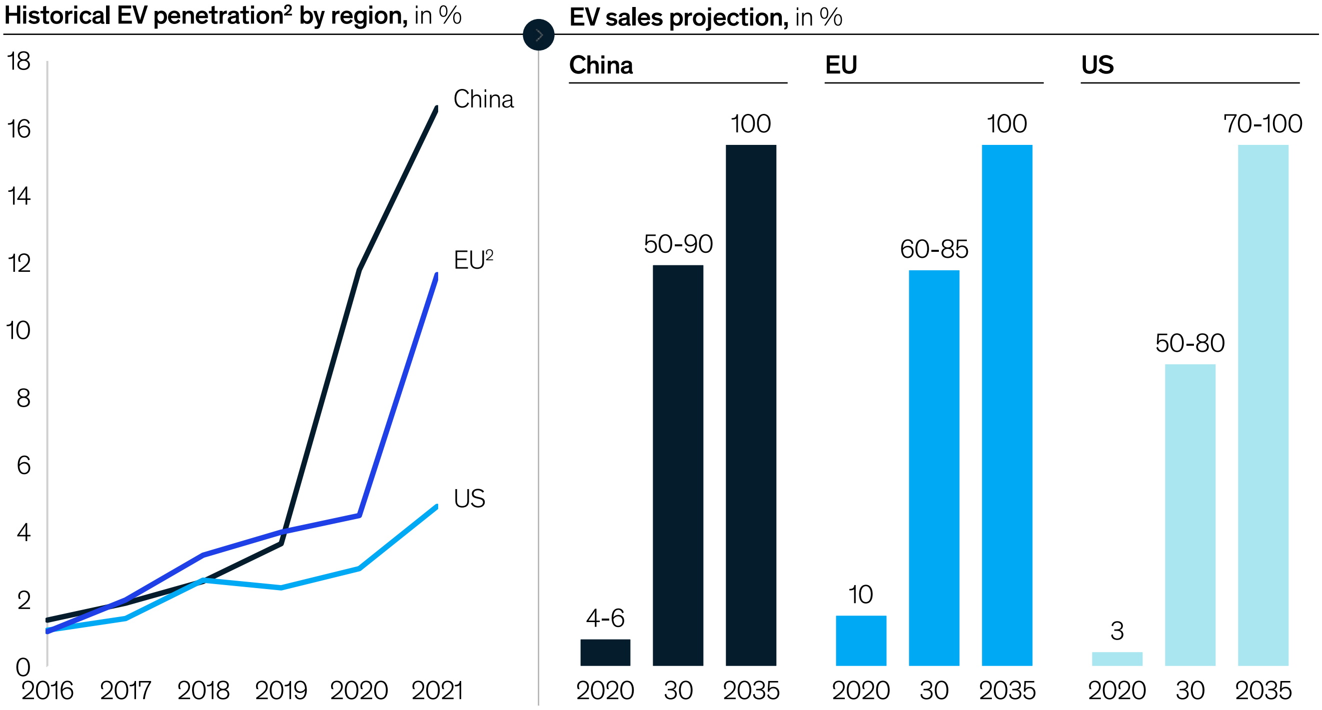
[91] FAME, Ministry of heavy industries

Exhibit 22

## Electrification accelerating across regions.

EV[1] as a % of new passenger vehicle sales

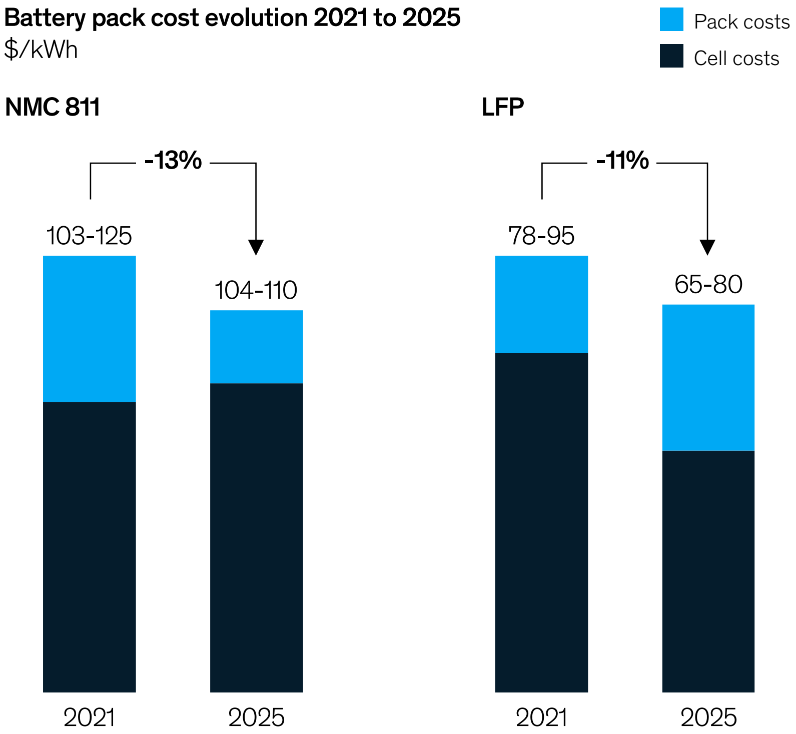


1. BEV, FCEV, PHEV.
2. EU+EFTA+UK.
3. Share of BEV and PHEV in percentage of total passenger car sales..

Source: McKinsey Electrification Model, McKinsey Centre for Future Mobility, Literature search, ICCT, EV Volumes, IHS

Exhibit 23

## Battery costs declining rapidly, powering the EV revolution.



### Main drivers of scale effect

- Increase in EV demand
- Improvement in learning & yield rates
- Increase in average plant size from 9 GWh in 2021 to 18 GWh in 2025
- Spread of direct & indirect cell production costs such as labour, SG&A, logistics, R&D costs and PPE & depreciation

### Main drivers of technology effect

- Energy density increase (impact on direct material and fixed costs) as well as component technology of cathode, anode and electrolyte
- Gains from next-generation cathode (advanced NMC 811)
- Reduction in the cost of cell components such as separator, copper foil, aluminium foil, etc.

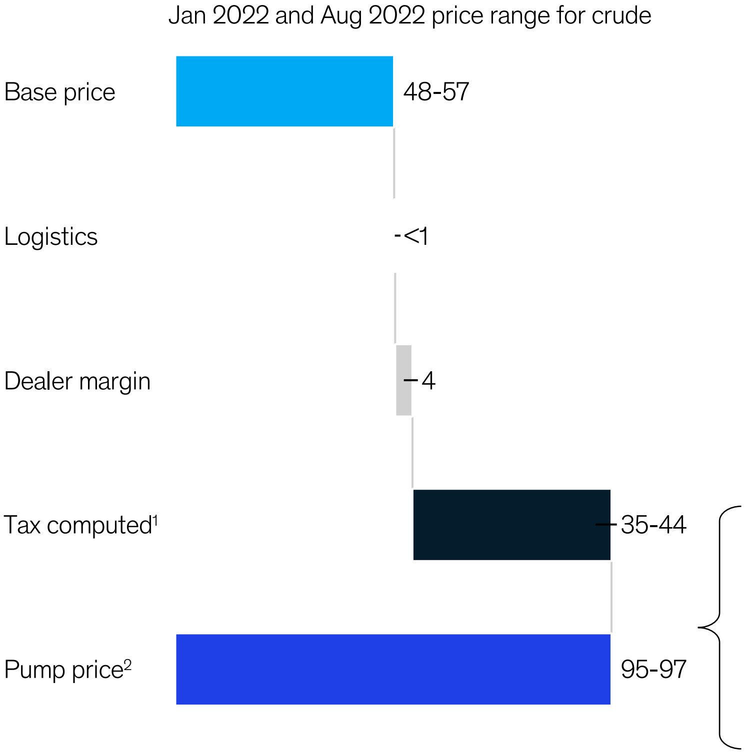
Note: Cost+ at 10 GWh plant in China, excluding the LFP royalties; LFP Export VAT 13%.

Source: McKinsey Battery insights – Battery Cost model

Exhibit 24

## Substantial implicit carbon tax on automotive fossil fuels.

**Fuel price breakdown (Delhi example),** INR/lit



| Fair taxation | Implicit carbon tax (INR/lit) | Implicit carbon tax (USD/tCO$_2$e) |
|---|---|---|
| At 5%[3] of product cost[4] | 33-41 | 190-240 |
| At 18% of product cost[4] | 25-34 | 140-200 |

**Assumptions**

1. Includes excise duty and VAT; ignores OMC losses or absorbed costs.
2. Gross sale price at the pump without any fair taxation at Delhi is INR 96.72 in Aug 22, INR 95.41 in Jan 22.
3. Current average electricity tax rate.
4. Product costs are a summation of base price and logistics costs and dealer margins.
5. Per litre consumption of petrol produces 2.3 kg of CO$_2$; i.e., 435 litres of petrol produces 1-ton CO$_2$.

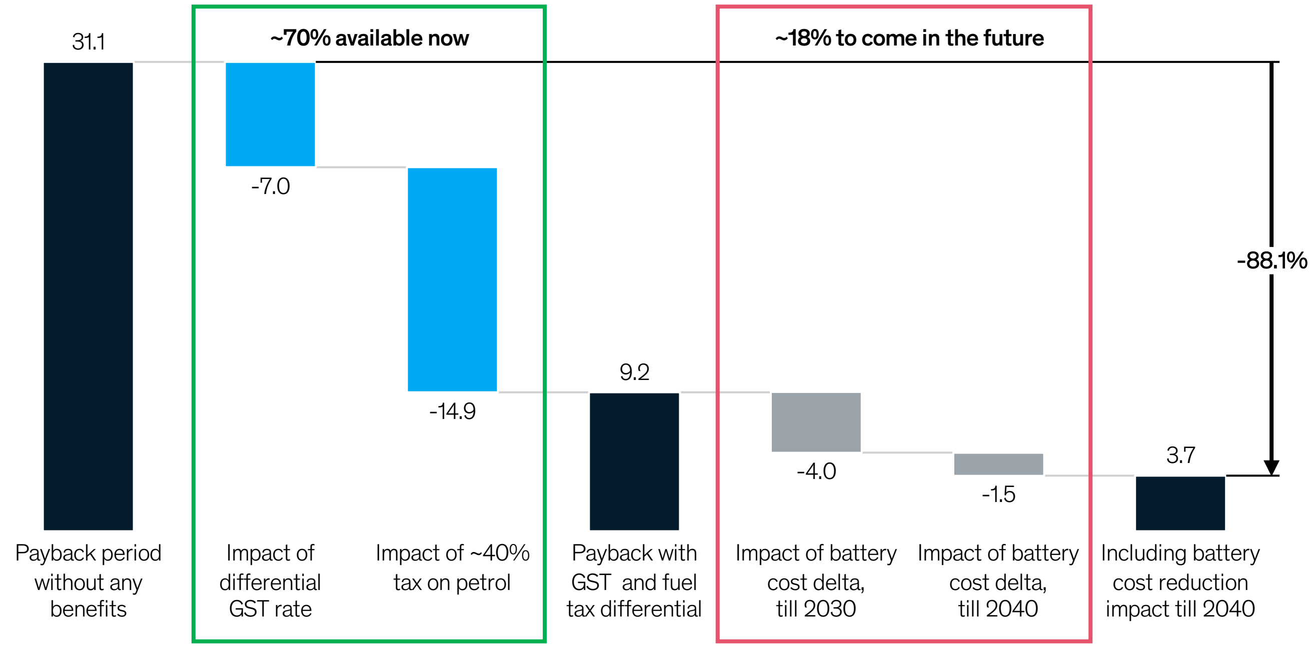
Source: Press, McKinsey analysis

Currently, the EV cost difference versus ICE vehicles is substantial which is a big deterrent to EV adoption. But due to the factors previously mentioned and their continuous favourable movement, the payback of owning an EV versus an ICE passenger car would reduce from nine years today to less than four by 2040 (Exhibit 25).

Exhibit 25

## Current support covers a significant gap in economics; more to come with technology advancement.

**TCO payback period (years); simulated for an eSUV[1] running 30 km per day in 2022**



| | | | |
|---|---|---|---|
| 5% GST in xEVs vs 28% in SUVs assumed | Roughly 50% taxation (central and state) assumed within INR 100 per litre price of petrol | Battery cost of $90 per kWh assumed | Battery cost of $50 per kWh assumed |

Assumptions - INR 1 million ICE on road vs INR 1.6 million EV with 30 kWh battery; 300 days per year.

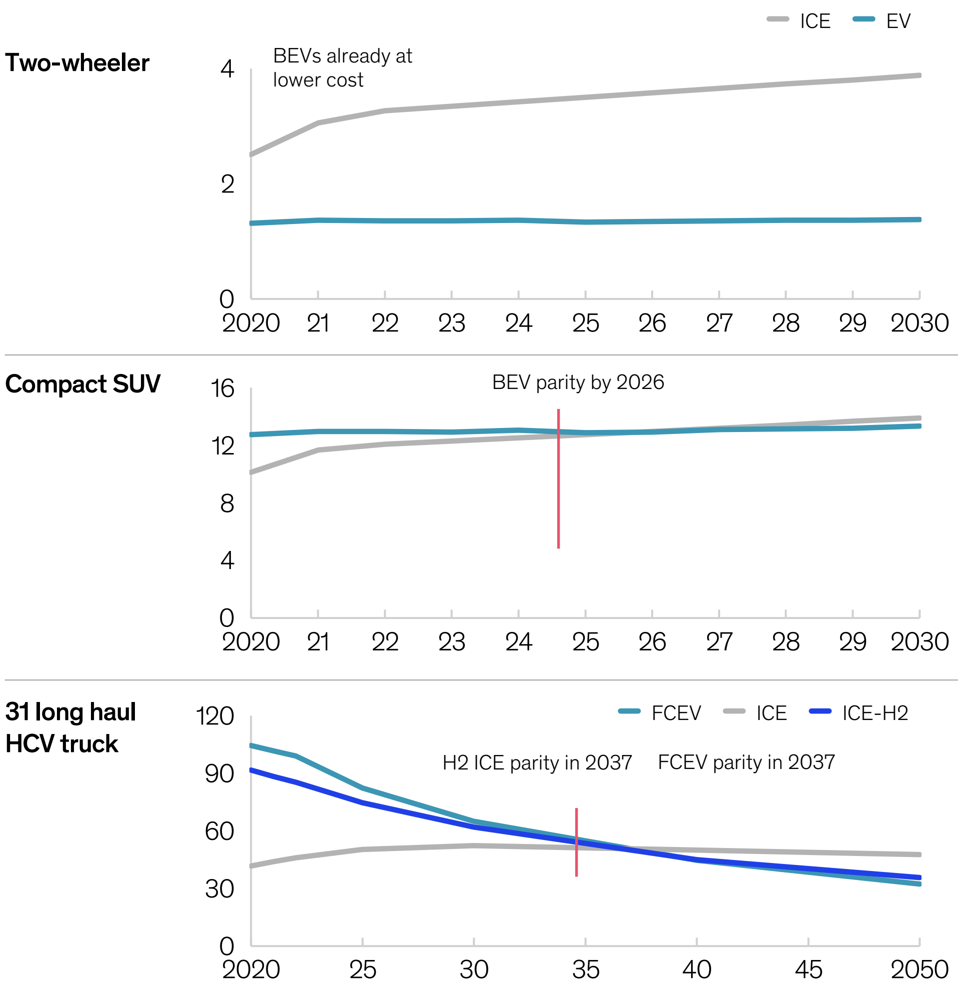
Source: McKinsey analysis

EVs for different vehicle categories become competitive at different points versus ICE. Two-wheeler EVs already cost less on a TCO basis, while others achieve parity progressively over time (Exhibit 26).

Exhibit 26

## India TCO curves by segment (EV vs ICE).

INR per km



**Assumptions**

ICE price[3] (INR lakhs): ~0.7
BEV price[3] (INR lakhs): ~1.1
Battery pack: 2.5-4 kWh
Lifetime: 7-8 years
Daily running: 50km

ICE price[3] (INR lakhs): 10-11
BEV price[3] (INR lakhs): 15-17
Battery pack: ~30 kWh
Lifetime: 7-8 years
Daily running: 30km

ICE price[3] (INR lakhs): <40
FCEV price[3] (INR lakhs): ~167
H2 ICE price[3] (INR lakhs): ~58
Fuel cell: 180 kW
Battery: 50 kWh
Lifetime: 7-8 years
Daily running: 300 km

1. ICE2
2. FCEV
3. Price today

Source: McKinsey Centre for Future Mobility, McKinsey Hydrogen Insights

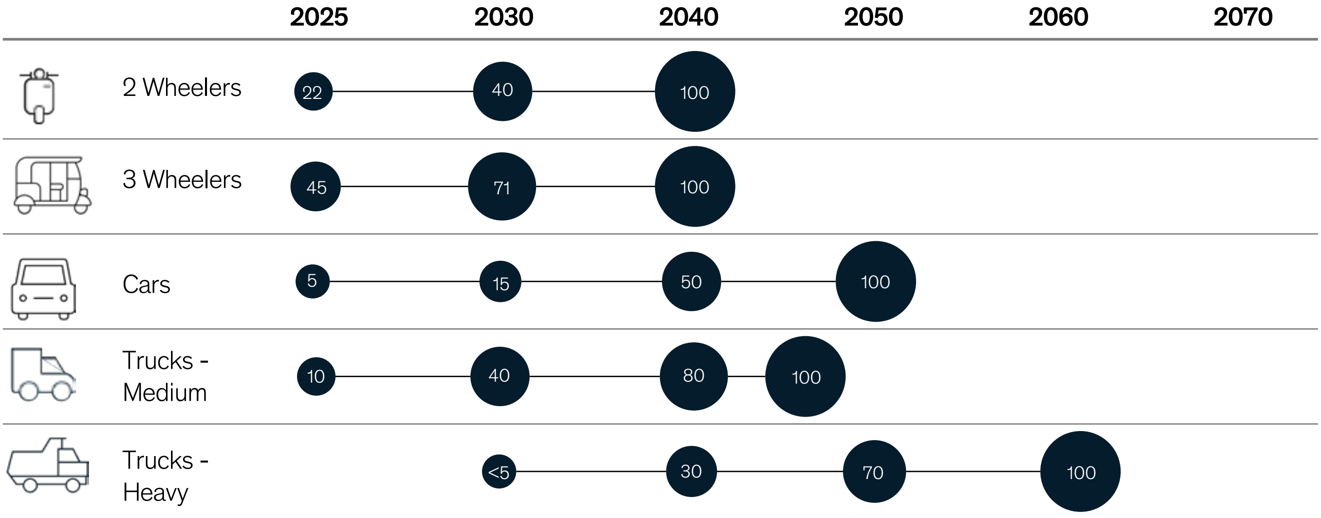
Based on these strong enabling forces, two- and three-wheeler sales are expected to be fully electric by 2040. Passenger cars, which require relatively larger battery sizes, could see an inflection point in electrification around 2030 when battery costs go below $100 / kWh and the charging network develops at scale. Medium and heavy commercial vehicles (MCVs and HCVs) including inter-city buses will most likely take the fuel-cell way to electrify (FCEV) as batteries typically create dead weight and reduce carrying capacity. For mass adoption of the FCEV technology, the fuel cell cost would have to come down to $60–70 / kW and at-nozzle hydrogen cost to less than $3 / kg by 2050, which is likely to happen only in the 2040s. Hence, the electrification of MCVs and HCVs is going to be slower than all other vehicle types with 100 percent new vehicle electrification likely only post-2055 (Exhibit 27).

This will mean that the full parc of vehicles would be 95 percent electric by 2070. Additionally, increase in rail share of freight – from about 25 percent currently to 45 percent by 2050, driven by initiatives like the dedicated freight corridors – has the potential to reduce CV demand by half a million, leading to further abatement. This leads to net-zero automotive tailpipe emissions by 2070 in our LoS scenario (Exhibit 28).

Exhibit 27

## EV adoption timelines: LoS scenario.

EV penetration in new vehicle sales, %[1]

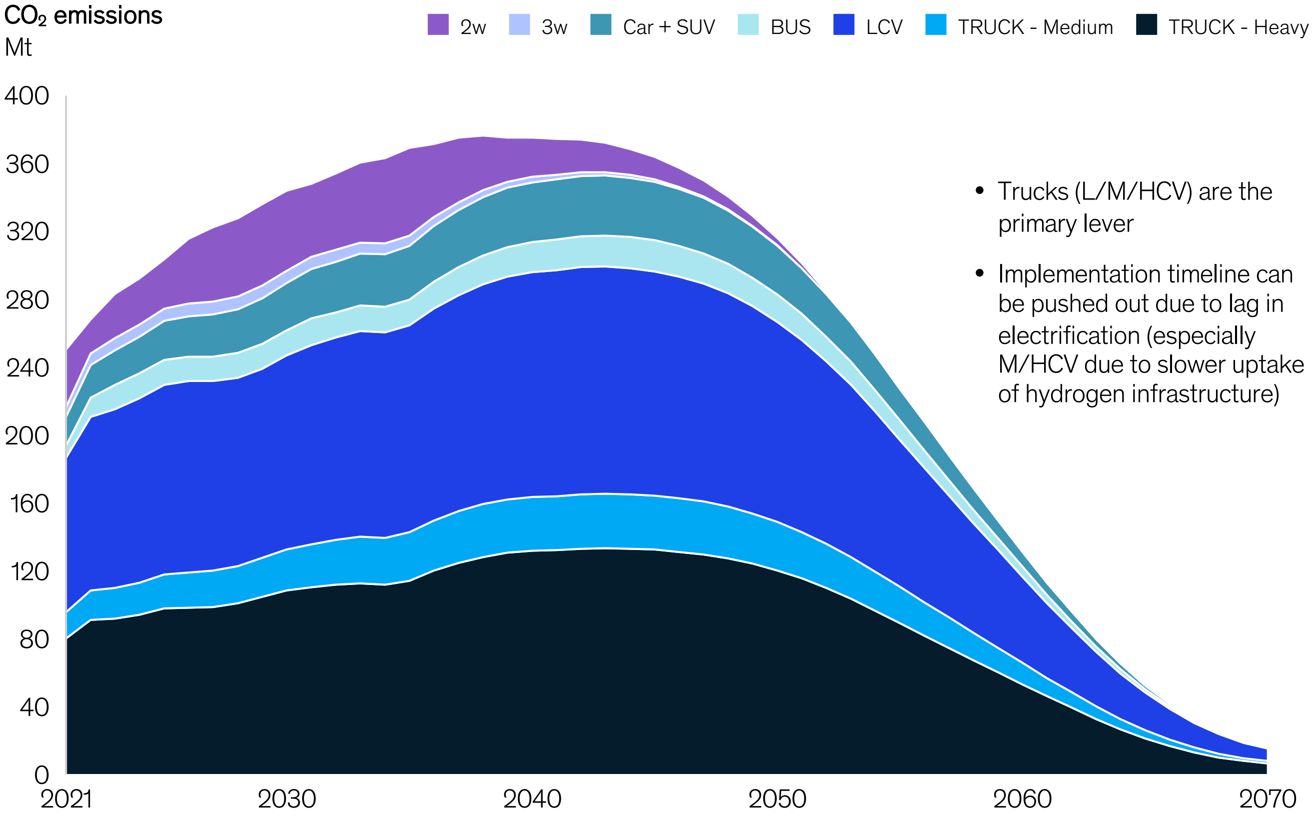


1. 100% is representative of >90% - long tail exists in most use cases.

Source: McKinsey analysis

Exhibit 28

## LoS scenario – vehicular emissions would peak around 2040.



- Trucks (L/M/HCV) are the primary lever
- Implementation timeline can be pushed out due to lag in electrification (especially M/HCV due to slower uptake of hydrogen infrastructure)

Source: McKinsey Evolve Tool, Automotive Practice/Decarbonisation Team analysis

### The Accelerated scenario

If India accelerates interventions to address adoption challenges and drives reforms to encourage investments, along with targeted affirmative actions, near net-zero tail-pipe emissions may be possible by 2050. In this scenario, EV penetration growth could be higher across all categories of vehicles and reaching 100 percent EV sales by 2035 for two- and three-wheelers, 2045 for cars and 2050 for heavy commercial vehicles (Exhibit 29).

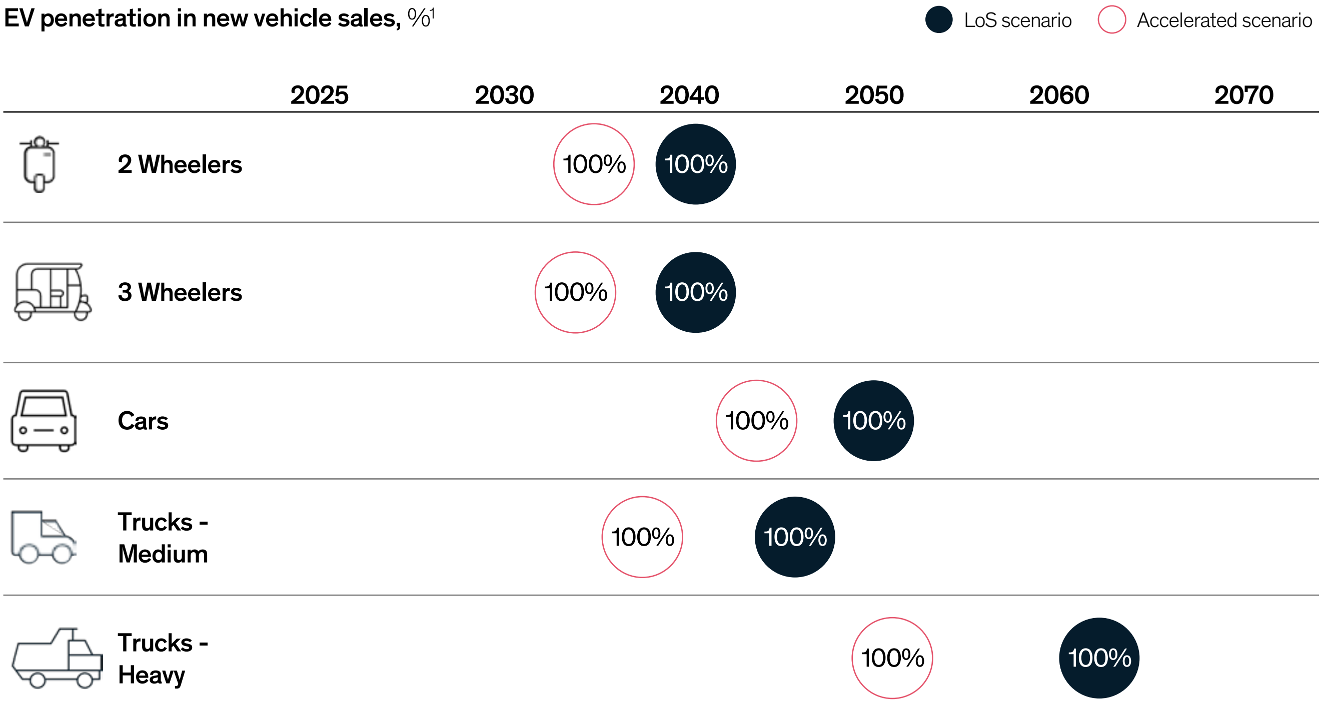
These new vehicle sales trajectories, along with useful life cycles of the existing and new ICE vehicles sold, would mean the full parc of vehicles reaches 90 percent electrified by 2050, leading to near net-zero tailpipe emissions by 2050 (Exhibit 30).

### Investments would be needed for the abatement scenarios

Interestingly, in a rapidly growing automotive market, trucks will decline with higher EV penetration, given the lower capital intensity of EVs and their supply chains (Exhibit 31).

Exhibit 29

## EV adoption timelines: Accelerated scenario vs. LoS scenario.

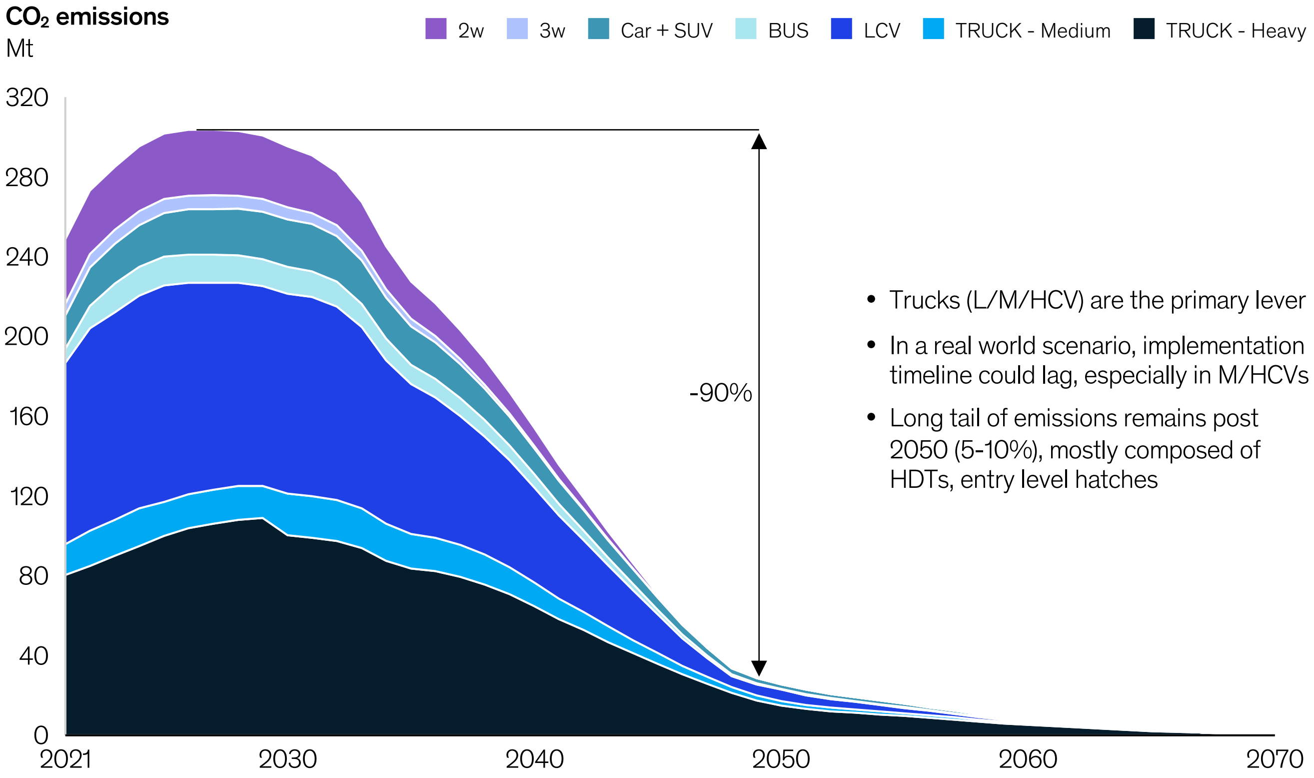


1. 100% is representative of >90% - long tail exists in most use cases.

Source: McKinsey analysis

Exhibit 30

## Accelerated scenario vehicular emissions would peak around 2030.



- Trucks (L/M/HCV) are the primary lever
- In a real world scenario, implementation timeline could lag, especially in M/HCVs
- Long tail of emissions remains post 2050 (5-10%), mostly composed of HDTs, entry level hatches

Source: McKinsey Evolve Tool, Automotive Practice/Decarbonisation

Exhibit 31

## Transition from ICE to BEV expected to reduce the capex intensity for vehicle manufacturers and their suppliers.

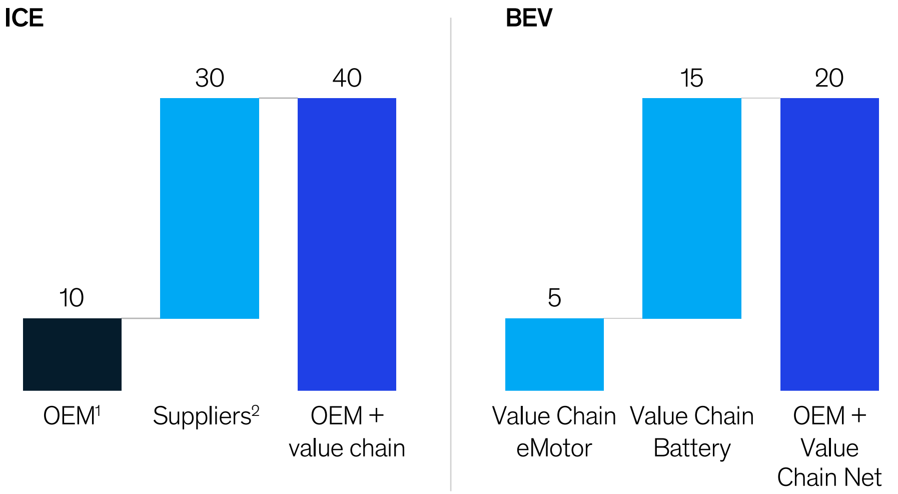
**What will change**

- IC engine and transmission will be replaced by battery plus motor
- Mechanical controls (clutch, gears, throttle wires) to electrical controls
- Exhaust system with no replacement

**What will remain the same**

- Chassis/ Body
- Steering, suspension, braking systems
- Interiors

**Manufacturing capex (for what will change) – for 1-million-units capacity**
(INR ‘000 Cr)



1. Based on capex data for Suzuki Powertrain India Limited; data has been adjusted for inflation and differences in economies of scale.
2. Based on observation that value chain capex is typically ~3x OEM capex.

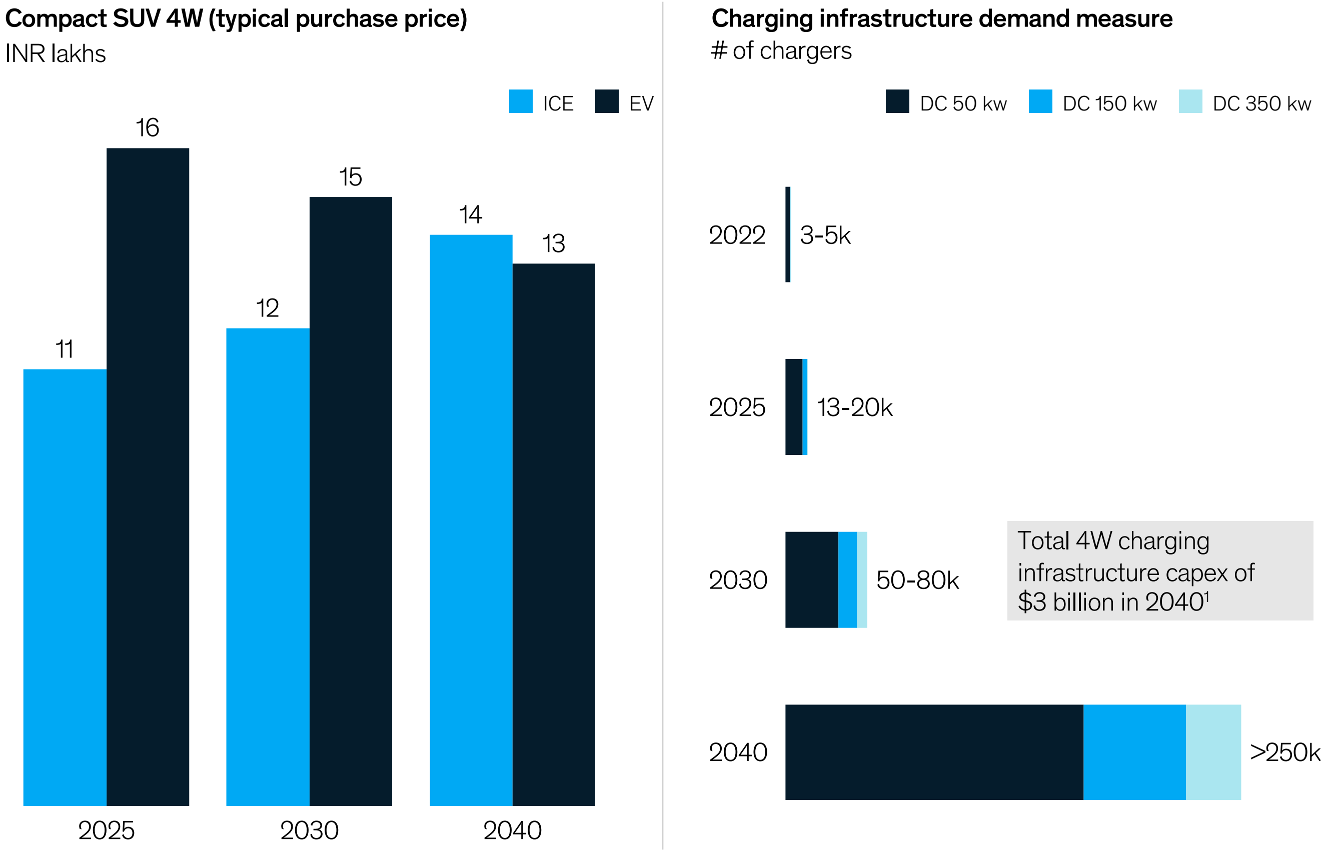
Source: McKinsey Analysis, Expert inputs, Press, IHS Markit

However, the EV customer will need to bear higher up-front costs relative to a conventionally fuelled vehicle. And to power up the EVs, substantial investment will be needed for the charging infrastructure (Exhibit 32).

The total incremental Capex for this green transition is sizeable – $1.9 trillion till 2070 for the LoS scenario; and an extra $1.3 trillion till 2070 for the Accelerated scenario. On the positive side, migration to EVs would have significant savings on Opex – with Opex totalling $9.0 trillion till 2070 for the LoS scenario ($6.1 trillion without taxes), and additional Opex savings of $3.7 trillion in the Accelerated scenario ($2.5 trillion without government taxation) (Exhibit 33).

Exhibit 32

## Customer purchase price ('capex') of EV higher but declining.


**Compact SUV 4W (typical purchase price)**
INR lakhs

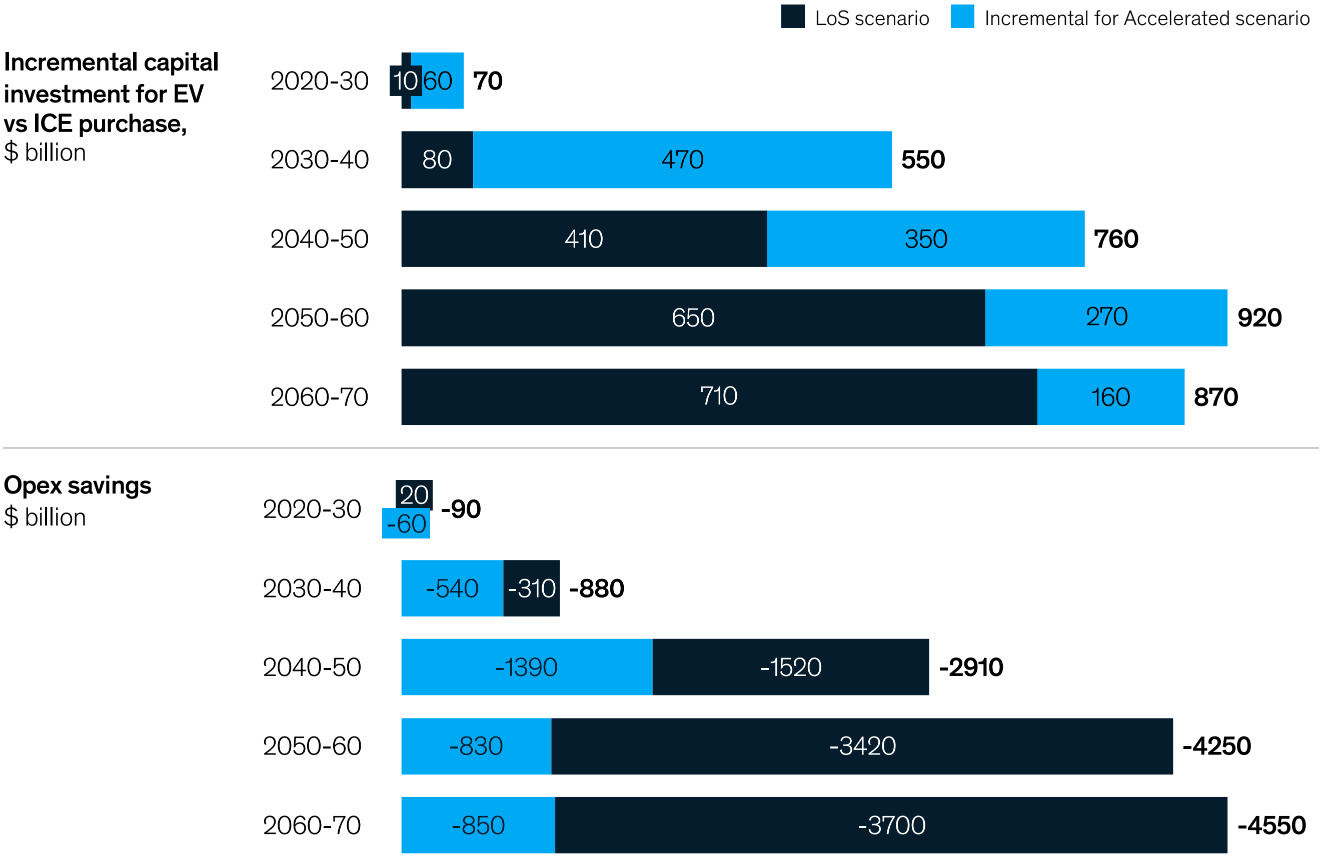
**Charging infrastructure demand measure**
# of chargers

[1] Assuming DC 50/150 kW installation cost at ~$7500 per charger and DC 350 kW at ~$42000 per charger.

Source: McKinsey Analysis, Press

Exhibit 33

## Accelerated scenario vs LoS: Higher Capex investment compensated for by lower Opex.



| $ trillion | Till LoS | Additional from accelerated |
|---|---|---|
| Incremental Capex spend | 1.9 | 1.3 |
| Incremental Opex savings (without taxes) | 6.1 | 2.5 |
| Incremental Opex savings (with taxes) | 9.0 | 3.7 |

Source: McKinsey analysis

## Accelerated scenario: benefits

Accelerated transition to electric vehicles will unlock several benefits:

- **Earlier peak and lower emissions.** The automotive emissions peak around 2040 in the LoS scenario and get to net zero by 2070. In the Accelerated scenario, the peak comes around 2030, followed by reduction and near net-zero $CO_2$ emissions by 2050 (Exhibit 34). This would mean a cumulative delta abatement of 7 $GtCO_2e$ from now till 2070 in the Accelerated versus the LoS scenario.
- **Reduced import dependence for fuel and associated Forex savings.** India imports oil worth about $100 billion currently. Relative to the LoS scenario, the Accelerated scenario saves $1.2 trillion till 2050 and $2 trillion till 2070 in Forex for oil. Netting off battery and battery material imports, which are higher in the Accelerated scenario, would still lead to substantial savings — $0.9 trillion till 2050, $1.7 trillion in savings till 2070 (Exhibit 35).
- **Lower obsolescence.** Faster transition to electrified mobility would also mean less Capex investment in older technology leading to lower obsolescence. Additionally, the EV manufacturing footprint is less Capex intensive (about 50 percent lower), making India's manufacturing capital more productive (Exhibit 31).
- **Path for a global play.** In the Accelerated scenario, the Indian automotive industry can reimagine its global play. India is already exporting a large volume of two-wheelers (25 percent of production; 4 million units) and three-wheelers (over 60 percent of production, 0.5 million units)[92] and can leverage this disruption to lead the change to EVs and take a leadership position in India-similar export markets (e.g., Africa, LatAm, SE Asia). Significant upheaval in global trade led by changing geopolitics presents the perfect opportunity for Indian vehicle manufacturers to scale their global ambitions.

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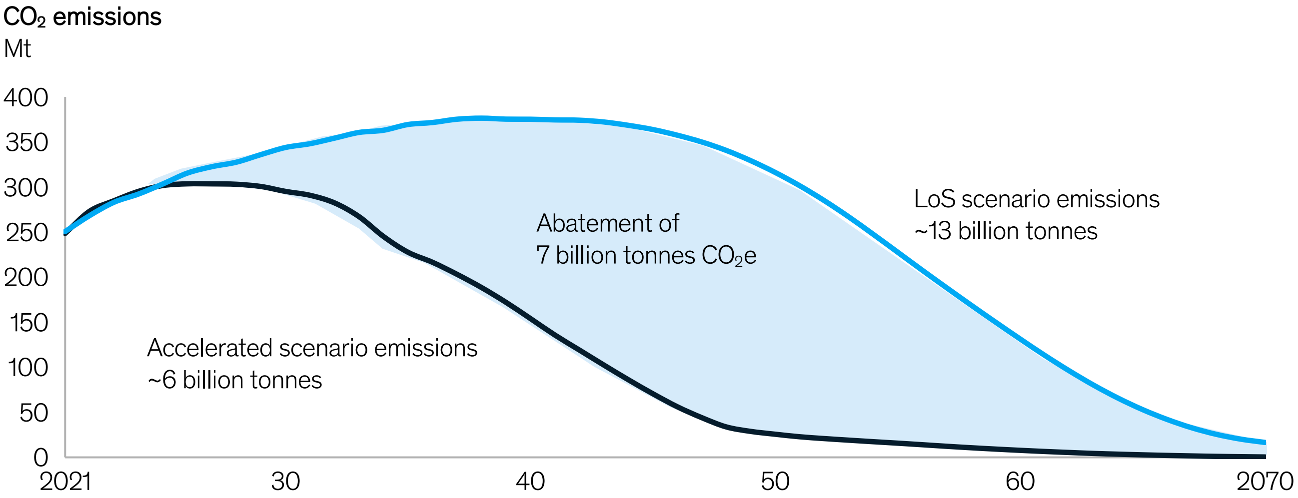
[92] SIAM.

Exhibit 34

## Emissions trajectory: LoS vs. Accelerated scenarios.



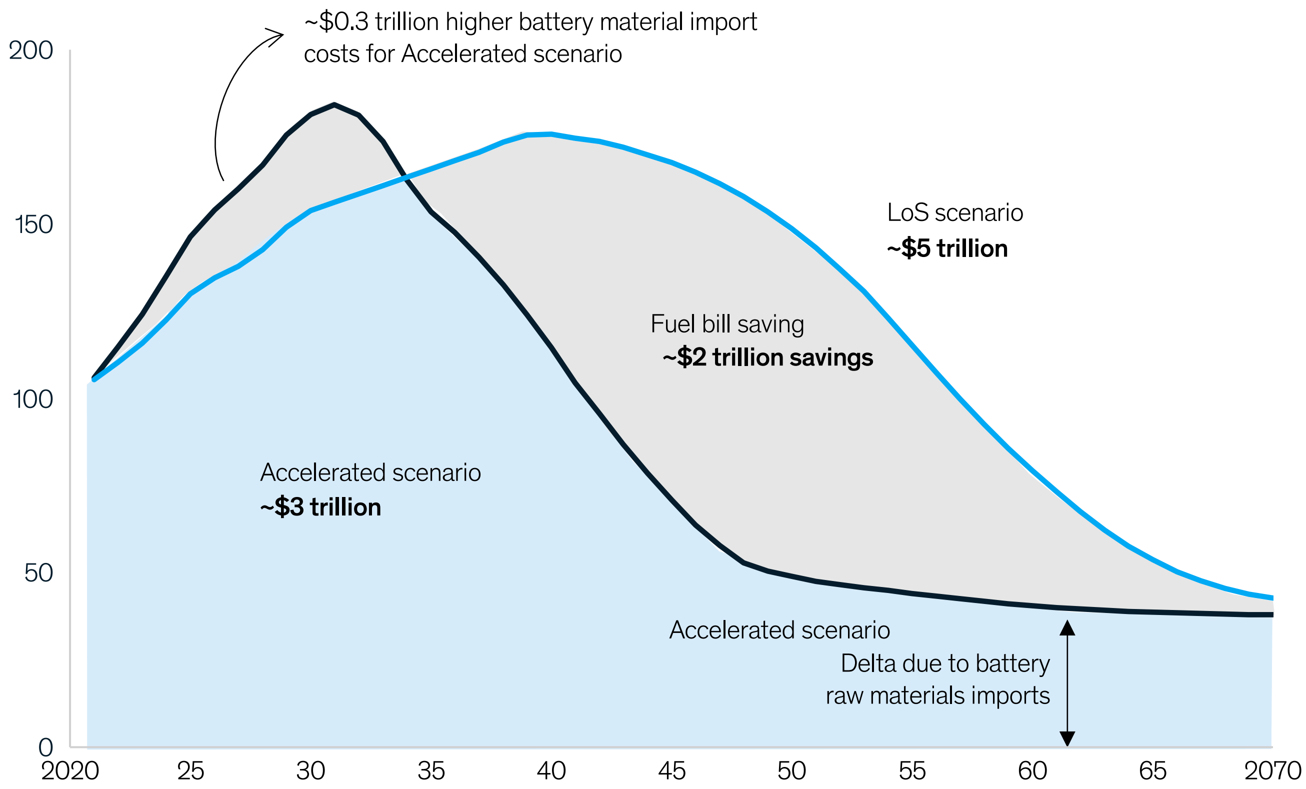
Source: McKinsey Evolve Tool, Automotive Practice/Decarbonisation Team Analysis

Exhibit 35

## Reduced import bill related fuel imports net of battery imports.

**Import bill for import of crude and battery/ battery raw material,** $ billion

Illustrative



1. Discounted cash flows with base of 2022.

Source: McKinsey Analysis

**Key Assumptions**

- Oil imports – % of import vis-à-vis demand: 85%; 100 lit crude producing 22% petrol and 37% diesel; Per barrel of oil = 159 liters
- Battery materials imports – Chemistry: NMC 811; Manufacturing losses: 30%

## Proposed enablers for automotive decarbonisation

These enablers include:

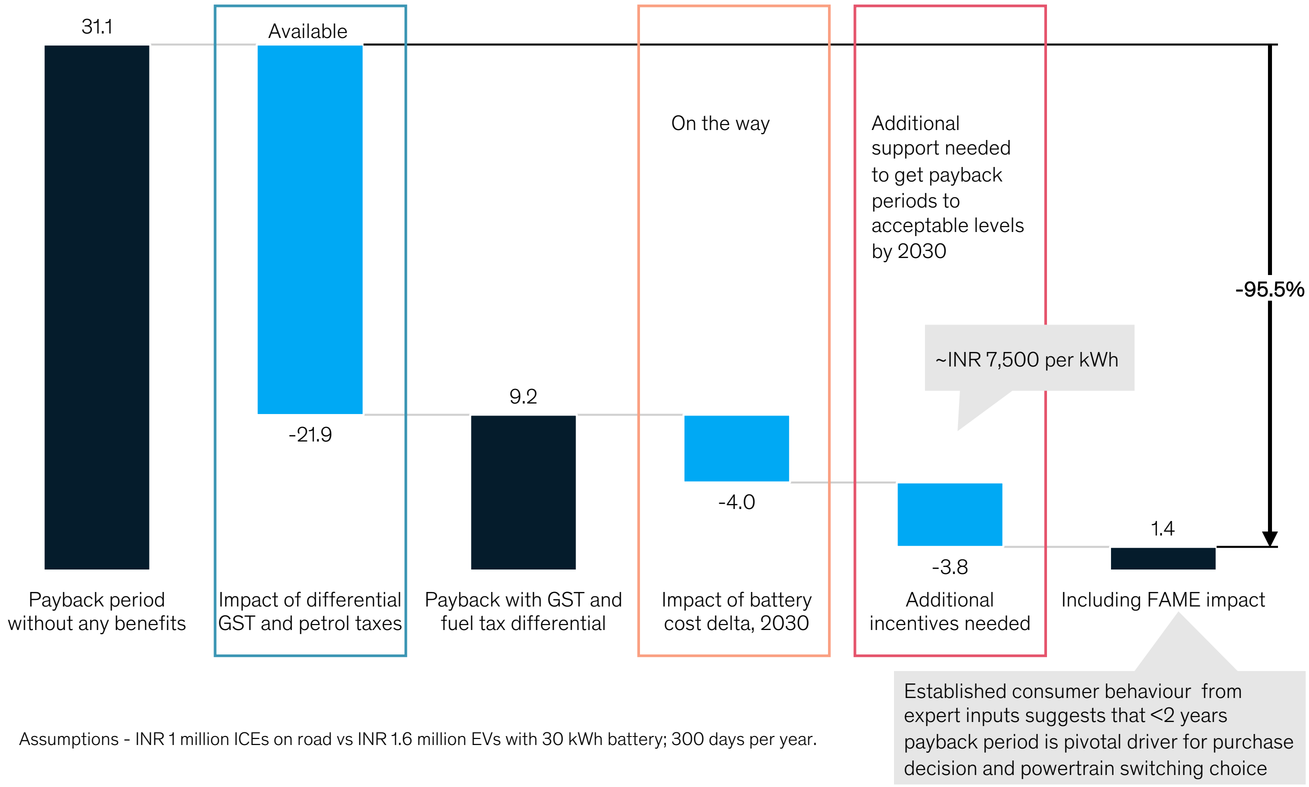
- At scale and fast localisation of battery giga-factories, with the best cost curves achieved around seven to ten years earlier, i.e., $70–75 / kWh by 2030 and $55–60 / kWh by 2040; along with investment in new technologies like solid-state, sodium-ion.
- Lower hydrogen fuel cell costs, which are essential for large CV electrification through FCEV technology, as well as making sure that hydrogen is competitive and widely available. The trajectory of this would need to be accelerated by ten years – to get to $60–70 / kW fuel-cell cost and at-nozzle hydrogen prices less than $3 / kg by 2035.
- Continued stimulus, in the form of fossil fuel taxes, GST benefits and the FAME subsidy until at least 2030; and potentially extending the FAME subsidy to vehicle categories where it is not available like passenger cars (Exhibit 36). Additionally, scrappage benefits especially when the replacement vehicle is an EV, along with strict enforcement of vehicle age norms, can help a faster turnover of existing parc into EVs.
- Investments to support build out of enabling charging infrastructure, through the government's own investment, Capex subsidy for first installers, etc.
- Initiatives that accelerate transition of road freight toward electrified-rail freight (e.g., DFCs) could need to be fast-tracked to get to the target rail share of 45 percent by 2040.
- Targeted affirmative actions on hard-to-abate segments like HCVs.

Much like the power sector, the automotive sector has great tailwinds and a once-in-a-generation opportunity for Indian automotive companies to seize the initiative and lead the sector in the region and globally. However, to make this a reality will require the support of multiple stakeholders, the right policy initiatives, infrastructure support and investment in technology / manufacturing localisation.

Exhibit 36

### FAME incentives needed for sustainable payback by 2030 for passenger cars.

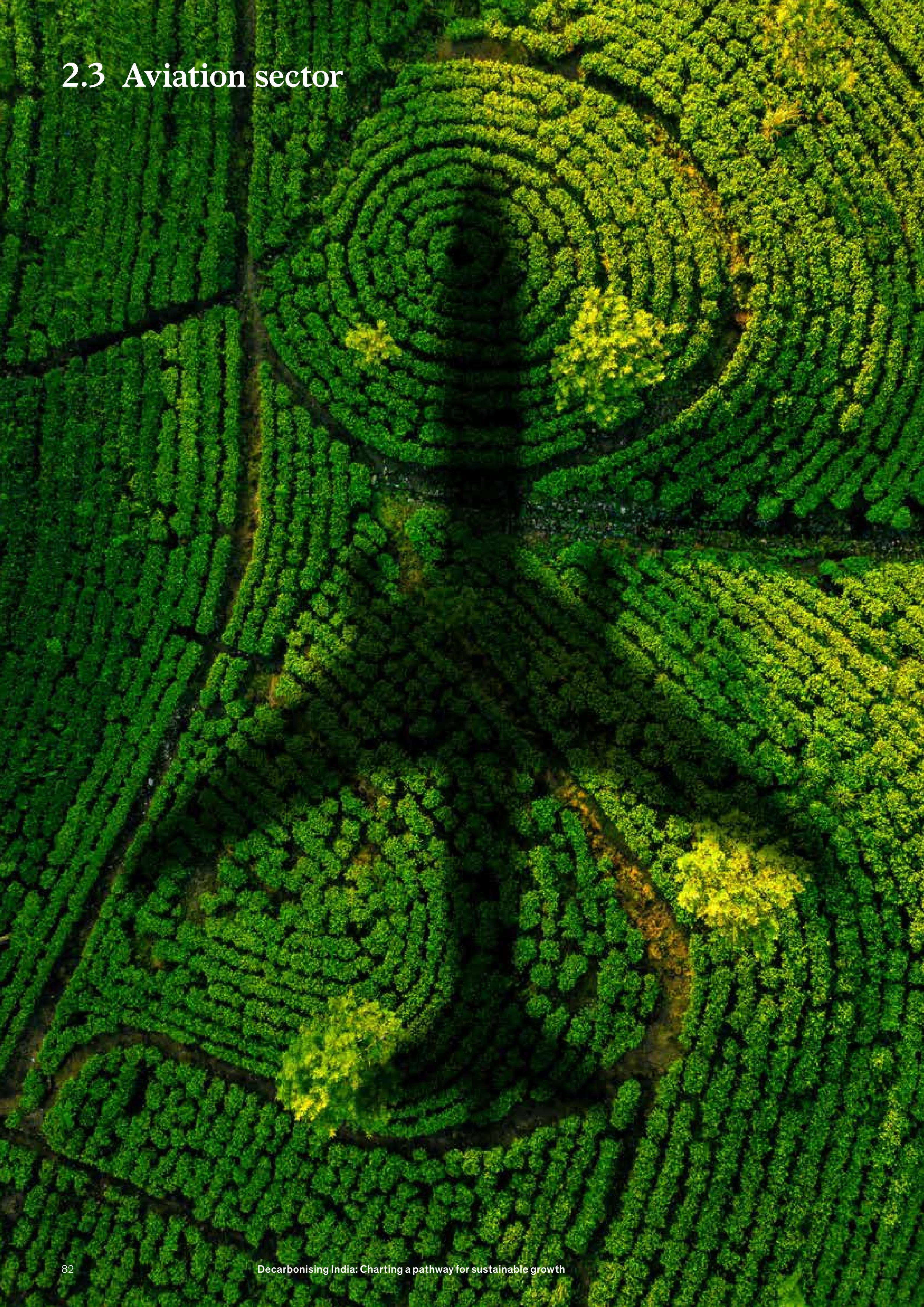
**TCO payback period (years); simulated for an SUV[1] running 30 km per day in 2022**



1. Assumptions - INR 1 million ICEs on road vs INR 1.6 million EVs with 30 kWh battery; 300 days per year.

Source: McKinsey analysis

# 2.3 Aviation sector



## Key takeaways

**Aviation accounts for small but growing emissions.** Aviation accounts for roughly five percent of the transport sector's overall emissions. These emissions are expected to increase as demand for air travel continues to rise at three and a half percent per annum over the next 50 years and could grow from 16 $MtCO_2e$[93] per annum in 2019 to 126 $MtCO_2e$[94] per annum by 2070.

**It is a hard-to-abate sector** as the technologies needed for decarbonisation, such as electric aviation and hydrogen-powered jets, are in a nascent stage of development. The most feasible abatement option, sustainable aviation fuel (SAF), faces feedstock constraints for scaling up production. In fact, directing scarce biomaterials to SAF might be better than using these for surface transportation, where electrification is an economic option.

**Emissions halve in the LoS scenario** to around 63 $MtCO_2e$[95] by 2070 with phased adoption of SAF (from ten percent blending in 2030 to 50 percent in 2070).

**Emissions halve in the Accelerated scenario by 2050**, if 50 percent blending is achieved in 2050, leading to cumulative abatement of 260 $MtCO_2e$ by 2050 (relative to LoS). This is through the increased use of municipal solid waste (MSW) for SAF, with the assertion that domestic and export SAF is the highest value use for MSW.

**There will be benefits to accelerating the transition.** These include increased farmer income (INR 2400/ha/year by selling agriculture residue), decreased amounts of MSW ending up in landfills, reduced import bills ($210 million[96] annually saved by blending ten percent SAF[97]) and an increase in jobs created due to the SAF ecosystem (segregation systems and manufacturing). Furthermore. after meeting its future blending requirements, surplus SAF can be exported ($13.55 billion in revenue from 5.5 Mnt[98] SAF exported annually).

**Biomaterials will need to be made preferentially available for SAF and bio-feedstock production will need to be scaled up.** Apart from favourable policies to appropriately direct biomaterials for SAF use, infrastructure would need to be built for agricultural and forest residue collection, segregating MSW at source, and producing SAF. Additionally, policy measures, such as mandatory blending requirements, may also help unlock demand.

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[93] Source: United Nations; Shyamsundar et. al., 2019; expert interviews; McKinsey Global Institute.
[94] Calculation based on increase in consumption of fuel by aviation sector (31.6 MtPA) in 2070.
[95] Based on assumption that overall emission reduces by 50 percent due to blending of carbon neutral fuel.
[96] World Economic Forum's Clean Skies for Tomorrow (CST) initiative.
[97] Average price of SAF considered $2438/ton as shown in exhibit 37.
[98] Refer exhibit 41 for detailed analysis.

## The aviation sector today

Currently, aviation is not a significant contributor to India's emissions, accounting as it does for five percent of emissions from the mobility sector and half a percent of India's total emissions. However, these are expected to grow rapidly to net-GHG emissions of around 126 $MtCO_2e$ per annum by 2070 (around six percent of overall emissions in the LoS scenario). Additionally, emissions from the aviation sector have an impact that is two to three times greater on the environment than do emissions from road transport due to the additional non-$CO_2$ pollutants directly released by them.[99] Hence, decarbonisation of India's aviation sector is crucial.

Furthermore, global mandates on the sector mean that action will need to be taken immediately if penalties or expenses on carbon credits are to be avoided. For instance, the Carbon Offsetting and Reduction Scheme for the Indian aviation sector's (CORSIA) offsetting requirements (mandatory second phase for all member states) will be applicable for all Indian airline operators from 2027.[100] Aero turbine fuel (ATF) is currently priced at $1003/ton versus likely SAF costs of $1800/ton[101] (no producer margin or taxation component included) (Exhibit 37). With blending mandates, additional costs of $1.8 to 1.9 per typical domestic flight (10 to 50 percent blend range) would need to be passed on to the consumer (Exhibit 38).

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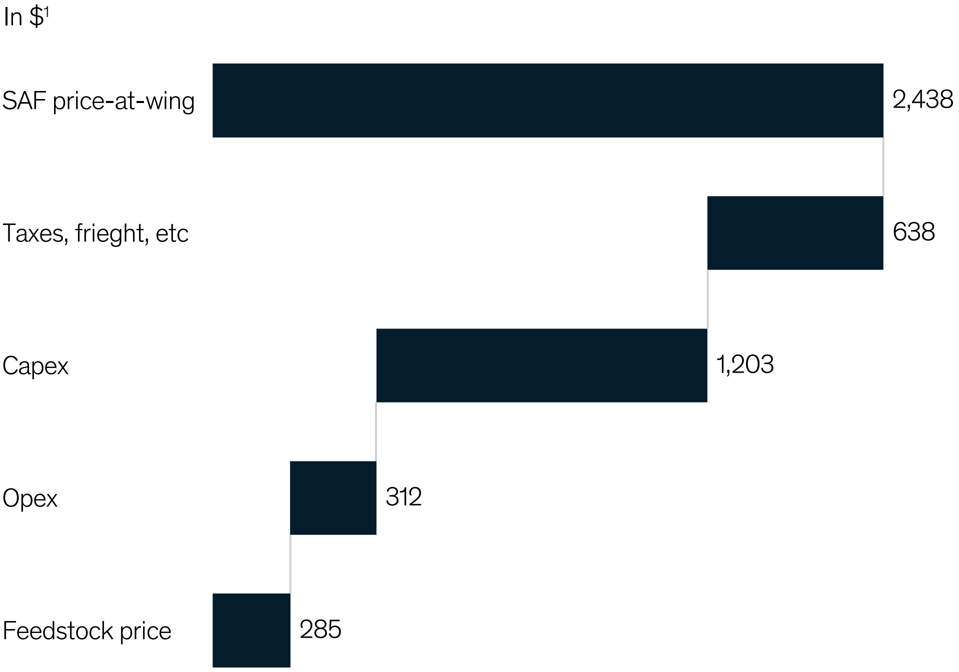
[99] WEF clean sky initiative; Transport environment.

[100] CORSIA offers a harmonised way to reduce emissions from international aviation while respecting the status of member states. It is voluntary for organisations till 2027. However it will become mandatory for all organisations from, 2027 onwards. "Measures taken to address $CO_2$ emissions from Civil Aviation," Press Information Bureau, December 13, 2021. https://pib.gov.in/PressReleseDetailm.aspx?PRID=1780858

[101] This cost is at the factory level; Source: World Economic Forum's Clean Skies for Tomorrow (CST) initiative.

Exhibit 37

### Scale-up of SAF can create a value chain with inherent incentives encouraging farmers to reduce stubble burning.



- Farmers can receive an additional stable income from selling agricultural residues as feedstock for SAF production
- Additional income is in the order of magnitude of 15%
- Significant air quality co-benefits exist in selling residues and harvesting them rather than "stubble burning"

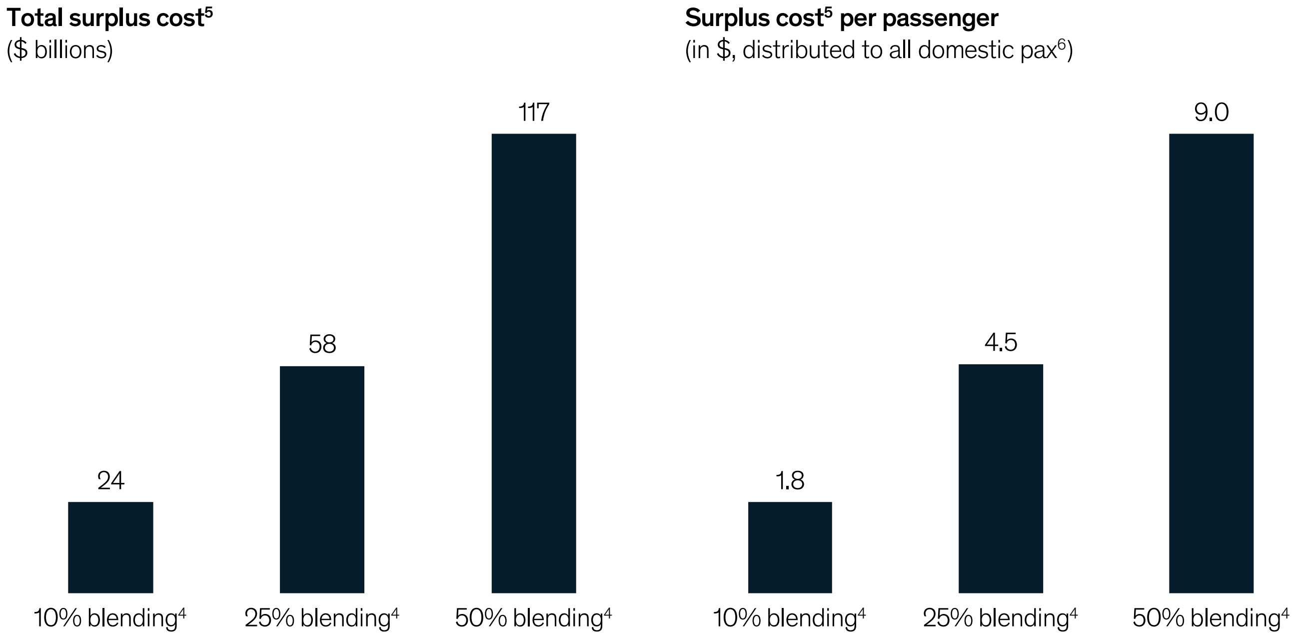
1. Model assumes a GAS-FT pathway using agricultural residue feedstock.

Source: McKinsey India DSE

## Cost implications[102] due to SAF blending from end consumer

Exhibit 38

### Passenger premiums vary from $1.80 to $9.00 for a typical domestic flight, depending on the blend, ranging from 10–50%.



**Domestic demand assumptions for 2030**

**6.8 million**
tons jet fuel demand[1]

**220 billion**
revenue passenger km[1]

**150**
PAX/flight[2]

**1,148 km**
per flight[3]

1. From SAF demand estimate model.
2. 80% set load factor on Boeing 747.
3. Length of Mumbai-Delhi route.
4. Average price at wing at $1,980 per ton of SAF (no producer margin included) and $1,003 for fossil jet fuel.
5. 70 INR/$, rounded numbers.
6. Total of 190 million passengers.

Source: Press search; expert interviews; McKinsey analysis; GEP SAF production cost model, World Economic Forum's Clean Skies for Tomorrow (CST) initiative

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[102] World Economic Forum's Clean Skies for Tomorrow (CST) initiative

## The LoS scenario

SAF is the only realistic option if the sector has to be decarbonised in the next 10–15 years. SAF is a synthesis of renewable feedstocks, such as organic municipal waste, agricultural and forestry residues, and can be used as a fuel by the current aircraft fleet (certified to run up to 50 percent SAF).[103] Electric planes (limited by battery weight – 50 kg of battery replaces 1 kg of liquid fuel) and hydrogen-powered aircrafts have not been commercialised yet.

SAF can be produced using four kinds of feedstock: agricultural residue, municipal solid biowaste, sugar steams and residue lipids (used cooking oil). Agricultural residue and municipal solid biowaste are best suited as feedstock for SAF (with a combined potential of around 9 Mt per annum in LoS versus 14 Mt per annum in the Accelerated scenario, Exhibit 39). Sugar stream is a less feasible option and would compete with food sources. Collection of waste and residue lipids at scale may pose a logistical challenge.

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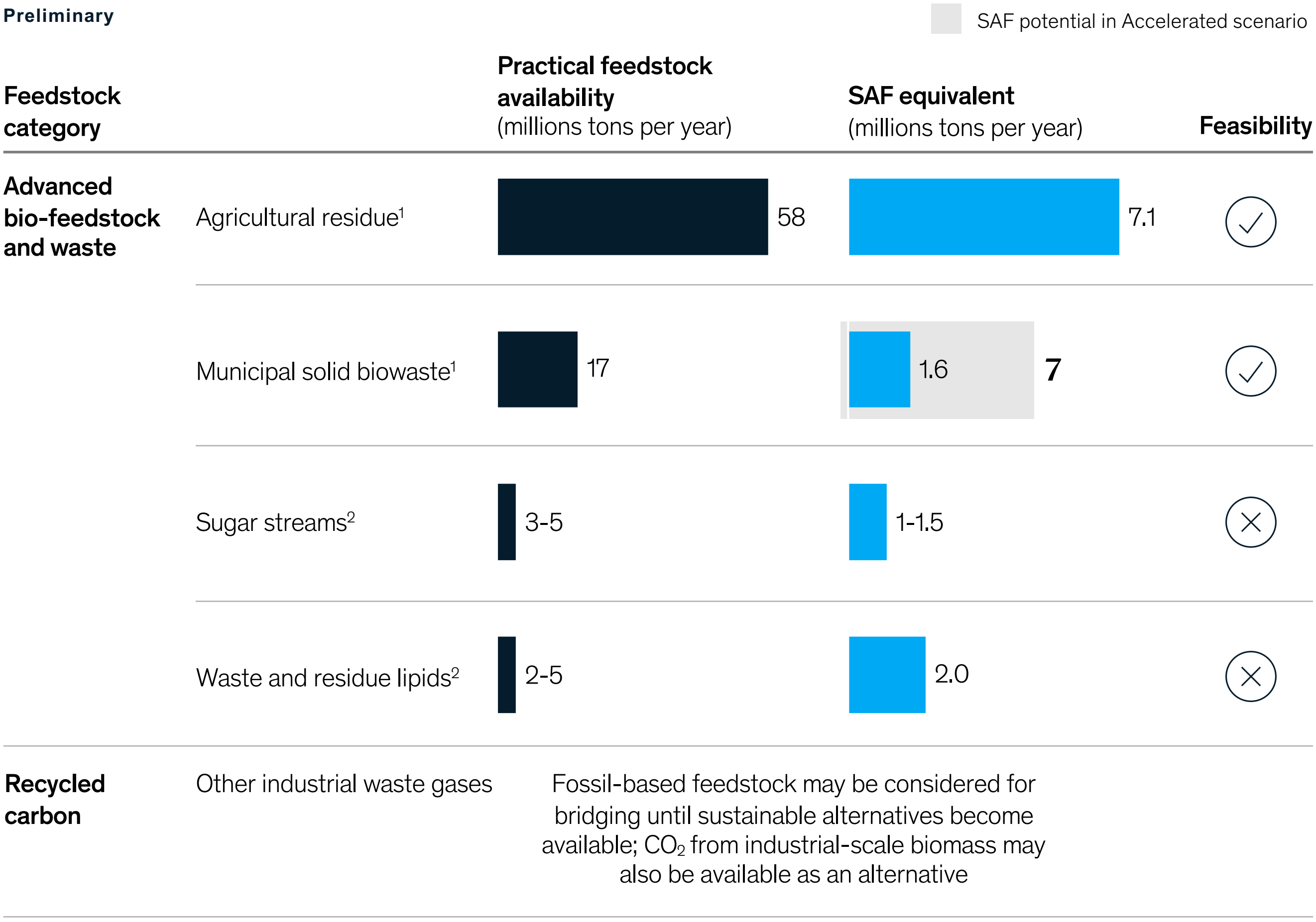
[103] Boeing announced its intention to deliver aircraft that can fly on 100 percent SAF by 2030 indicating a major shift planned for the sector

Exhibit 39

## India has the potential to produce 9 Mt per annum SAF by 2050 in the LoS scenario.



1. From McKinsey material circularity model.
2. From WEF report on "Deploying Sustainable Aviation Fuels at Scale in India: A Clean Skies for Tomorrow Publication.

This scenario assumes an SAF blending ratio of 50 percent by 2070 and the implementation of CORSIA. In this scenario, with an assumed cost reduction of 20 percent, SAF will continue to remain uncompetitive against ATF in 2050. This limits domestic SAF demand to future blending mandates, providing India with the opportunity to export its SAF surplus of around 5 Mt per annum for three decades before its own demand catches up (Exhibit 40).

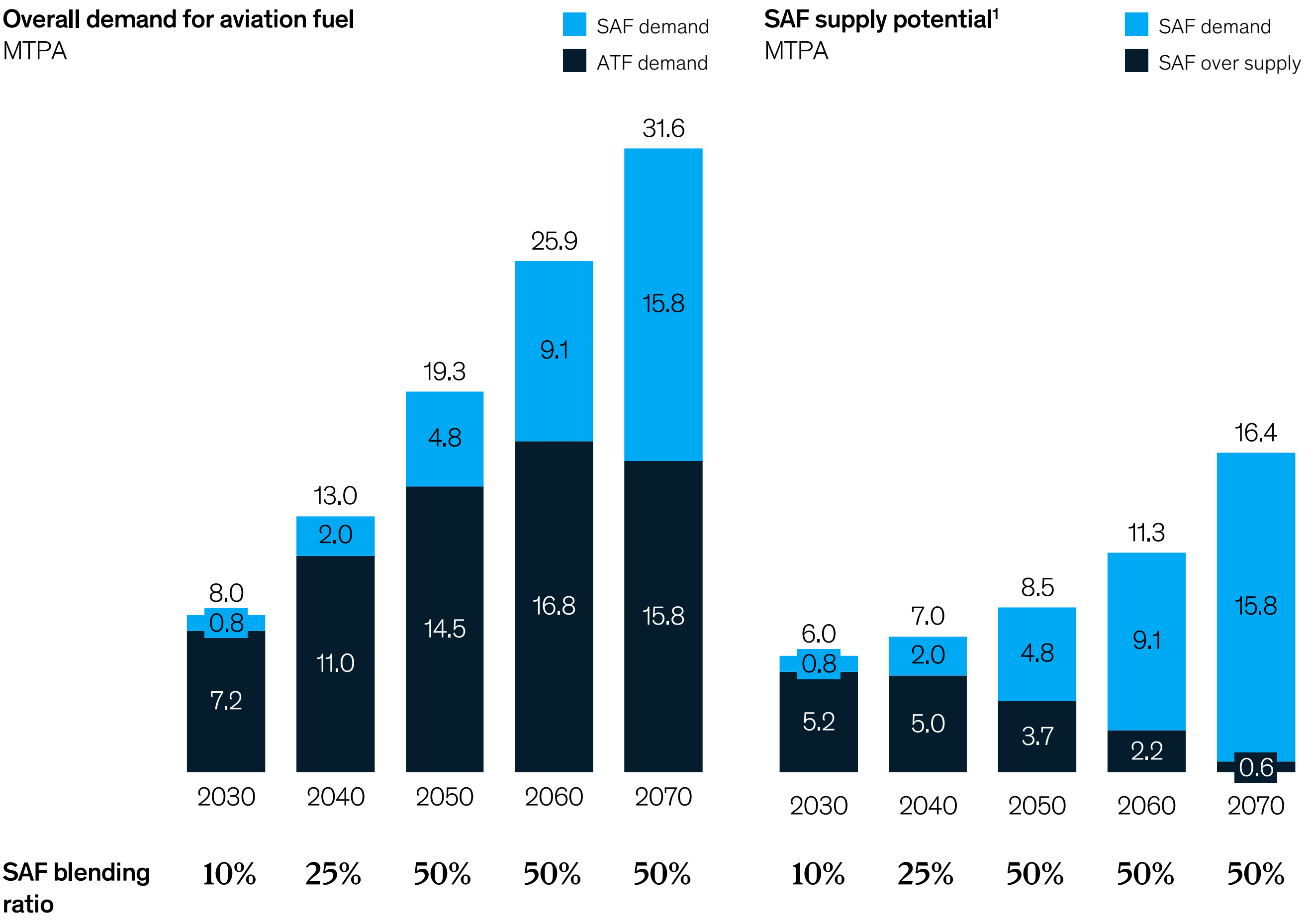
## The Accelerated scenario

In the Accelerated scenario, India could potentially reduce 50 percent of the aviation sector's emissions by 2050 and continue as a net exporter of SAF (with an SAF surplus of around 5.5 Mt per annum, Exhibit 41), leading to annual emissions abatement of 267 $MtCO_2e$ by 2050. In this scenario, we assume 7 Mt per annum of SAF production from municipal waste (relative to 1.8 mt in LoS).

Agricultural residue for SAF is assumed to be capped since it would compete with other hard-to-abate sectors such as cement. Limited segregation at source for MSW also constrains SAF production. The higher value of SAF could catalyse waste collection systems for MSW, not only serving the aviation section but also reducing landfills while enhancing municipal incomes.

Exhibit 40

### SAF demand and supply potential during the LoS scenario.

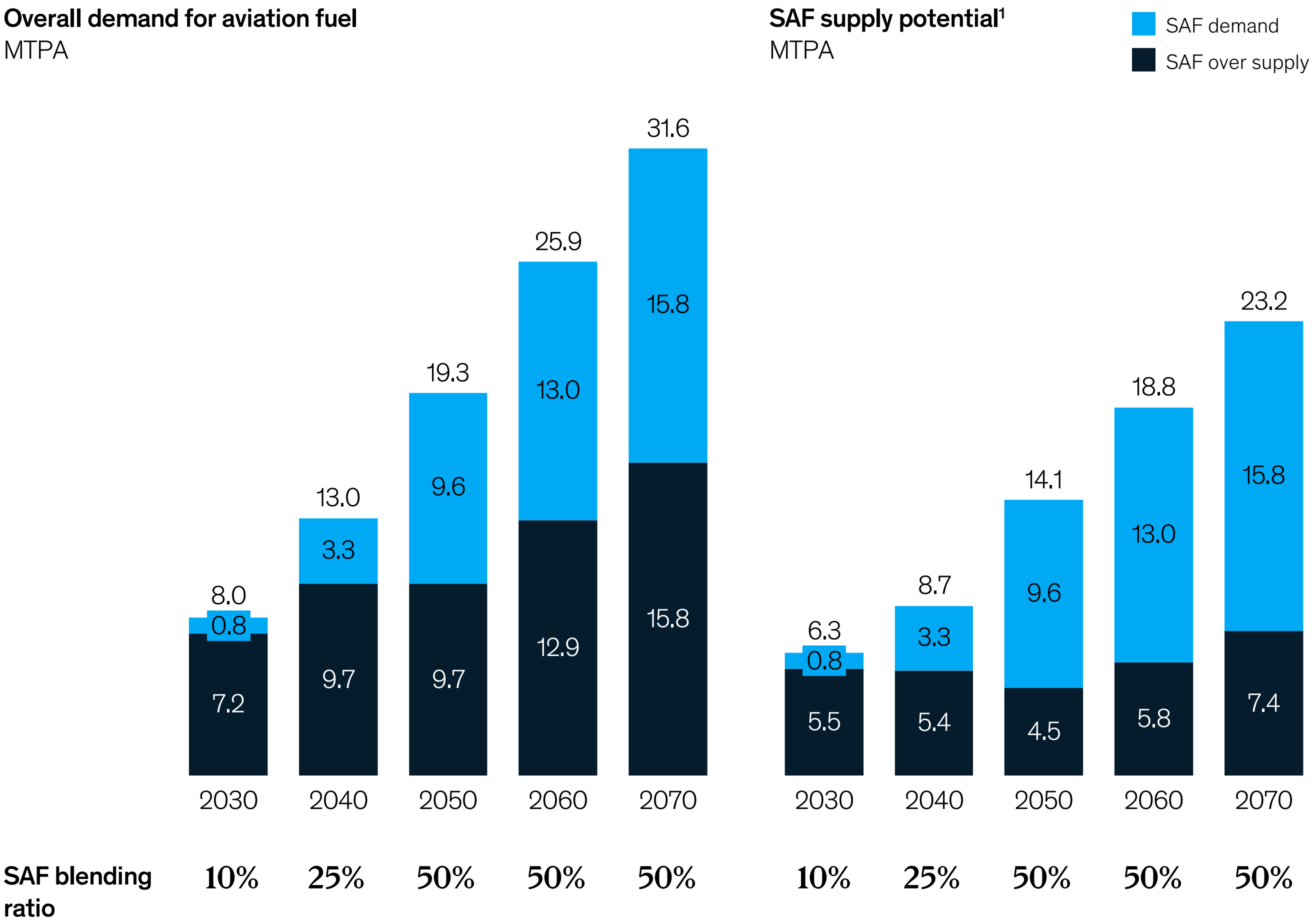


1. Total SAF potential comprises SAF from biomass and organic MSW. SAF from biomass is expected to go from 5.7 Mt per annum in 2030 to 8.5 Mt per annum in 2070. Similarly, SAF from MSW is expected to from 0.2 Mt per annum in 2030 to 7.9 Mt per annum in 2070.

Source: McKinsey SAF supply potential model and O&G model

Exhibit 41

## SAF demand and supply potential during the Accelerated scenario.



1. Total SAF potential comprises SAF from biomass and organic MSW. SAF from biomass is assumed to go from 5.7 Mt per annum in 2030 to 8.5 Mt per annum in 2070. Similarly, SAF from MSW is expected to go from 0.6 Mt per annum in 2030 to 14.7 Mt per annum in 2070.

Source: McKinsey SAF supply potential model and O&G model

## Investment would be needed

In the Accelerated scenario, production of SAF to maximum potential would require a total investment of $347 billion by 2050, which is almost one-and-a-half- times the expected investment in the LoS scenario (Exhibit 42).

## Proposed enablers for aviation decarbonisation

Considerations could be given to policy settings that encourage use of SAF over other uses of biomaterials in sectors where there are better abatement options (e.g., electrification is a real option for surface transportation, but there are no other options for aviation). Although technologies for SAF production exist, these need scaling and feedstock would need to be unlocked by:

- Setting up the end-to-end infrastructure required for aggregating agricultural wastes and residue, and segregating MSW at source;
- De-risking investment in the first wave of SAF production scale-up by providing investment support or appropriate viability gap funding;
- Potentially extending the National Policy on Biofuels 2018 to introduce a blending mandate for SAF and other supportive policies (e.g., reduced taxation in line with other biofuels);
- Categorising the SAF industry as a priority sector which qualifies it for an array of benefits. Institutes such as the National Bank for Agriculture and Rural Development are already providing concessional soft loans,[104] extending comparable schemes to SAF stakeholders could spur the growth of the supply chain, especially for waste segregation.

While aviation can appear a hard-to-abate sector, the opportunity to innovate around SAF production using biomaterials provides a real opportunity to decarbonise a large part of the sector while continuing to innovate around new aviation technologies that, while not existing today, might emerge in the future, to ensure the sector can reach net zero.

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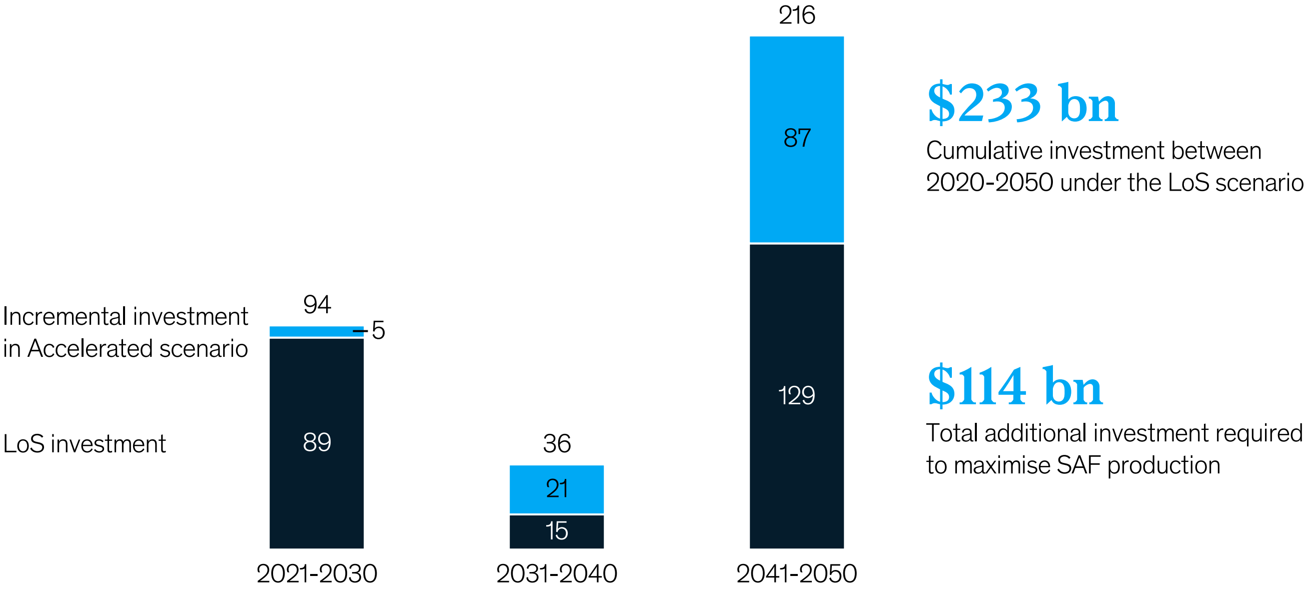
[104] National Bank for Agriculture and Rural Development.

Exhibit 42

### Producing SAF to its maximum potential would require an additional investment of $347 billion between 2021–2050.

**Decade-wise investments[1] for SAF production**
$ billion



| | 2021-2030 | 2031-2040 | 2041-2050 |
|---|---|---|---|
| Incremental investment in Accelerated scenario | 5 | 21 | 87 |
| LoS investment | 89 | 15 | 129 |
| Total | 94 | 36 | 216 |

1. Includes investments only for setting up of GAS-FT based unit SAF production units using agriculture residue and organic MSW.

Source: McKinsey material circularity model and WEF report on "Deploying Sustainable Aviation Fuels at Scale in India: A Clean Skies for Tomorrow Publication"

# 2.4 Cement sector

## Key takeaways

**Cement accounts for about five percent of India's current emissions** (156 $MtCO_2e$ in 2019) and is among the hardest sectors to abate, since two-thirds of the carbon emissions are from the separation of $CO_2$ from limestone, while a third are from the use of fossil fuels.[105] Without any proactive abatement initiatives, emissions will likely grow with cement demand at 2.1 percent per annum, leading to annual emissions of 431 $MtCO_2e$ by 2070. On top of this, an additional annual 93 $MtCO_2e$ could be emitted due to higher clinker use driven by a diminishing supply of fly ash and slag from the coal-based power plants and steel sectors, increasing total emissions to 524 $MtCO_2e$ by 2070.

**In the LoS scenario, emissions can be reduced to 378 $MtCO_2e$ per annum by 2070,** if the industry can find other clinker substitutes and adopt carbon-neutral biofuels (to meet 40 percent heat demand versus the current three percent).[106] There are very few other levers in the LoS scenario which are cost competitive or are currently technically feasible at scale.

**In the Accelerated scenario, absolute emissions could be reduced to 88 $MtCO_2e$** per annum by 2050 and remain at similar levels till 2070. CCUS, accelerated adoption of biomass-based fuels (to meet 70 percent heat demand), increased adoption of clinker substitutes (such as recycled concrete) and lean design could reduce the emission intensity of the industry from its current 0.54 $tCO_2$/ton cement to 0.13 $tCO_2$/ton cement by 2050. The Accelerated scenario would have a cumulative abatement that is 9.5 $GtCO_2e$ more than the LoS scenario by 2070.

**Levers corresponding to 45 percent of abatement in the Accelerated scenario also save cement production costs** and help supply a growing demand for green cement.[107] With growing sustainable architecture and green building practices in construction, new green business opportunities (such as disassembly focused concrete blocks and green cement) and new business models (like green concrete) could also emerge. Abatement of the remaining 55 percent of emissions in the Accelerated scenario would likely require policy and technology enablers like carbon pricing and improved capture technologies to encourage CCUS. Policy enablers, including preferential allocation of biomass for cement and green cement-blending mandates, may also be needed to drive clinker substitutes and green fuels. Achieving decarbonisation will likely require additional technology breakthroughs, such as renewables-powered electric kilns and carbon storage in saline aquifers.

**The Accelerated scenario will likely require $351 billion more in Capex investment than the LoS scenario by 2070.** Acceleration could also see cumulative Opex savings of $118 billion more than the LoS scenario by 2070, due to lean design, higher clinker efficiency and use of green fuels and refuse derived fuel (RDF) from waste at lower costs than fossil fuels.

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[105] UNFCC – India's biennial submission; climate action tracker; Laying the foundation for Zero Carbon Cement (McKinsey Report).

[106] Analysis based on data from CII waste exchange.

[107] Analysis based on data from CERC.

## The cement sector today

Concrete is the second-most consumed product globally after potable water.[108] Given its performance characteristics and the broad availability of limestone, cement (and therefore concrete) will remain the construction material of choice globally.

Currently, cement accounts for roughly five percent of India's emissions.[109] However, it is a particularly hard sector to abate, given the processes involved in cement production. Two-thirds of the emissions from cement are from the clinker manufacturing processes[110] for which there are currently no straightforward solutions for abatement.

Considering the Indian cement sector performs better than global sector averages on clinker ratios (65 percent in India versus more than 70 percent globally)[111] and energy efficiency (due to younger cement plants), traditional levers alone will not be sufficient to decarbonise fully and, therefore, we would need to innovate beyond these levers to achieve net zero in this sector.

## The LoS scenario

Emissions are expected to increase with demand for cement and remain in line with GDP growth till 2035, tracking the population growth rate till 2070 and leading to an average annual growth of 2.1 percent over this duration. This could lead to a cement demand of 814 Mt per annum by 2070, compared to 289 Mt in 2019, and a per capita consumption of between 350kg and 370kg by 2070 from its per capita consumption of 209 kg in 2019.[112]

Decarbonisation of the power and steel sectors would reduce the availability of clinker substitutes (fly ash and slag). In the absence of sufficient clinker substitutes like pozzolan and calcined clay, clinker use could grow, increasing the cost of cement by \$70/ton to \$75/ton by 2050 (around a 30 percent cost increase) and emissions by 0.55 $tCO_2$/ton of clinker (a 93 $MtCO_2e$ per annum increase by 2070).[113]

Without a concerted effort, therefore, annual cement emissions could grow from 156 $MtCO_2e$ in 2019 to 524 $MtCO_2e$ by 2070. However, there is an opportunity to reduce annual emissions to 378 $MtCO_2e$ through low-cost decarbonisation levers, as detailed next (Exhibit 43):

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[108] MIT Libraries

[109] UNFCC – India's biennial submission; climate action tracker

[110] Laying the foundation for Zero Carbon Cement (McKinsey Report)

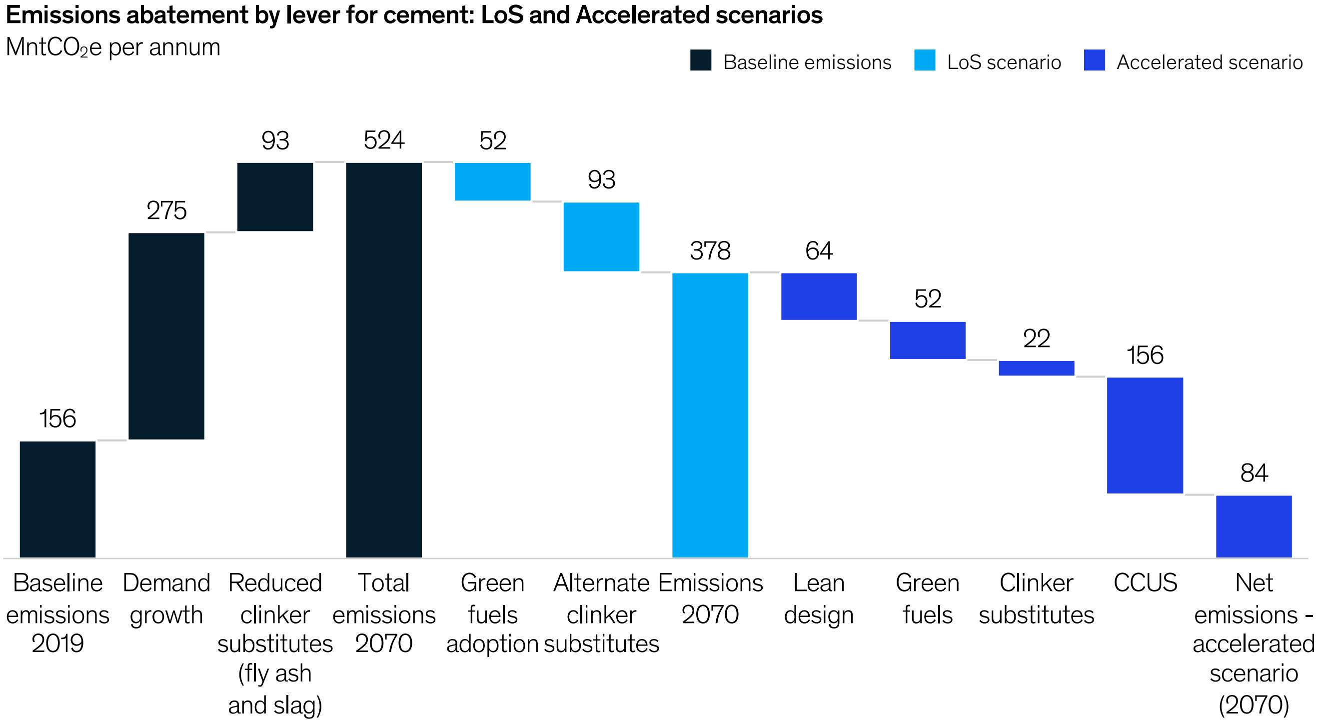
[111] Analysis based on market costs for clinker and its substitutes

[112] Global Insight; ICR; BNP Paris Bas

[113] CERC

Exhibit 43

### Various decarbonisation levers could reduce annual emissions to 378 $MtCO_2e$ by 2070 in the LoS and 84 $MtCO_2e$ in the Accelerated scenarios.



- Adopting green fuels such as biomass to replace fossil fuels like coal and pet coke. Alternative fuels, such as carbon-neutral biomass and RDF, could supply 40 percent of the heat demand from cement kilns by 2070, up from the current three percent. For example, using the biomass recovered from crop residue from up to 50 kilometers around cement plants and utilising RDF from surrounding towns and cities could lead to an annual reduction in energy emissions from the sector of 52 $MtCO_2e$ by 2070.
- Maintaining the clinker-to-cement ratio at the current level of 65 percent by sourcing alternatives to fly ash and slag, like pozzolan and calcined clay. The industry may need to explore multiple options for clinker substitutes to meet the gap created by curtailed fly ash and slag supplies. This would also help maintain cement production costs, since clinker manufacturing is usually more expensive than clinker substitutes. With the continued use of gypsum to constitute five percent of cement, clinker substitutes of pozzolan and calcined clay could be increased. However, this would not be sufficient to close the gap created by the reduction in supply of fly ash and slag. Other options could be recycled concrete paste and bio-ash (like rice-straw ash, rice-husk ash and bagasse ash). This would likely come at a higher cost initially but as the material circularity infrastructure matures, these could present cost-saving opportunities.

These levers could reduce cement's emission intensity by 27 percent, from 0.64 $tCO_2$/ton of cement in 2019 to 0.47 $tCO_2$/ton of cement in 2070.

Moreover, the cement industry could convert this challenge of reducing emissions into a green business opportunity by leveraging the evolving green building practices in construction. With the growing adoption of green building certifications in India, such as the Indian Green Building Council and Leadership in Energy and Environmental Design, there is a shift in the Indian construction industry toward sustainable design.[114]

State governments provide expedited environmental clearance to construction projects with green building certifications, and capital can be raised at better interest rates for construction projects with lower emissions.[115] As a result, there has been a 37 percent increase in green certified buildings in the past five years.[116] Sustainable design, use of recycled raw materials (10 percent for one point and 20 percent for two points) and lean designs are some of the criteria included in these certifications.[117]

As a result of these actions, absolute annual emissions in the LoS scenario could increase from 156 $MtCO_2e$ in 2019 to 378 $MtCO_2e$ by 2070 (versus the possibility of 524 $MtCO_2e$).

## The Accelerated scenario

Accelerated decarbonisation of the cement industry would require the intense application of four levers that could drive the reduction in emissions to 88 $MtCO_2e$ by 2050 and to 84 $MtCO_2e$ by 2070 (Exhibit 44). Cumulative emissions in the scenario would be 9.5 $GtCO_2e$ lower than in the LoS scenario by 2070.

1. **Adopting lean construction design and using alternative materials:** Accelerated adoption of green building norms, alternative materials and sustainable architecture could lead to the optimised use of cement in construction. This has already begun, albeit on a small scale, and is likely to continue increasing considering the fast-paced growth certified green buildings have seen in the last five years.[118] The Global Cement and Concrete Association (GCCA) estimates that there could be up to a 22 percent reduction in emissions through efficiency in design and construction.[119] In India, demand for cement could be about 15 percent lower in 2050 (21 percent in 2070) versus the LoS scenario if innovative construction methods, such as lean design, are adopted. This could lead to an annual emission reduction of 40 $MtCO_2e$ by 2050 and 64 $MtCO_2e$ by 2070 (Exhibit 45). This reduction could also create adjacent business opportunities for the use of cement by diversification into alternative materials such as disassembly-focused concrete blocks and recycled concrete-based aggregates.

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[114] India is ranked third in the world on US Green Building Council (USGBC) annual list of top 10 countries outside US

[115] Ministry of environment; forests and climate change

[116] IGBC; LEED

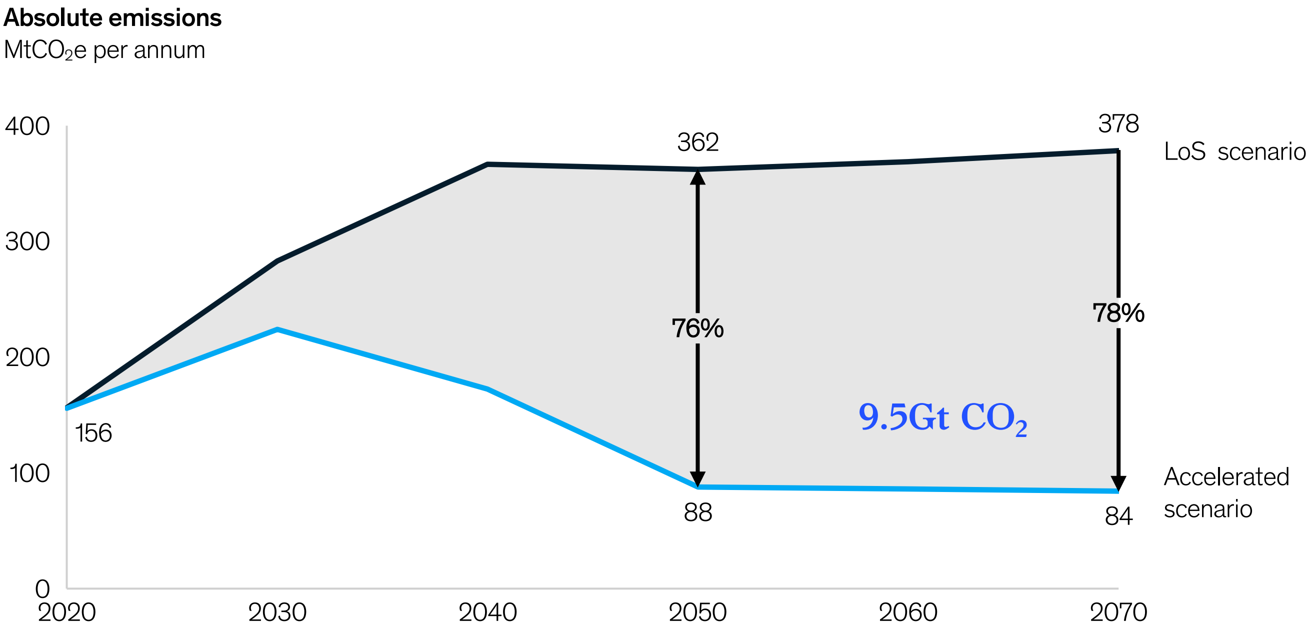
[117] IGBC green building certification guidelines

[118] IGBC; LEED

[119] GCCA – concrete future roadmap

Exhibit 44

## 76 percent reduction in emissions could be achievable in the Accelerated scenario vs the LoS.



Source: McKinsey Analysis

Exhibit 45

## Key levers to achieve the Accelerated scenario.

| | LoS scenario | Accelerated scenario | Additional emissions abated in Accelerated vs LoS scenario by 2070 |
|---|---|---|---|
| **Lean construction design and alternative material use** | No lean design and alternative materials | Higher efficiency in cement consumption through lean design and diversification opportunities into low carbon alternative materials (such as recycled concrete based aggregates, etc.) 14 percent by 2050; 21 percent by 2070 | 64 $MtCO_2e$ per annum |
| **Clinker-to-cement ratio** | 65 percent (same as current) | Reduces to 60 percent by 2050 with faster adoption of alternatives for fly ash and slag; more use of recycled concrete (20 percent permitted by BIS standards) | 22 $MtCO_2e$ per annum |
| **Heat demand met by green fuels** | 40 percent by 2070, up from three percent currently | 50 percent by 2050; 70 percent by 2070 | 52 $MtCO_2e$ per annum |
| **Carbon capture (CCUS)** | No carbon capture | 65 percent emissions captured for utilisation or storage of carbon, up from current 0 percent | 156 $MtCO_2e$ per annum |
| **New technologies** | Currently announced and implemented efforts in new technology considered like use of biofuels, alternative fuels | Use of technologies like kiln electrification, electrolysis instead of kiln combustion will depend on technology progress and scale up | Not quantified |

2. **Reducing the clinker-to-cement ratio** to 60 percent by 2070 versus its current levels of 65 percent could reduce emissions by 22 $MtCO_2e$ per annum. Moreover, clinker substitutes could also help save costs as they tend to be less expensive than clinker. A faster adoption of clinker substitutes could potentially save up to $15 / ton cement and thus add value to a growing green cement opportunity (Exhibit 46).

   With a faster reduction in fly ash and slag supply, accelerated adoption of innovative clinker substitutes would be needed (Exhibit 47).

   **Accelerating the adoption of recycled concrete paste** through improved circularity of construction and demolition (C&D) waste could achieve up to a 20 percent reduction in the clinker-to-cement ratio (in line with Bureau of Indian Standards [BIS] norms).[120] Cement produced with recycled concrete paste as a clinker substitute is commercially available in the European Union since 2021–2022.[121] Adoption of these technologies in India, combined with the availability of C&D waste, could drive recycled concrete paste as a clinker substitute. This would require rapid improvements in C&D waste recovery and recycling (75 percent would need to be recycled by 2070) as well as potential Capex investments at the cement plants.[122]

   **Increasing the use of bio-ash** could also help reduce the clinker-to-cement ratio. Availability of bio-ash would need to be ensured through blending mandates and policy design like fly ash and slag use policies, with bio-ash collection from sugar mills, etc.

3. **Increasing the use of alternative fuels** could potentially replace fossil fuels in cement kilns (Exhibit 48) and help reduce emissions by 45 to 50 $MtCO_2e$ per annum by 2050 (with reduction continuing at a similar pace thereafter till 2070).[123] While this is technically feasible even today, costs and availability of alternative fuels is a challenge. While alternative fuels could potentially increase cumulative costs by $15 billion by 2070 in the Accelerated scenario compared to fossil fuel use in the LoS, they would also ensure that cost fluctuations were a thing of the past because of the price changes of coal and pet coke and dependence on fuel imports. The alternative fuels could include:

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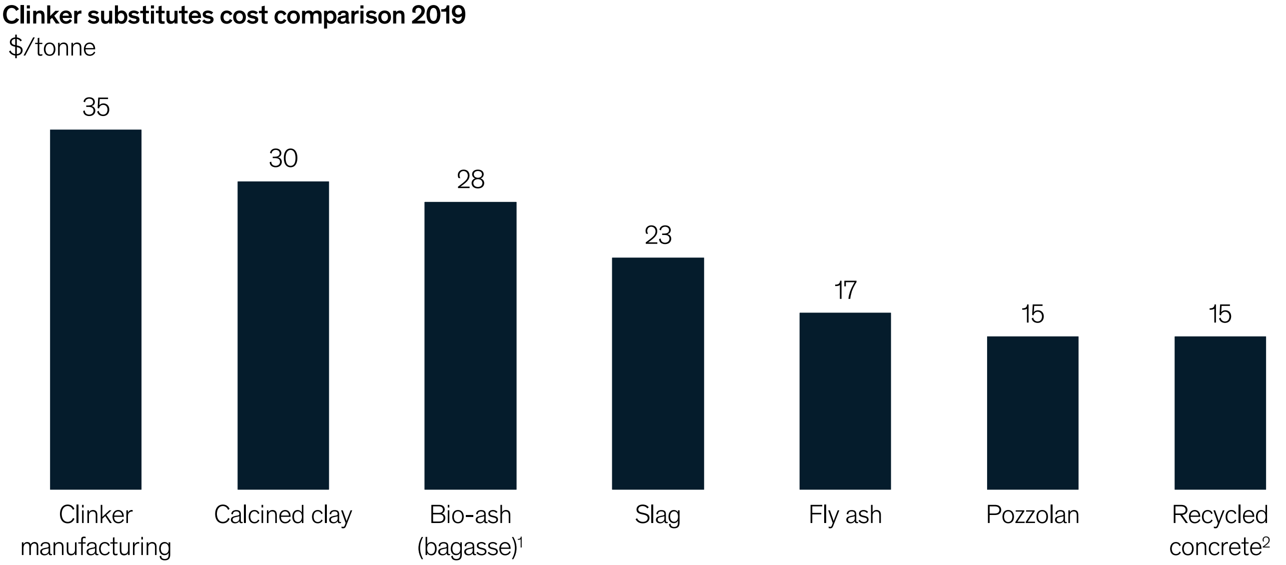
[120] CPCB.
[121] CEMNET.
[122] CPCB.
[123] India Energy Outlook 2021; McKinsey Analysis.

Exhibit 46

## Adaptation of clinker substitutes could add value to a growing green cement opportunity.

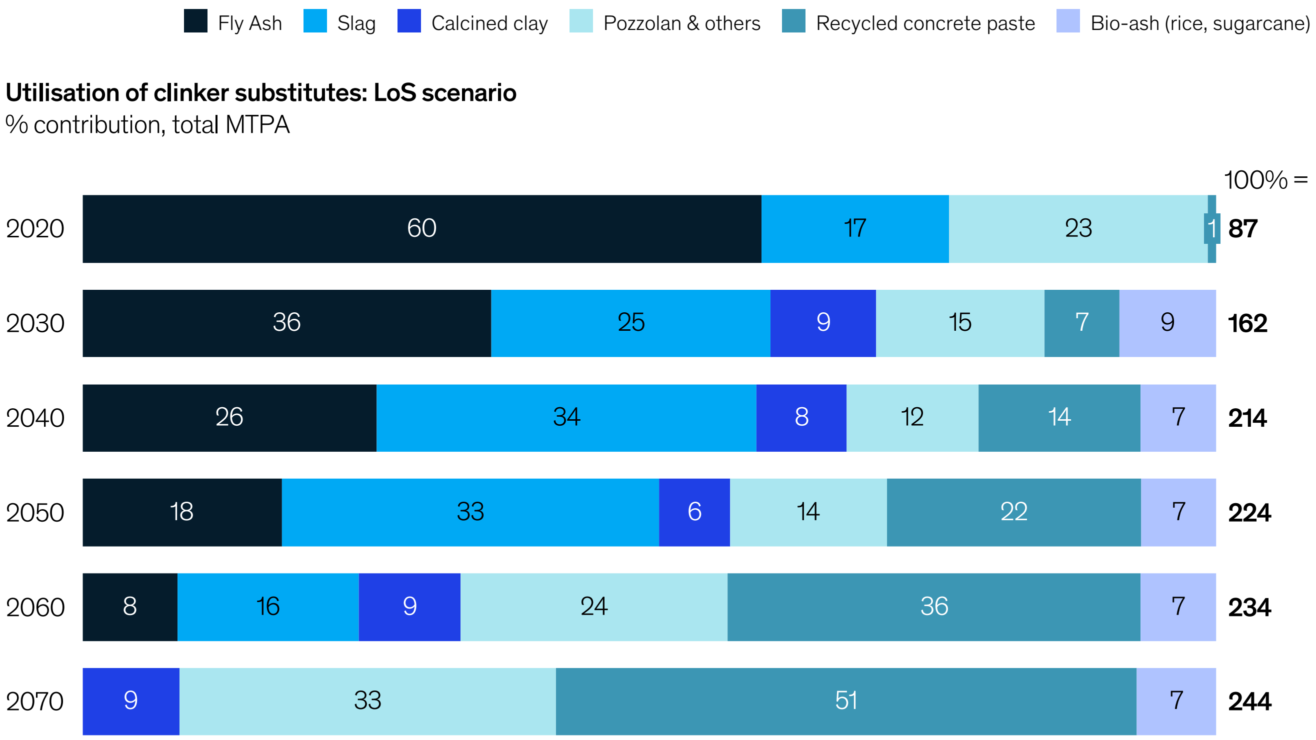


1. Based on bagasse prices from CERC, bio-ash is likely to cost less.
2. Based on recycled concrete prices in US (lower cost in range assumed).

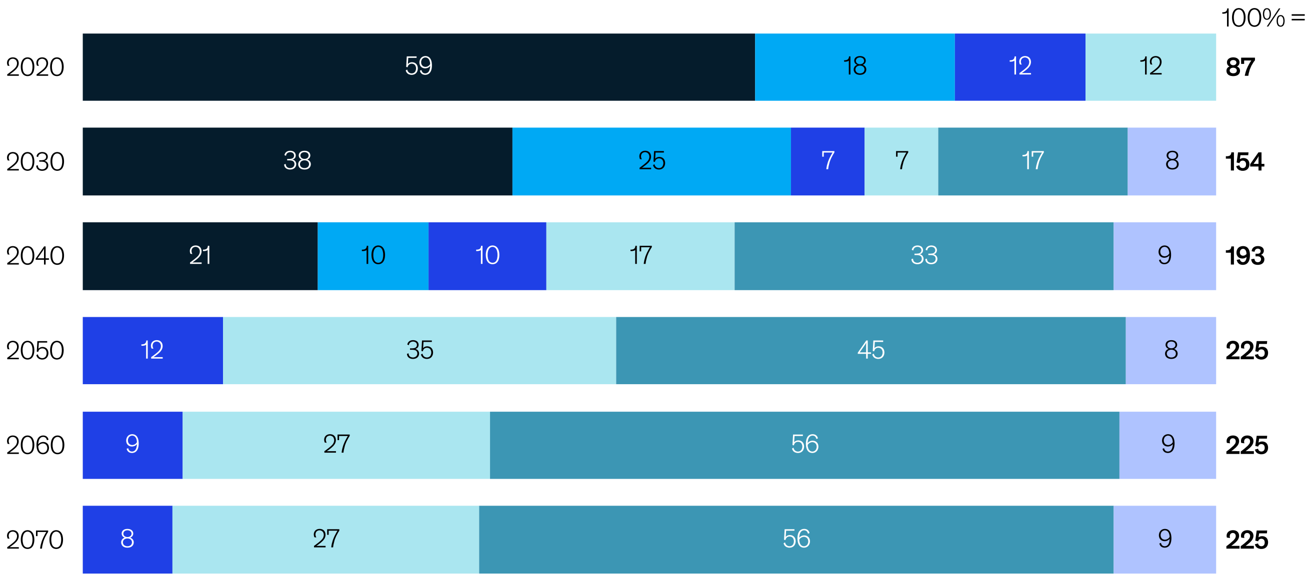
Exhibit 47

## As the availability of fly ash and slag gets curtailed, other substitutes will be needed to reduce the clinker ratio.

**Utilisation of clinker substitutes: LoS scenario**
% contribution, total MTPA



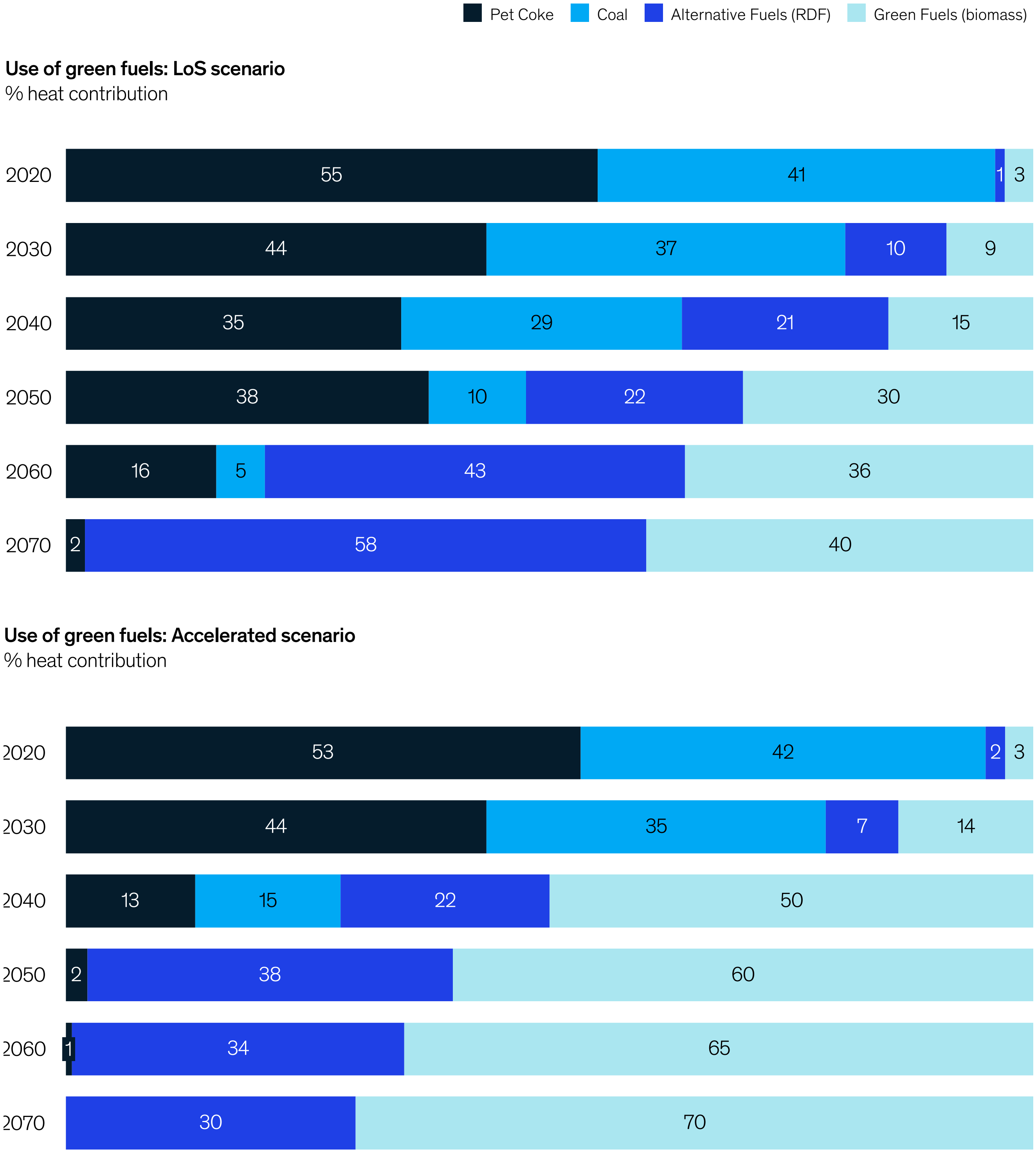
**Utilisation of clinker substitutes: Accelerated scenario**
% contribution, total MTPA



Source: DownToEarth; Heidelberg cement; Holcim; Indian Minerals Yearbook 2020; OECD-FAO Agricultural Outlook; Science direct; Researchgate; World Energy Outlook (IEA); McKinsey steel net zero scenario

Exhibit 48

## Green fuels can reduce emissions by around 90 MMTPA in the Accelerated scenario by 2070 to meet 70 percent of the heat demand in cement kilns.



- Carbon-neutral green fuels, such as agricultural waste, crop residue and bagasse, to meet 70 percent of heat demand. Between 45 Mt and 50 Mt of crop residue annually may be needed by 2070 to meet this demand and would likely require collection of crop residue from farmers up to 100 km away (500 Mt of crop residue is generated annually in India currently).
- Use of RDF from municipal solid waste, as well as plastic, tyre and other waste material. About 30–40 Mt of RDF may be needed annually by 2070.
- Other potential fuels that could be used as green fuels for cement kilns including green hydrogen and other biofuels (e.g., algae-based biofuels) which are in a nascent stage of development and are not included in our calculations.

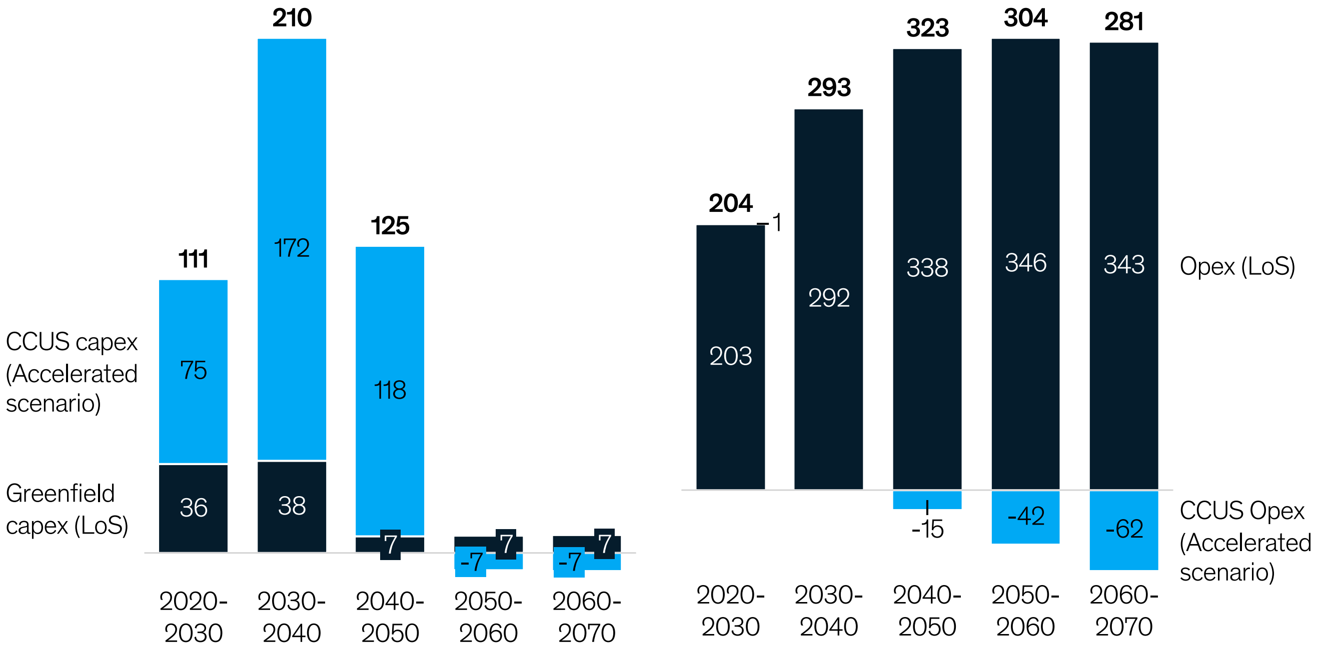
4. **Adopting new CCUS technologies** may be necessary for capturing 65 percent of the remaining emissions and abating about 160 $MtCO_2e$ per annum by 2070. However, this would require extensive investment in carbon-capture set ups at cement plants, as well as in the utilisation, transportation and storage of the captured carbon. Among the carbon-capture technologies available, amine scrubbing is the primary technology in use today. However, there are multiple carbon-capture technologies being developed that may have lower costs than the primary industry pathway today. The set up for CCUS infrastructure in India, potentially a hub model, may require support in terms of policy, regulations and investments in pipeline infrastructure for $CO_2$ transportation, and exploration for new storage potential. Part of the captured carbon could be utilised in the cement industry for carbon-cured concrete, artificial limestone and other applications. However, the technological and economic feasibility of these need to be established first.

## Implications of the Accelerated scenario

The Accelerated scenario would need a total Capex investment of $446 billion from 2020–2070. Of this investment, $387 billion would likely be required by 2070 for the CCUS set up (for capture, transportation and storage), with cumulative Opex costs of $162 billion by 2070. A Capex investment of $59 billion would be needed by 2050 for greenfield cement plants to meet incremental demand in this scenario. However, the greenfield investment would be $36 billion less than in the LoS scenario due to optimised cement demand through lean design levers. These Capex investments can be front loaded, with more than 70 percent of the capital investment needed by 2040 in the Accelerated scenario (Exhibit 49).

Exhibit 49

**The Accelerated scenario may require Capex investments of $446 billion but produce net Opex savings of $118 billion by 2070.**



**Capex investment for Accelerated scenario,** $ billion

**OPEX for Accelerated scenario** $ billion

The Accelerated scenario will likely incur an incremental CCUS Opex of $162 billion by 2070, but also create savings of $288 billion by 2070, creating net Opex savings of $118 billion by 2070. These savings will be the result of optimised cement demand, increased adoption of alternative fuels and improved clinker efficiency.

With a shift toward sustainable architecture and green building practices, there could be an opportunity to drive green premia via green cement and adjacent products, such as green concrete, recycled aggregates and disassembly focused concrete blocks.[124] For instance, clinker-free cement in France is currently leveraging a green premium of 30–40 percent compared to average conventional cement prices, although this is still on a small scale.[125]

Due to higher overall investments in the Accelerated scenario compared to the LoS scenario, cement costs are likely to increase by three to five percent, leading to a one to one-and-a-half percent increase in construction costs.

## Proposed enablers for cement decarbonisation

Achieving the Accelerated scenario would require investment from various stakeholders in the cement industry, policy, investment and technology enablers

1. Policy enablers for consideration for accelerating the transition include:
    - Blending mandates, which could help the decarbonisation transition in cement manufacture. Such policies might include blending mandates for recycled concrete as clinker substitutes of up to 20 percent by weight of cement, or the mandated use of bio-ash as a clinker substitute.
    - Green fuels prioritisation policy, which could help prioritise crop-residue use as biomass for cement kilns (and other applications) and avoid crop residue burning as a result.
    - Demand signals for green cement such as carbon pricing, carbon emissions trading and green building certifications. This could be especially useful for high-cost decarbonisation levers like CCUS and could incentivise investments.
    - Construction and demolition waste management policy enforcement, which, in addition to blending mandates, could drive circularity in cement.
2. Investment will be needed in research to develop and scale up CCUS. A CCUS hub model, with policy and investment support, could also enable a cost-efficient route for transportation and storage (further detailed in the CCUS section).
3. Investment in R&D will be needed for alternative, lower-emission technologies like kiln electrification, electrolysis-based cement production and solar-energy concentration for cement production. These are yet to be tested in the cement industry and the scale up will be capital intensive.

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[124] GCCA – concrete future roadmap.
[125] Press search; Cemnet.

# 2.5 Steel industry

## Key takeaways

**One tenth (11 percent) of India's emissions are from steel** (about 250 $MtCO_2e$ in 2020).[126] With growth in steel demand, this is projected to rise to ~620 $MtCO_2e$ by 2045.

**In the LoS scenario,** these emissions progressively reduce to ~360 Mt per annum by 2070 as the intensity declines by 80 percent. Higher use of scrap (6 to 8X current levels) and hydrogen-based steel-making, once it becomes competitive from 2045, will drive the transition.

**In the Accelerated decarbonisation scenario,** India's steel emissions would peak at ~355 $MtCO_2e$ Mt per annum declining to ~205 $MtCO_2e$ Mt per annum by 2050 (about 80 percent of current levels). This would require a $CO_2$ price on emissions ($50/ton $CO_2$ by 2030), thereby making hydrogen-based steel-making competitive versus the BF-BOF process.

**Cumulative emissions would be lower by five billion tons** by 2050 in the Accelerated scenario relative to the LoS scenario (ten billion tons by 2070). While the Capex intensity of the steel-making step would decline in hydrogen-based steel-making, incremental spending on green power and hydrogen would likely require an additional Capex of about $135 billion, which is about 40 percent on top of the Capex on the steel value chain across technologies. Also, cumulative Forex savings of approximately $500 billion would accrue through to 2050 from reduced spending on coking coal in the Accelerated scenario. India would also avoid locking into about 200 million tons of BF-BOF technology in the Accelerated scenario.

**India can leverage premium priced green steel demand** in jurisdictions like Europe, Japan and Korea to kickstart this ambition. Additionally, it can start exporting green pig iron and green steel from the early 2030s, generating revenues of $11 billion annually.

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[126] UNFCCC.

## The steel sector today

The steel sector accounts for about 11 percent of India's total $CO_2$ emissions and is expected to remain a significant carbon emitter. Steel production is expected to grow sevenfold to around 785 MMTPA by 2070, on the back of rising steel demand driven by India's economic growth (Exhibit 50).

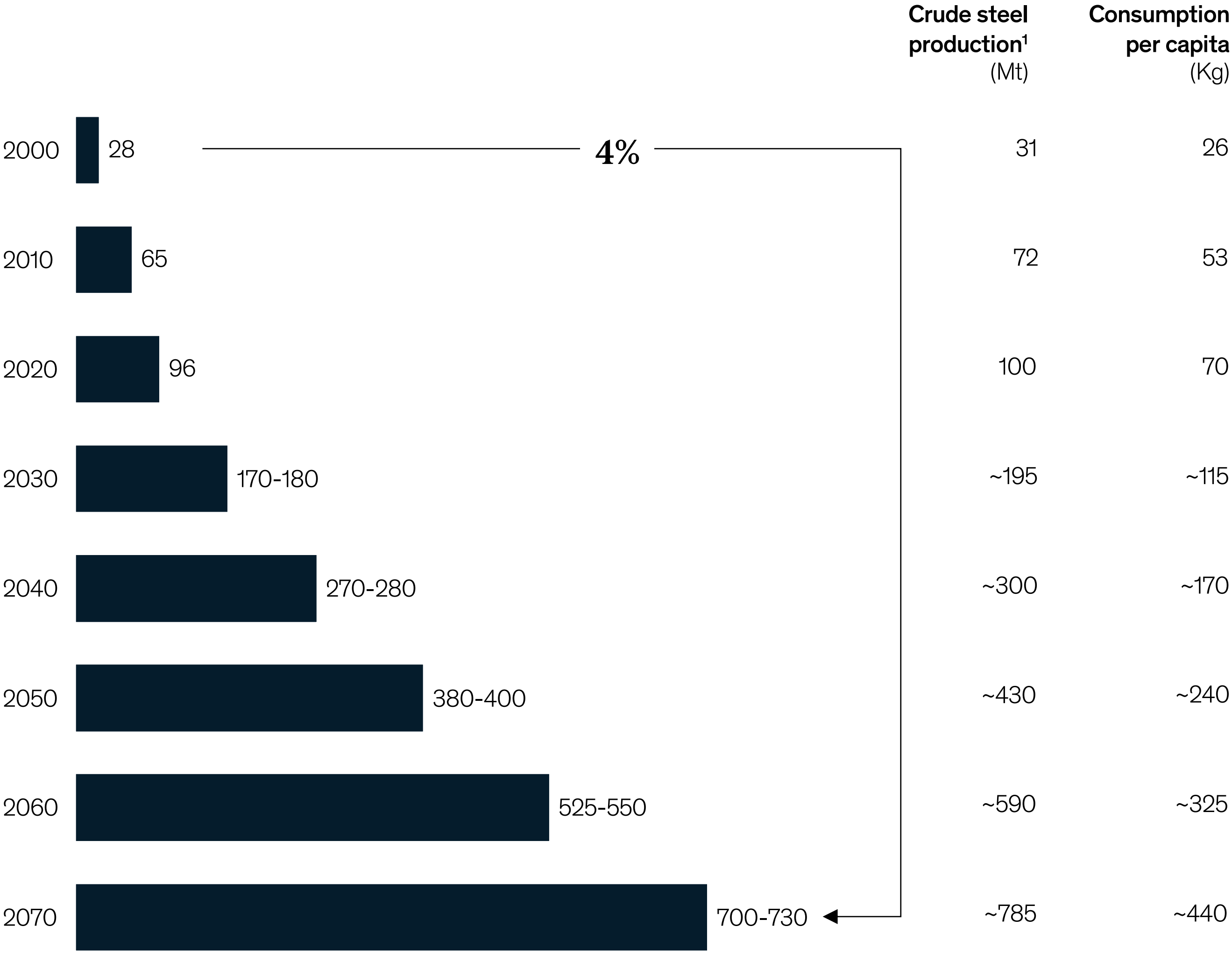
As a first step towards decarbonising the existing assets, about three-five percent of the emissions from the integrated BF-BOF plants could be abated using NPV positive levers mostly related to energy efficiency (Exhibit 51). Depending on the asset configuration of the plant, total abatement could be 25 percent with the use of other currently value-negative, Opex- and Capex-intensive levers such as scrap charging and use of biomass.

In the longer term, decarbonising steel will require a transition to low emission technologies (Exhibit 52).

Exhibit 50

### Forecast steel demand.

MMTPA



1. Crude steel production calculated as 1.1x finished steel demand.

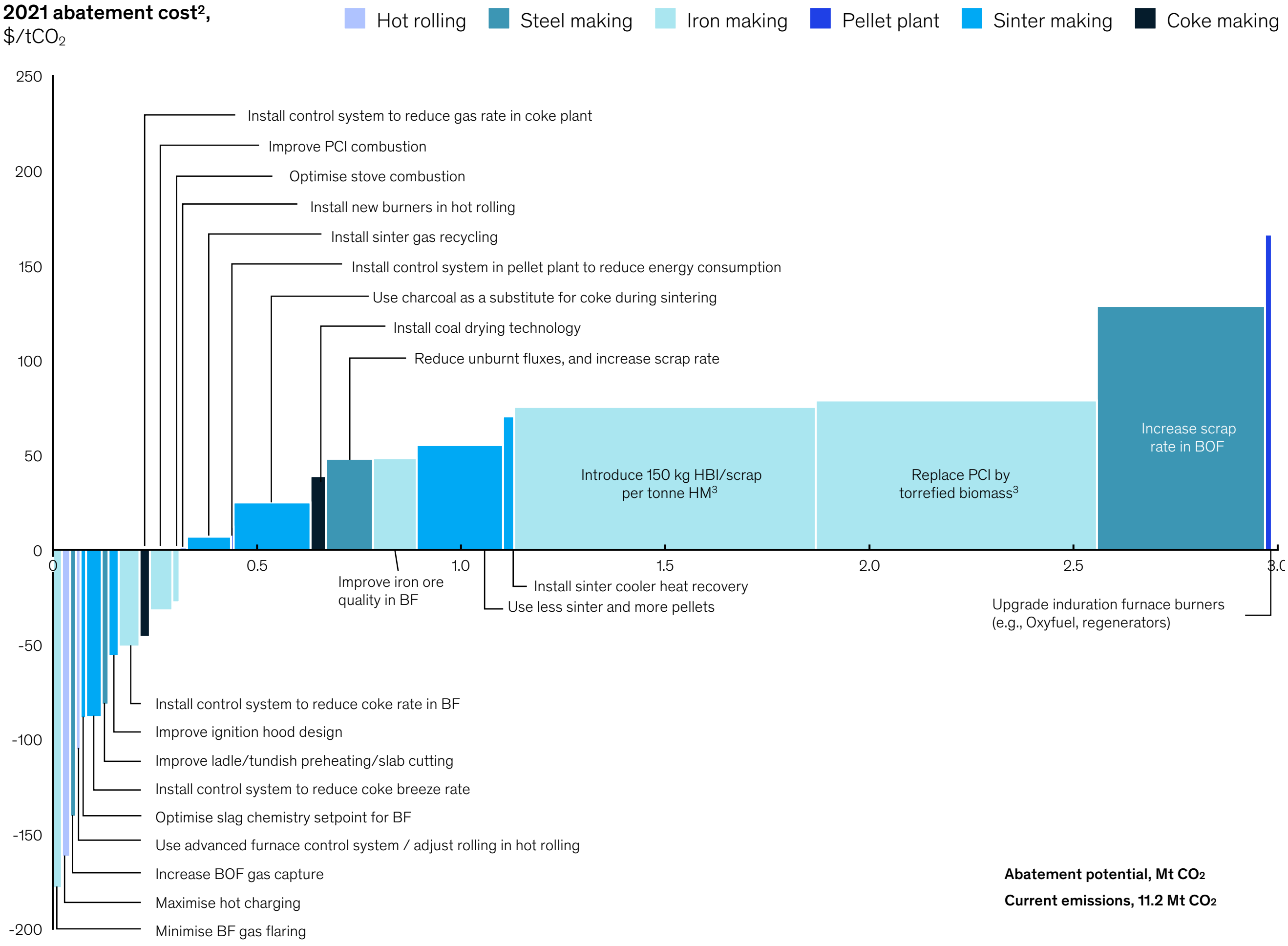
Source: McKinsey steel demand model, United Nations population division

Exhibit 51

## India BF-BOF abatement curve.

### BF-BOF plant with 5 MMTPA liquid steel production and emissions at 2.4t$CO_2$/t HRC[1]

Abatement potential highly dependent on plant configuration



| | | | | |
|---|---|---|---|---|
| **0.3 mt** | **~25%** | **$58/t** | **2.9 mt** | **$150 mn** |
| Abatement from NPV positive levers | $CO_2$ abatement potential | Abatement cost | Abatement from all levers | Capex to abate ~25% $CO_2$ |

1. HRC production of 4.7 Mt per annum; baseline emissions: Cokemaking-12%; Sintermaking-10%; Pelletizer-2%; BF-59%; BOF-3%; Sec.metallurgy-5%; HR rolling-9%.
2. Abatement costs are calculated on an NPV basis. Capex is assumed to be incurred in the beginning of the year and impact on opex and carbon abatement is realised by the end of year for a period of 5 years, discounted at 10%; LT price assumptions: coke-340$/t; PCI-160$/t; biomass-350$/t; sinter fines-50$/t; HBI-270$/t; natural gas-10$/GJ; electricity-0.07$/KWh.
3. Assumes sufficient availability of biomass and HBI for early movers; biomass and HBI/scrap availability is likely to be an issue if several players start pulling this lever.

Note: Levers which have overlap (e.g., closing sinter plant and pulling levers in the sinter plant) and are high capex (>$50 million) have been removed. However, impact of pulling levers across emission steps has not been removed as abatement impact of all levers is assumed at constant steel volumes.

Source: McKinsey asset decarbonisation assessment tool

Exhibit 52

## Low-emission steel-making technologies.

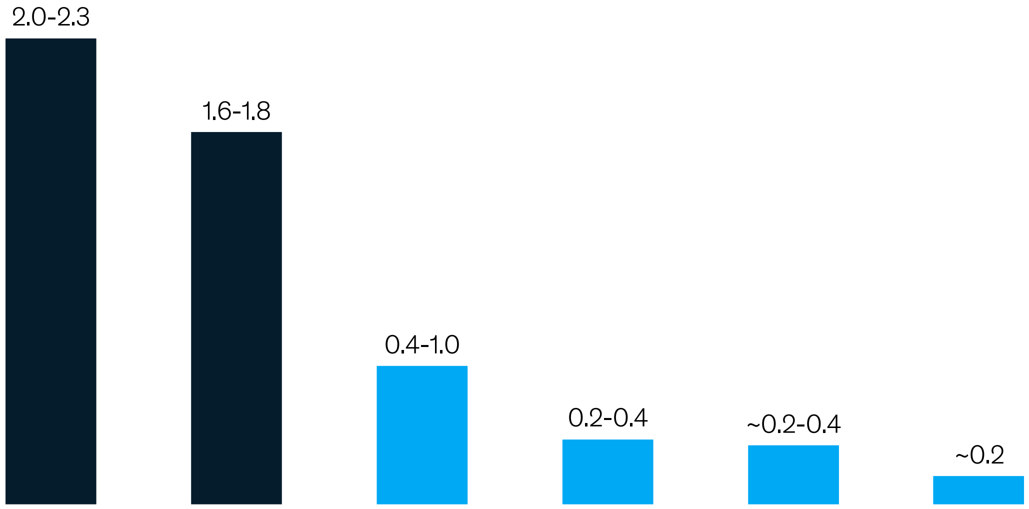
Not exhaustive, varying technology maturity

🟦 Low carbon steel making technologies

**Maturity** ◔ Low ● High

| | **BF-BOF** | **BF-BOF with efficiency** | **BF-BOF + CCS** | **DRI-EAF w. Natural gas + CCS** | **DRI-SAF-BOF w/ green hydrogen** | **Scrap EAF** |
|---|---|---|---|---|---|---|
| **Approach** | Reduction of iron ore by coking coal in BF converted to steel in BOF | Energy efficiency and process improvements such as feedstock quality, digitalisation | Add carbon capture technology to existing BF-BOF plants | Natural gas-based DRI with an EAF, and capture $CO_2$ emissions | Combine green hydrogen-based DRI, arc furnace and BOF | Melt high quality scrap in EAF |

**Emissions $tCO_2$/t liquid steel[1]**



| | **BF-BOF** | **BF-BOF with efficiency** | **BF-BOF + CCS** | **DRI-EAF w. Natural gas + CCS** | **DRI-SAF-BOF w/ green hydrogen** | **Scrap EAF** |
|---|---|---|---|---|---|---|
| **Max. decarbonisation potential using RES[2], %** | Baseline | ~20-25% | -50-80% | -80-90% | -85-90% | -85-95% |
| **Logic/limitation** | Abatement limited by availability/ cost of scrap/ biomass | No step change decarbonisation of the plant | Lack of regulatory clarity; significant Capex requirements | Will apply selectively in India | Requires cheap H2 (~1-2$/Kg) to be cost competitive | Limited by scrap supply |
| **Maturity** | ● | ● | ◔<br>No CCS cases, minor CCU | ●<br>Emirates Steel | ◑<br>Industrial demo plants and large announced projects | ● |

1. Across Scope 1-2.
2. % vs. BF-BOF; RES – Renewable Energy Source.

Source: McKinsey, Expert inputs

## The LoS scenario

In the LoS scenario, the emissions intensity of India's steel industry could be reduced by around 80 percent—from approximately 2.0 $tCO_2$/ton steel to 0.5 $tCO_2$/ton steel by 2070, through a combination of energy efficiency, closure of carbon inefficient technologies like coal-based direct reduced iron (DRI) and adoption of low emission intensity routes (Exhibit 53).

The LoS scenario plays out in two phases: the first phase with continued addition of virgin steel capacity on the BF-BOF route, followed by a second one when green hydrogen-based steelmaking becomes more competitive than BF-BOF around 2045 (Exhibit 54).

In the first phase, $CO_2$ emissions would likely grow from the current 250 Mt to around 620 Mt by 2045. $CO_2$ intensity would, simultaneously, fall from 2.0 $tCO_2$/ton CS to around 1.7 $tCO_2$/ton CS due to improvements in the energy efficiency of BF-BOF and addition of electric arc furnace (EAF) scrap.

In the second phase, low emission technologies (i.e., EAF scrap and green hydrogen-based steel) ramp up to 90 percent of total steel production with simultaneous closures of BF-BOF units, reducing emissions to around 355 Mt $CO_2e$ by 2070 (i.e., 0.5 $tCO_2$/ton of crude steel).

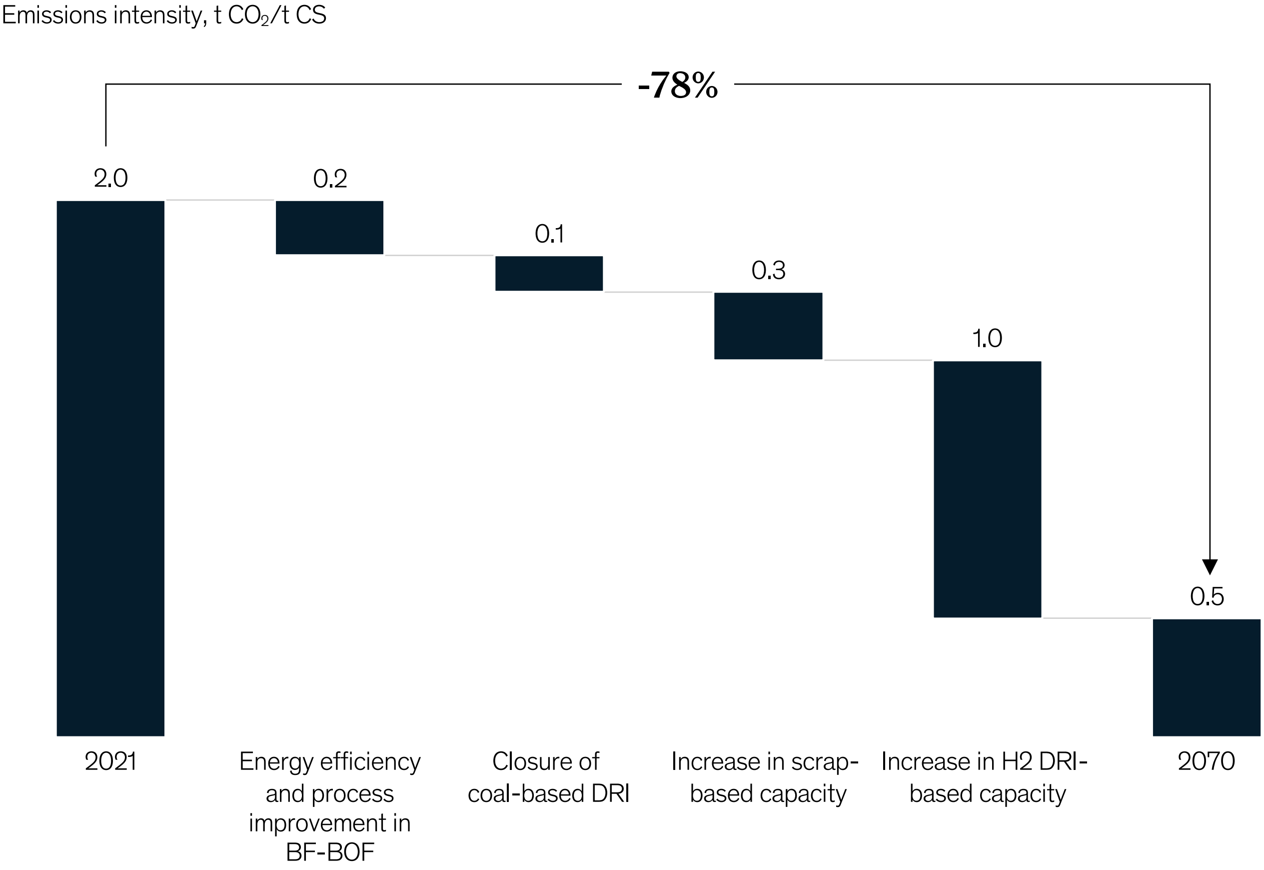
The LoS scenario would require the proposed enablers:

1. **Capacity addition on the EAF-scrap technology route.** This will depend on the availability of high-quality scrap. India has the potential to increase its scrap collection rate by establishing a scrap collection network. Scrap availability could increase six- to sevenfold by 2050 if scrap collection rates from the end sectors increased from their current levels of 30 to 35 percent to around 65 to 70 percent, in line with other regions (Exhibit 55). Increased scrap availability could grow EAF-scrap based production threefold to 65 Mt per annum by 2050.

Exhibit 53

### Emissions intensity reduction of steel industry (2021–2070).

**LoS scenario**

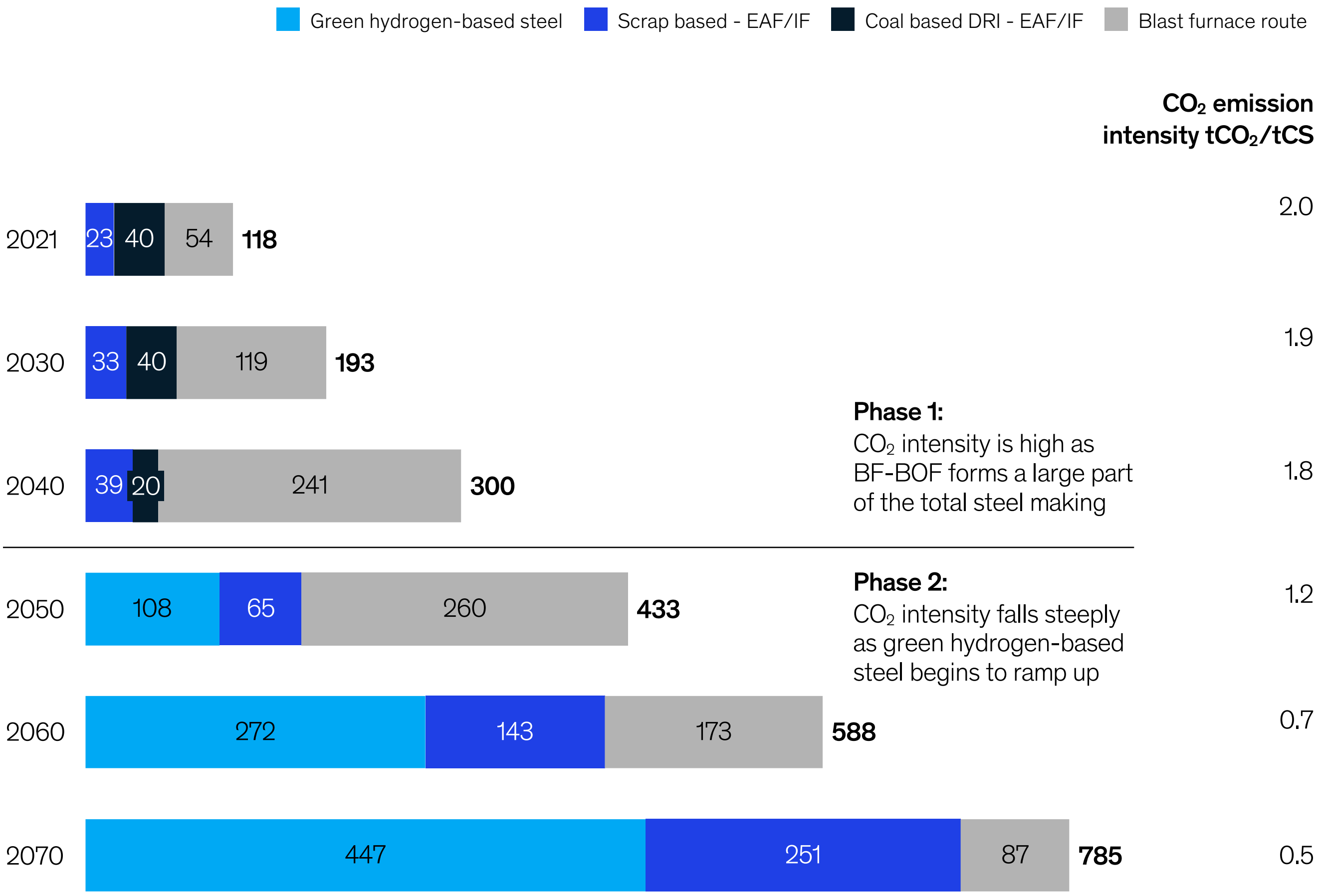


Source: McKinsey decarbonisation TCO model v14

Exhibit 54

## LoS scenario: crude steel production by route.

MMTPA



Note: Assumptions for capacity closures: BF-BOF capacity will start decommissioning from 2045 and close entirely by 2080; Coal DRI based steel making capacity will start decommissioning from 2030 and close entirely by 2050

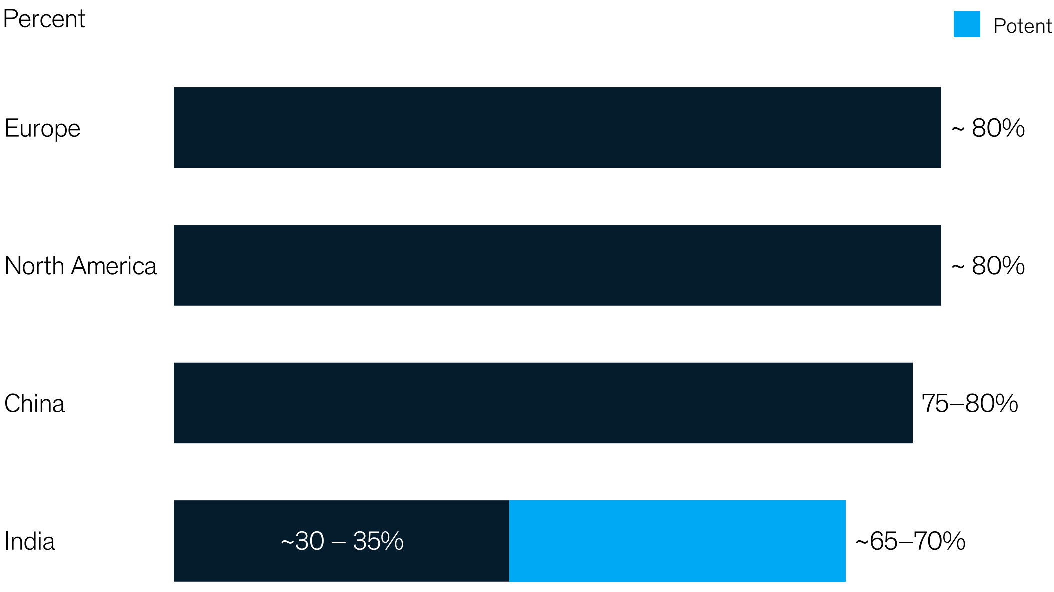
Source: McKinsey decarbonisation TCO model v14, Metal Bulletin

2. **Green hydrogen-based steelmaking.** This will likely be on a submerged arc furnace-basic oxygen furnace (SAF-BOF) route to utilise low grade Indian iron ore. Green hydrogen-based steelmaking would ramp up from 2040 onwards to account for about 25 percent of steelmaking capacity by 2050 and 55 percent by 2070. The switch from the BF-BOF route may require hydrogen prices to fall to $1 per kg by 2045 (Exhibit 56).

3. **Decommissioning of existing BF-BOF capacities.** This is assumed to start from 2045 as these assets become older than 35 years (~30 Mt in 2011). As BF-BOF continues to lose competitiveness and India's net-zero target approaches, decommissioning of assets is expected to accelerate with assets older than 30 years also being decommissioned from about 2055. All coal-based DRI capacities are assumed to decline from 2040 and close entirely by 2050.

Exhibit 55

## Steel scrap collection rate for different regions.



**China's scrap collection rate has significantly improved** in the last few years

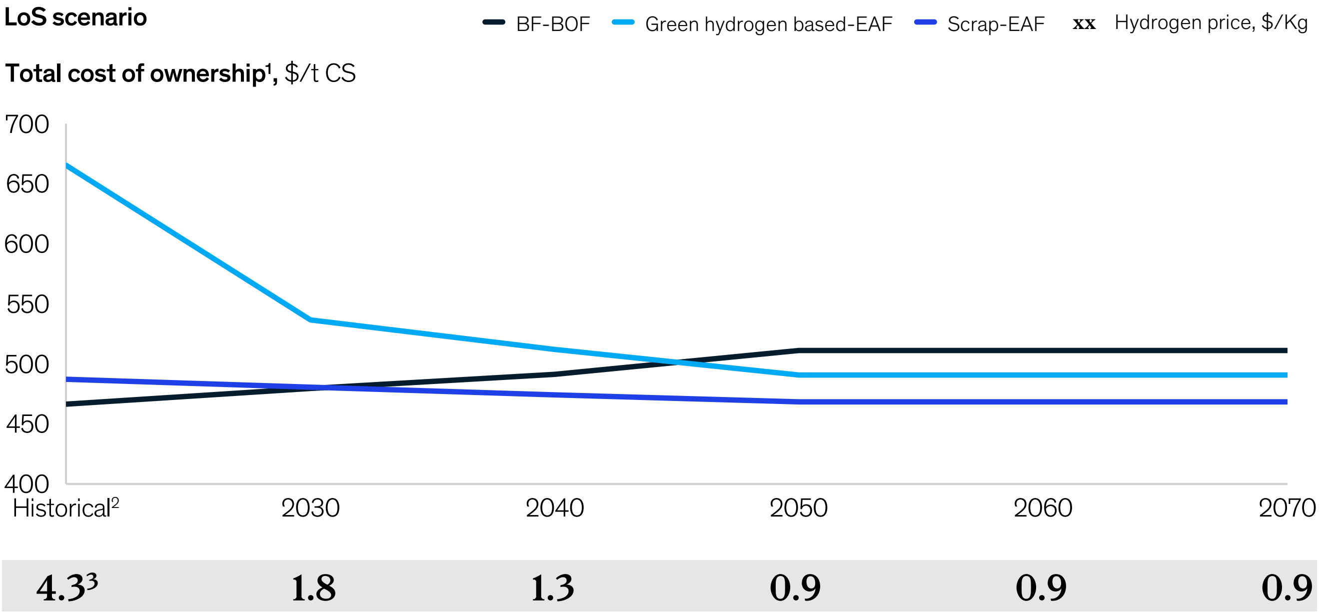
Scrap collection rates might improve further as countries are incorporating policies for better scrap collection and reuse

Note: Historically, estimated based on total availability in scrap pool and scrap consumption in crude steel production; Historical scrap consumption; For China: based on official scrap bottom-up usage data & calibrated with stated scrap policy/target; For other regions: estimated by closing the ferrous loop balance based on reported crude steel production, Pig iron and DRI data, and industrial average ferrous content in crude steel, pig iron, DRI and scrap & yield in steel-making process.

Source: Press search, McKinsey India decarbonisation team

Exhibit 56

## Steelmaking costs across routes.



1. TCO basis: Input prices assumptions: No $CO_2$ price; iron ore (62%) – 110$/t (2030, 2050); scrap price – 336$/t (2030, 2050); coking coal price – 175$/t (2030, 2050); hydrogen – 1.84$/kg (2030), 0.9$/kg (2050); BF-BOF cost increases due to labour inflation and annualising of additional Capex by BF-BOF players for decarbonisation initiatives.
2. Historical cost is based on an average price of the last five years of iron ore and coking coal.
3. Price for 2021.

Source: McKinsey decarbonisation TCO model v14, Metal Bulletin

## The Accelerated scenario

In the Accelerated scenario, $CO_2$ intensity will fall from around 2.0 $tCO_2$/ton CS to 0.5 $tCO_2$/ton CS by 2050, primarily due to the accelerated adoption of green hydrogen-based steelmaking enabled by a carbon price, higher scrap collection rates (Exhibits 57, 58), no further BF-BOF capacity addition after 2030 and closure of older BF-BOF and coal-based DRI capacities in the 2030s.

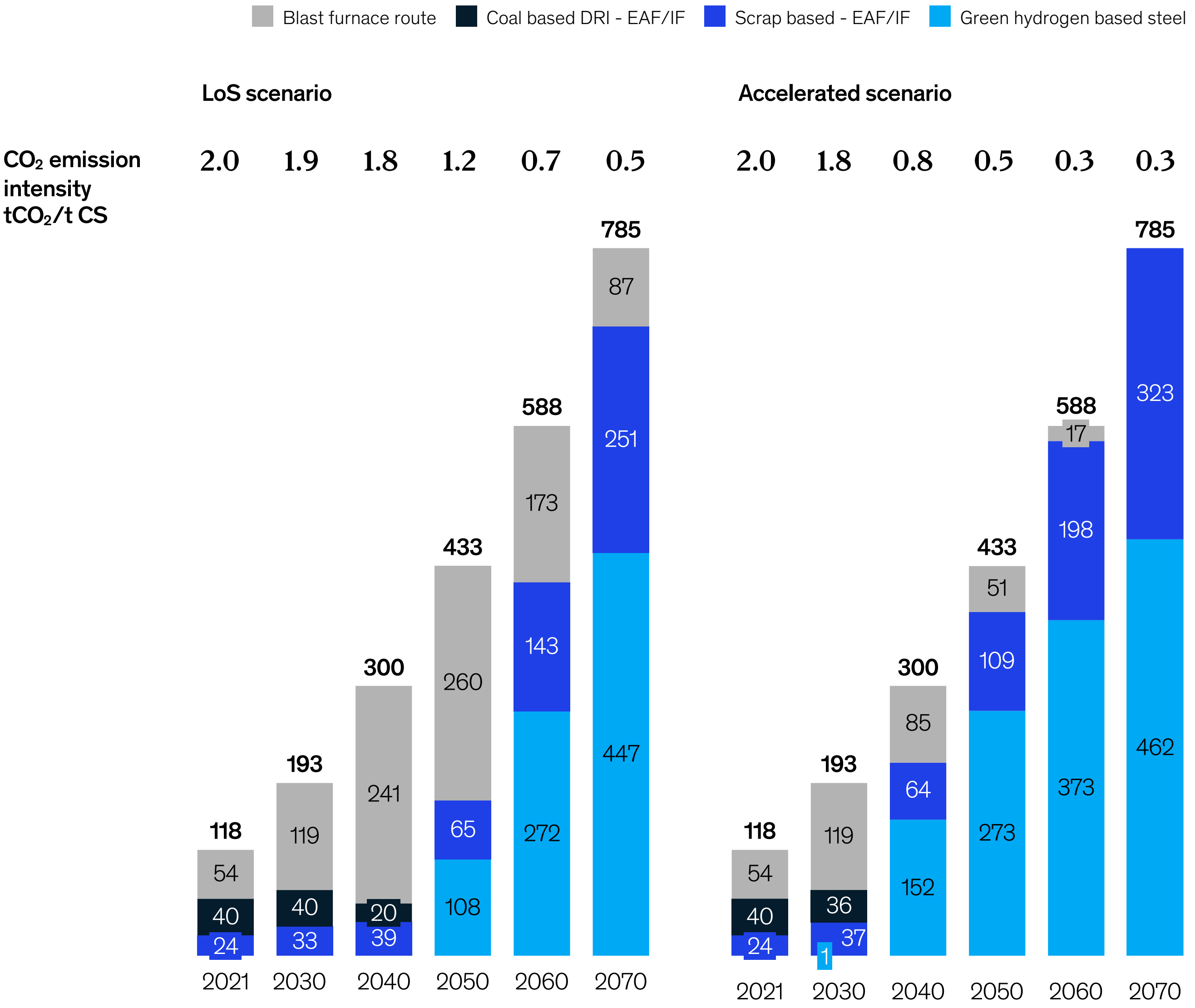
Carbon emissions will likely rise from their current 250 Mt until 2030 and then decline to around 210 Mt per year by 2050, despite a fourfold growth in steel production by 2050. Scrap availability for EAF-scrap in this scenario will increase relative to the LoS scenario, resulting in an additional ~45 Mt of EAF scrap production by 2050 (Exhibit 57).

The introduction of a \$50/t $CO_2$ price on every ton of $CO_2$ emissions would likely lead to green hydrogen-based steelmaking becoming more competitive than the BF-BOF process by 2030 (Exhibits 59, 60). Increases in coking coal prices could also fast-track the transition towards green hydrogen-based steel making.

Exhibit 57

### Crude steel production by route

MMTPA

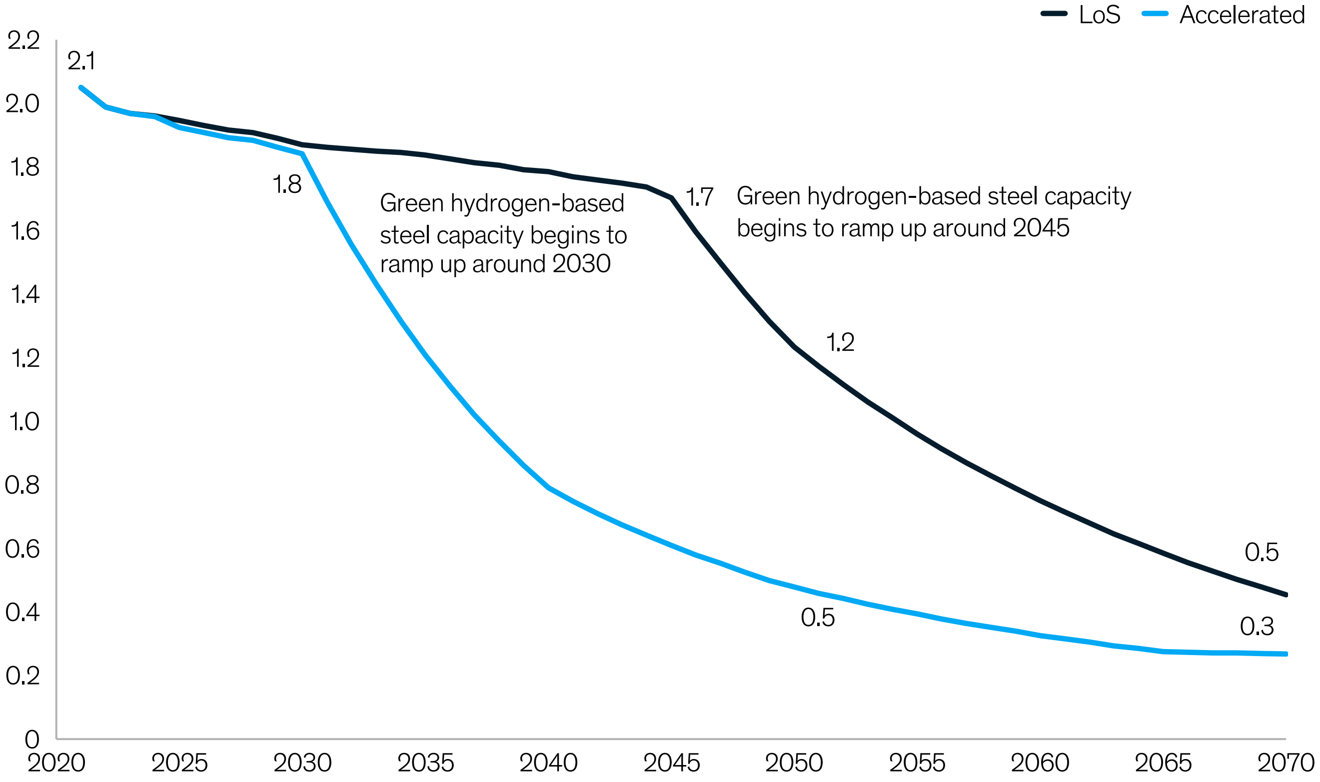


Note: Assumes scrap rate increasing from ~10% currently to 20% in BF-BOF by 2040; Scrap rate in green hydrogen based EAF at 10%; DRI usage in EAF scrap at 10% of total metallic mix.

Source: McKinsey decarbonisation TCO model v14, Metal Bulletin

Exhibit 58

## $CO_2$ emission intensity, $tCO_2$/t crude steel.

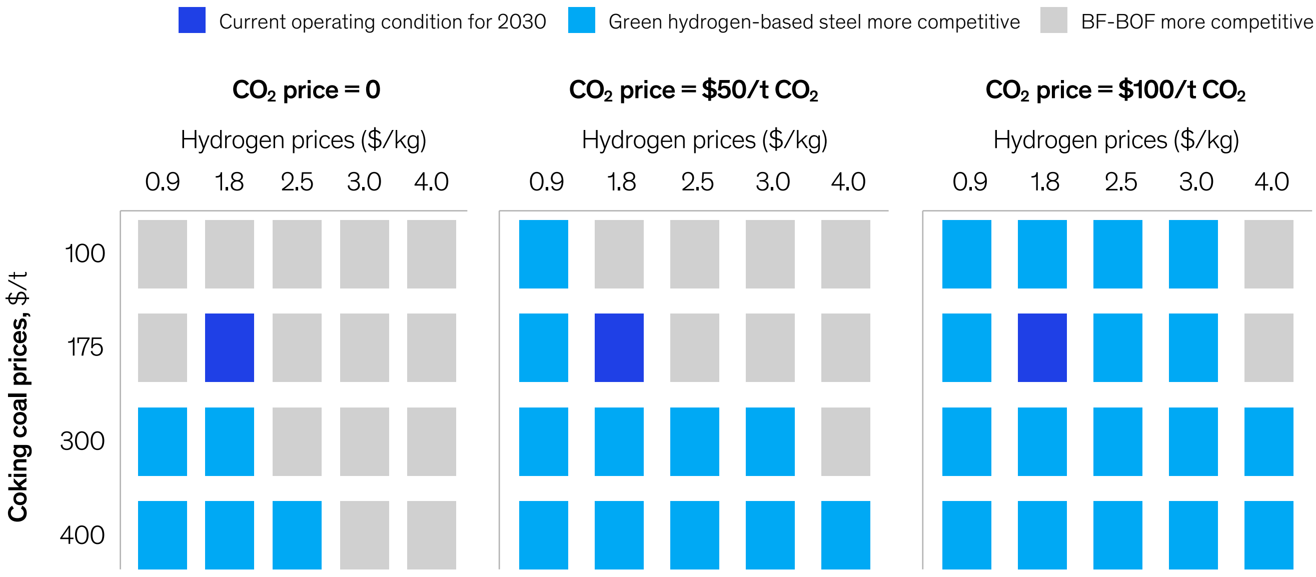


Note: 2021 $CO_2$ Emissions assumptions ($tCO_2$/t cs): BF-BOF – 2.3; Green hydrogen based steel – 0.4; EAF-Scrap – 0.3.

Source: McKinsey decarbonisation TCO model v14, Metal Bulletin

Exhibit 59

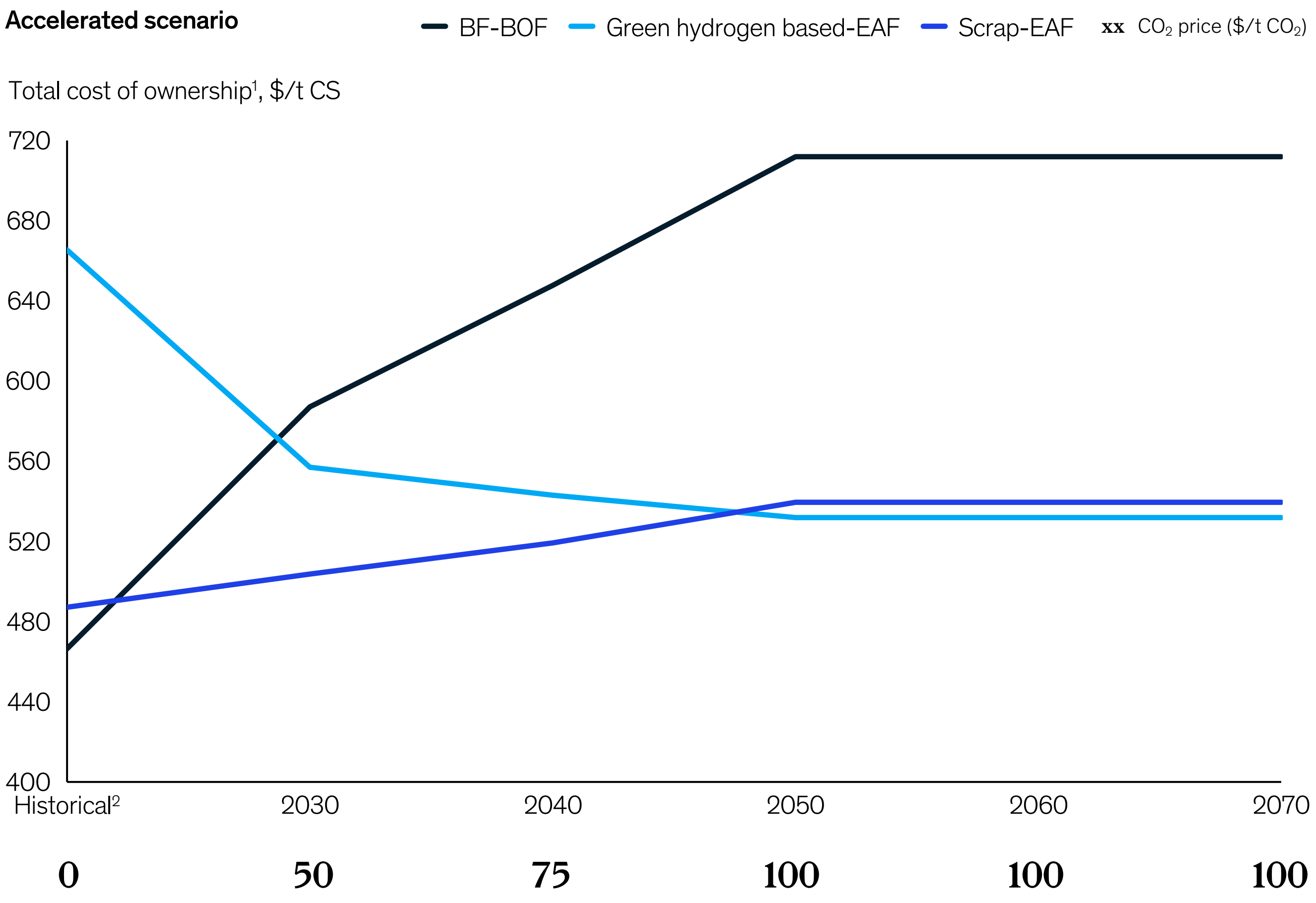
## BF-BOF vs Green hydrogen-based steel's cost competitiveness scenario.



Source: McKinsey decarbonisation TCO model v9, Metal Bulletin

Exhibit 60

## Steelmaking costs across routes.



1. TCO basis: Input prices assumptions: $CO_2$ price – 50$/t$CO_2$ (2030), 100$/t $CO_2$ (2050); Iron ore (62%) – 110$/t (2030, 2050); Scrap price – 346$/t (2030), 392$/t (2050); Coking coal price – 175$/t (2030, 2050); Hydrogen – 1.84$/kg (2030), 0.9$/kg (2050).
2. Historical cost is based on average price of last five years of iron ore and coking coal.

Source: McKinsey decarbonisation TCO model v14, Metal Bulletin

In this scenario, existing BF-BOF plants older than 35 years are assumed to be decommissioned from 2030 onwards, and all coal-based DRI plants are assumed to be decommissioned by 2040, replaced by green hydrogen-based steelmaking and EAF scrap routes (Exhibit 61).

### Implications of the accelerated decarbonisation

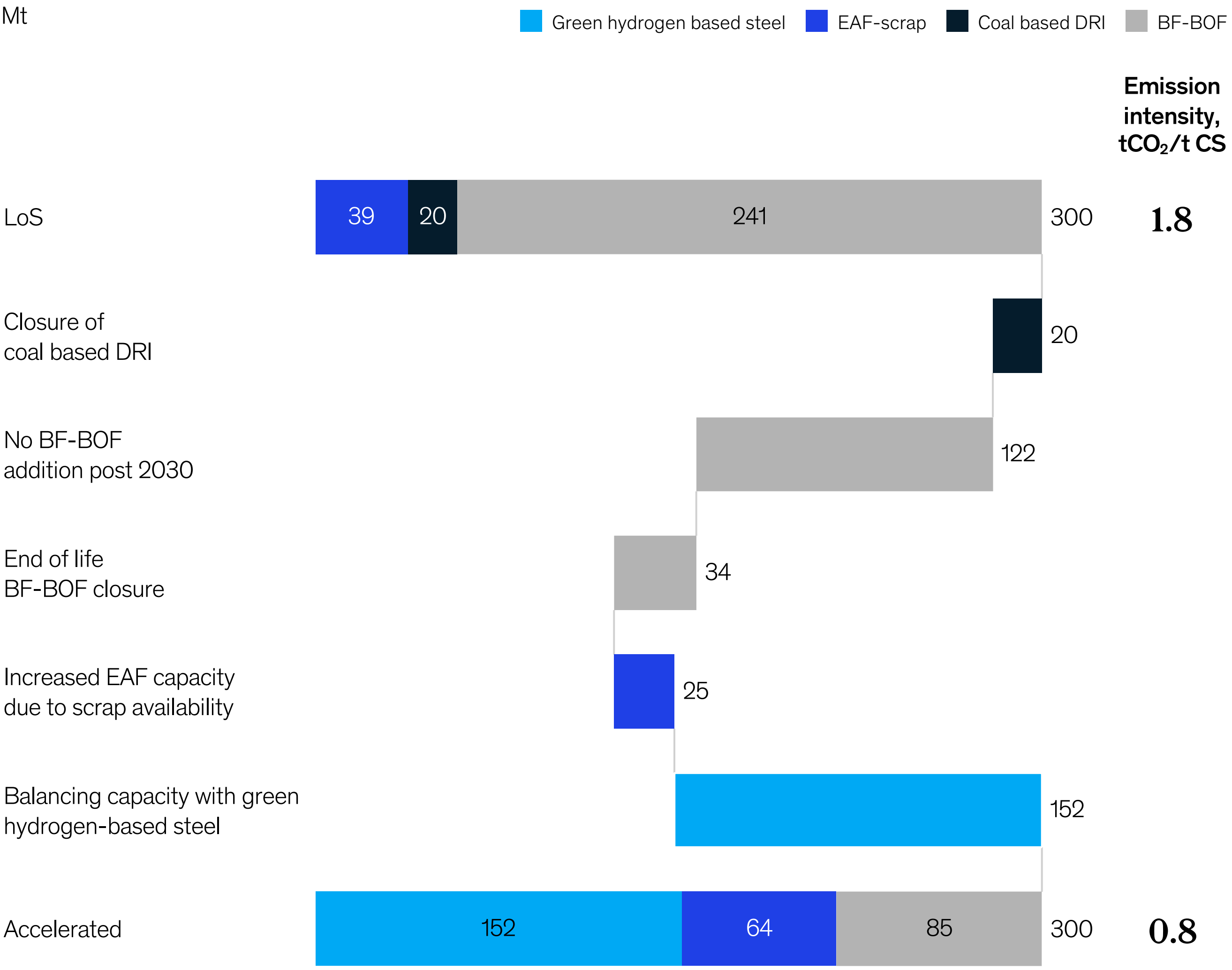
Accelerating decarbonisation in the steel sector could lead to an abatement of around 10 $GtCO_2e$ emissions, which would be half of the cumulative emissions in the LoS scenario between 2030 and 2070 (Exhibit 62).

The Accelerated scenario leads to reduced stranded BF-BOF capacity of about 50 Mt in 2050 compared to about 260 Mt in the LoS scenario. Reduced dependence on BF-BOF based steel production (and hence reduced dependence on coking coal imports) could lead to forex savings of around $500 billion by 2050.

India can also leverage premium-priced green steel demand in jurisdictions like Europe, Japan and Korea to export green pig iron and green steel. As green hydrogen-based steelmaking ramps up from the early 2030s, India can export green pig iron and green steel and generate revenues of $11 billion annually. Domestic availability of green steel will also safeguard indirect steel exports (such as machinery and automotive parts) which could be at risk due to carbon border adjustment tax in multiple regions.

Exhibit 61

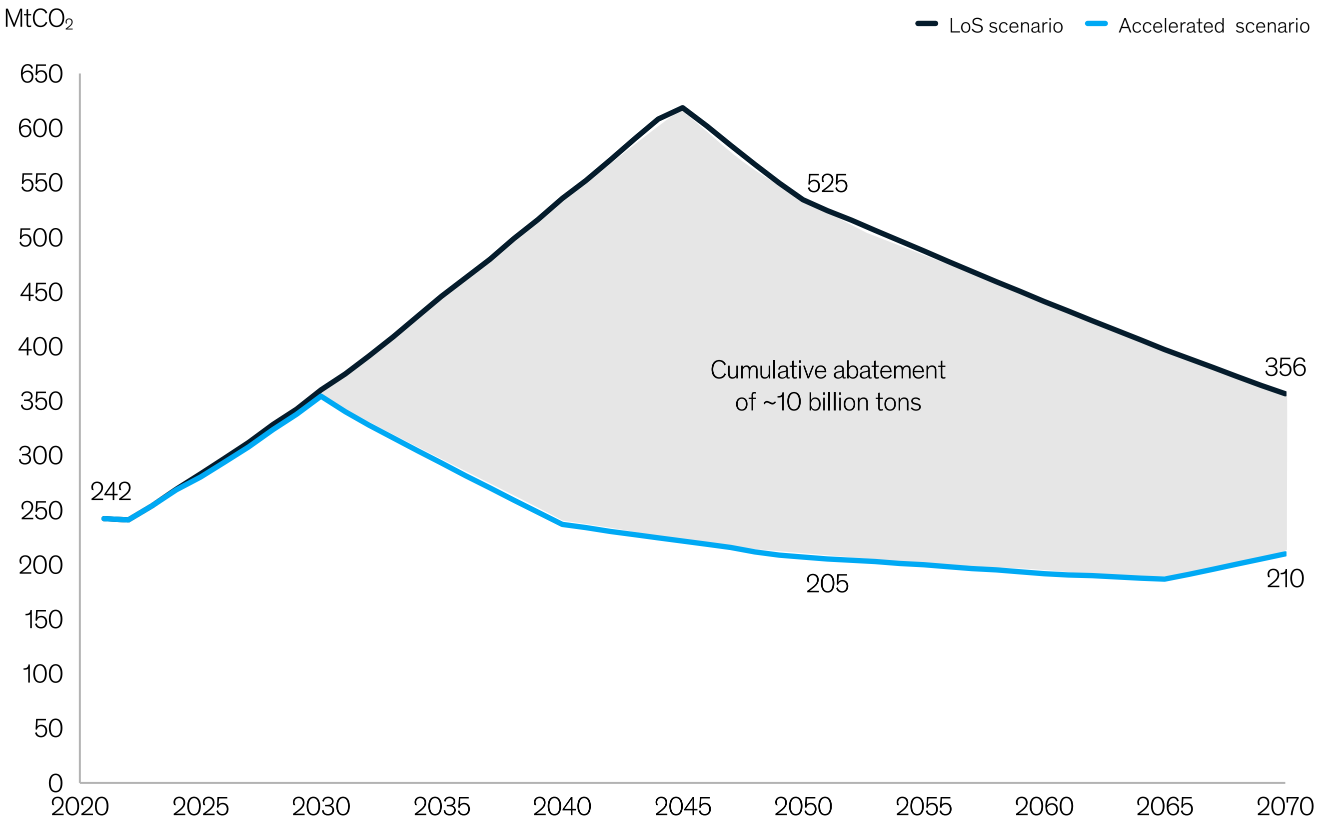
## Technology transition between LoS and Accelerated scenarios by 2040.



Source: McKinsey decarbonisation TCO model v14

Exhibit 62

## Steel industry emissions.



Note: 2021 $CO_2$ Emissions assumptions ($tCO_2$/t cs): BF-BOF – 2.3; Green hydrogen based steel – 0.4; EAF-Scrap – 0.3

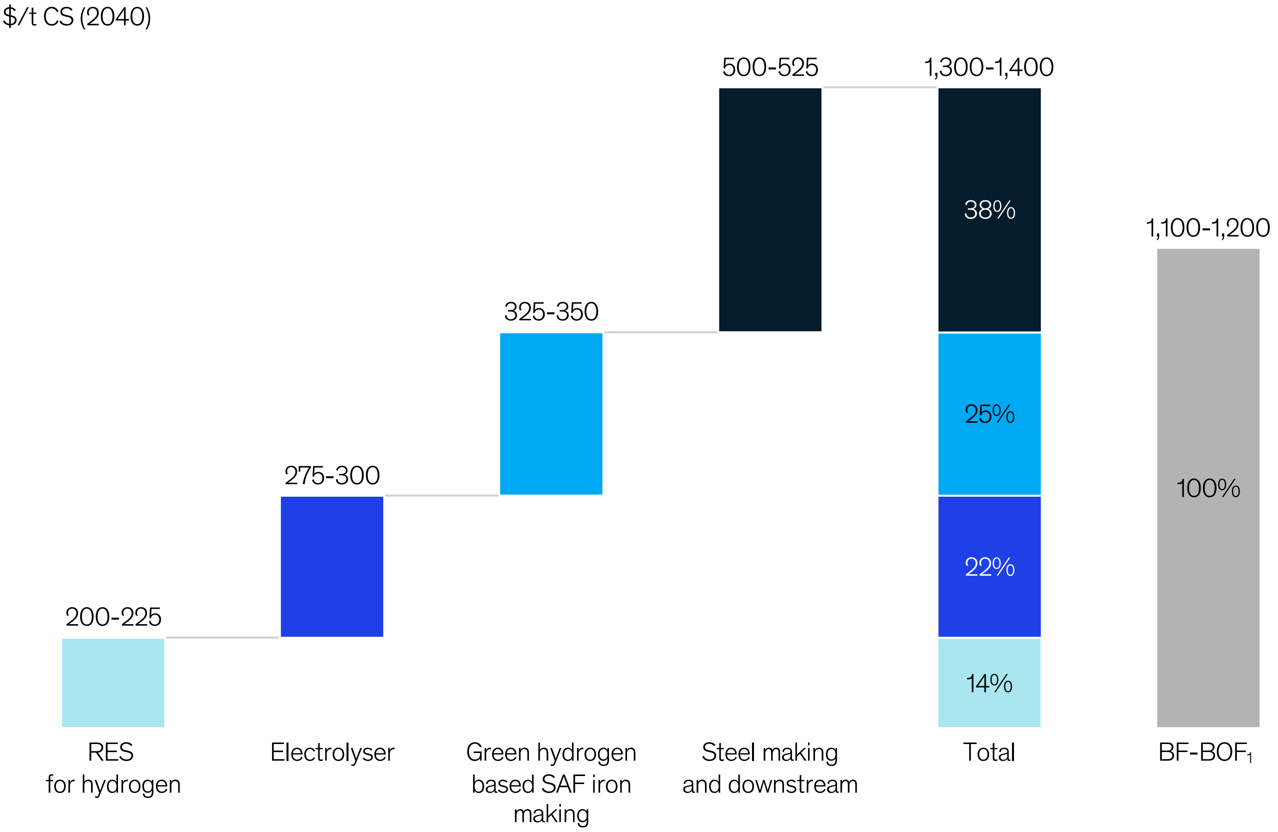
Source: McKinsey decarbonisation TCO model v14

The capital outlay, on an end-to end-basis, would likely increase, even though the steel-making process becomes less capital intensive. This is because of the extra Capex needed for hydrogen and renewable power (Exhibits 63, 64). This Capex is front-loaded in the Accelerated scenario with a much higher Capex than in the LoS scenario in the 2030-2040 period but is subsequently less than the LoS scenario in the 2040–2070 period (Exhibit 65).

The average cost of steel production in the Accelerated scenario is estimated to be higher (by 25 percent in 2040) than in the LoS scenario, driven by the carbon price, higher cost of scrap and the need for more electricity to partially offset the lower met coal needs. This will likely be passed on to consumers, with a small inflationary effect on the downstream sectors (Exhibit 66).

Exhibit 63

## Green hydrogen-based steelmaking Capex, including Capex for electrolyser and RES.



Steel: Green hydrogen based steel in 2040 = 123Mt; Capex = 850$/t CS; 1 t of DRI = ~8.1GJ hydrogen; BF- $1,000/t in 2021 (not including investments in coking coal mining and iron ore mining)

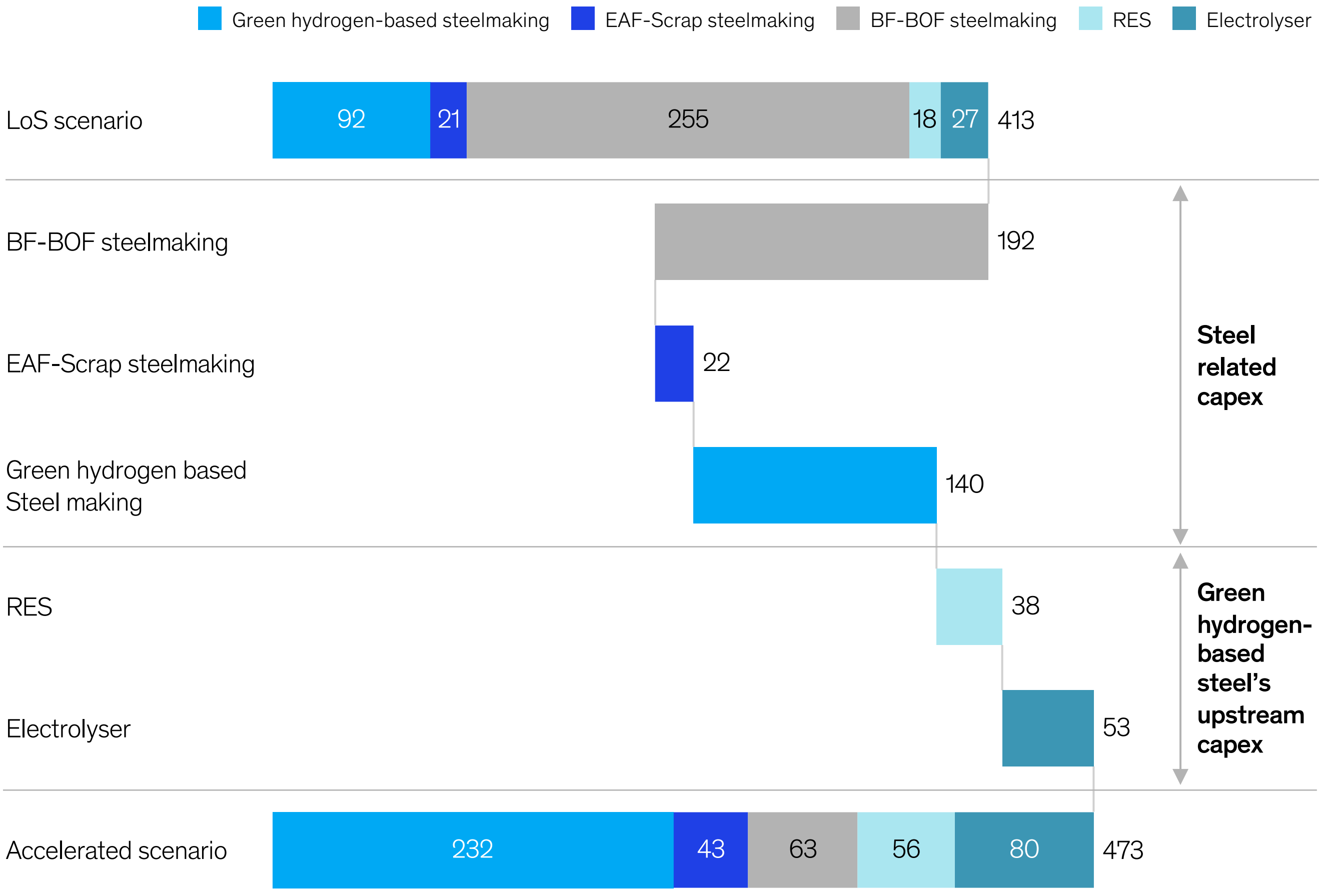
Electrolyser: 1Mt of hydrogen requires 17.95GW electrolyser capacity5; Capex = 267Mn$/GW electrolyser ; Cost of hydrogen produced = 1.45$/Kg
Renewable Energy Source (RES): Capex = 170Mn$/ GW solar electricity4; Solar Tariff = 0.9INR/KWh; AC PLF = 31.80%; Solar Capex = 170$/KW
1. Current capex of BF-BOF on 1000$/t

Source: McKinsey India decarbonisation team, Expert inputs, Literature search

Exhibit 64

## Capex requirement in two scenarios till 2050.

**Through chain capex,** $billion

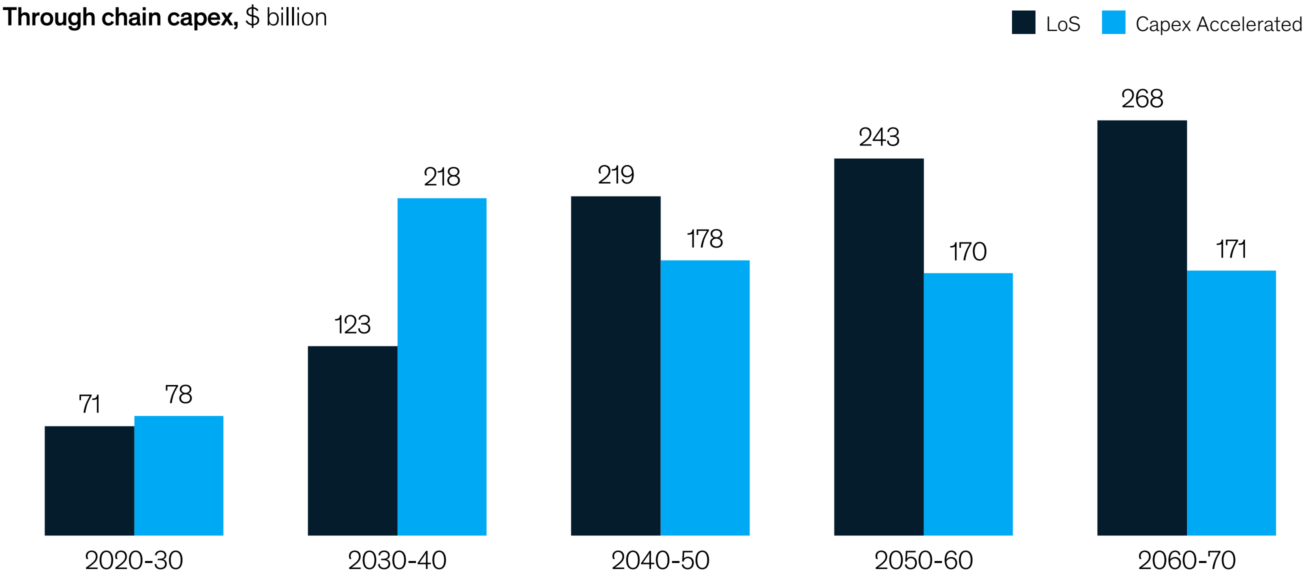


Steel: Capex intensity assumed: BF-BOF – 1000$/t; EAF-scrap – 500$/t; Green hydrogen based steel -850$/t; Capex intensity assumed to remain constant in real terms. BF-BOF capex intensity is estimated to increase by ~150$/t by 2050 as integrated players spend on various decarbonisation initiatives
Electrolyser: 1 t of DRI = ~8.1GJ hydrogen; 1Mt of hydrogen requires 17.95GW electrolyser capacity; Capex = 267Mn$/GW electrolyser ; Cost of hydrogen produced = 1.45$/Kg; Renewable Energy Source (RES): Capex = 170Mn$/ GW solar electricity; Solar Tariff = 0.9INR/KWh; AC PLF = 31.80%; Solar Capex = 170$/KW

Source: McKinsey India decarbonisation team, Expert inputs, Literature search

Exhibit 65

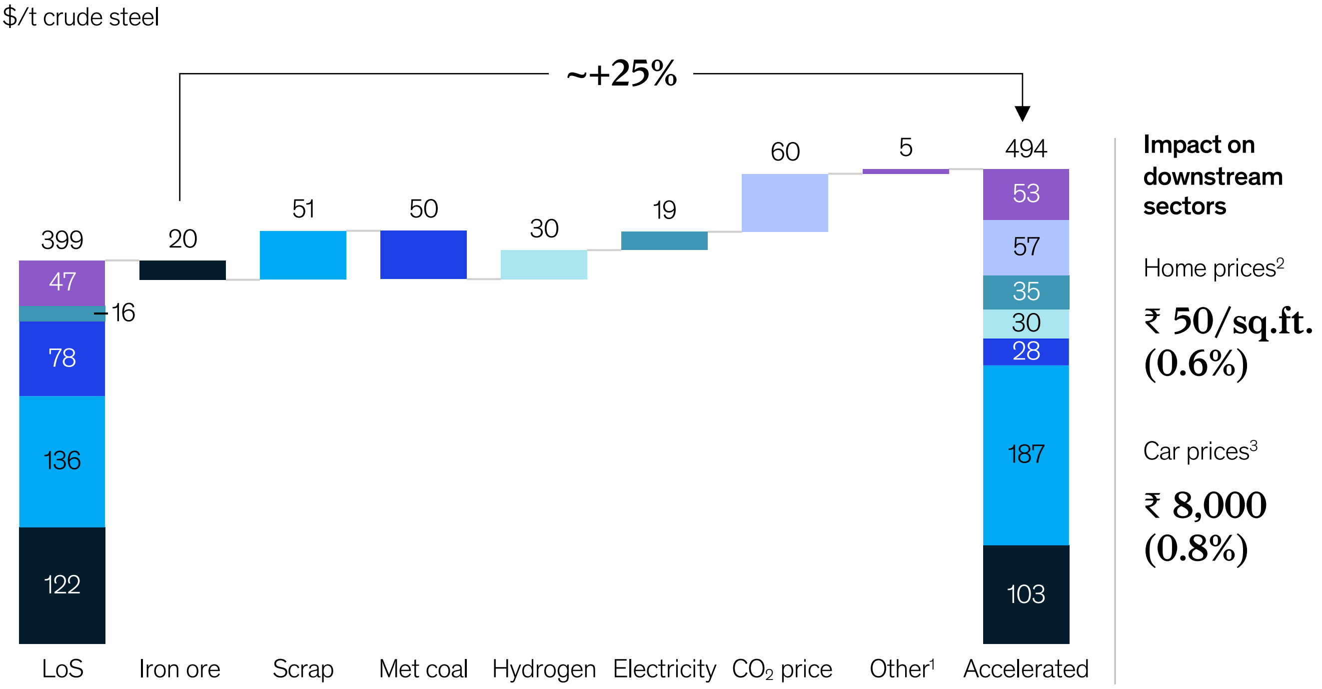
## Capex comparison – LoS vs Accelerated.



Source: McKinsey decarbonisation TCO model v14

Exhibit 66

## Steel industry cost of steelmaking in LoS and Accelerated scenarios in 2040.



1. Other includes costs such as labour, operations and maintenance, fluxes, natural gas and credits from internal gases
2. For a 1400 sq. ft. house in a metro at ~INR8,000/-per sq. ft.
3. For a mid-size sedan costing ~INR10Lacs.

Source: McKinsey decarbonisation TCO model v14

## Proposed enablers for steel decarbonisation

As mentioned earlier, a few enablers could be considered to accelerate the transition towards net zero:

1. **Introducing $CO_2$ pricing through compliance carbon markets:** The introduction of $CO_2$ pricing can be calibrated to incentivise low-carbon technologies, initially at a small scale, to give the domestic industry time to adjust. Carbon border adjustment mechanisms would also need to be considered in parallel for equitable treatment of the Indian steel industry.
2. **Mandating green steel consumption in the end-use sectors:** The government could mandate the use of green steel in setting targets for embodied carbon in public and private construction, as well as for automotive uses.
3. **Implementing policies for material efficiency and circular economy:** Policies which incentivise scrap collection and recycling, which discourage landfills and set up dismantling, collection and scrap-processing centres would need to be put in place.
4. **Accelerating low carbon technology adoption in steel:** Steelmaking technologies for hydrogen use with Indian raw materials, such as green hydrogen-based SAF-BOF, are still in the nascent stages of development globally. To start production of green hydrogen-based steel by 2030 in India, steel players would need clarity on $CO_2$ pricing in the next few years. They would also need to make required investments in research and development of this technology, ensure availability of cheap green electricity and hydrogen and collaborate with global partners on technology knowhow and sourcing of equipment.

# 2.6 Agriculture sector

## Key takeaways

**The agricultural sector accounts for nearly 20 percent (585 $MtCO_2e$) of India's emissions.**[127] It is a challenging sector for carbon abatement since it would involve engaging with 150 million farmers, over 95 percent of whom are small-hold farmers (own less than five hectares of land).

**In the LoS scenario,** emissions from agriculture are estimated to increase to 650 $MtCO_2e$ by 2030 and then gradually decline to 530 $MtCO_2e$ by 2070 driven primarily by improvements in fertiliser and energy use (largely reducing nitrate fertiliser use and intensifying rice cultivation). This is despite the expected tripling of the agricultural GDP and output by 2070.

**In the Accelerated scenario,** faster decarbonisation would likely reduce emissions to 315 $MtCO_2e$ by 2070, leading to a total abatement of 9 $GtCO_2e$. Nearly 60 percent of the abatement relative to the LoS scenario would be driven by sustainable rice cultivation, practising dry seeding and alternate wetting and drying (AWD) methods, further reducing nitrate fertilisers and shifting toward sustainable consumer alternatives, i.e., plant-based protein and millets.

**The remaining emissions in 2070 would be hard to abate, with a partial offset through carbon** removals from agroforestry and regenerative agricultural practices such as low soil tillage. India's croplands currently capture or sequester 267 $MtCO_2e$ annually. With accelerated adoption of regenerative practices, this could increase to over 370 $MtCO_2e$ annually by 2070, leading to net negative agricultural emissions.

**Sustainable agriculture has an economic upside for the farmer.** In the LoS scenario, sustainable farming could generate additional earnings of roughly INR 3,400/ha/year for farmers in the form of ancillary incomes from carbon credits, agroforestry and improved productivity by 2070. This could increase to INR 4,800/ha/year within the Accelerated scenario, presenting an additional revenue generation opportunity of $145 billion for Indian agriculture by 2070.

**Switching to GHG-efficient farming would require extensive education, access and incentives** given the inherent complexities of Indian agriculture. Setting up carbon markets for farmers could be a crucial enabler for encouraging uptake and realising benefits. Consumer behaviour will also need to change to more sustainable food alternatives — education campaigns could help promote sustainable consumer alternatives.

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[127] FAO

## The agriculture sector today

Agriculture is the bedrock of the Indian economy; it contributes 14 percent of the country's total GDP and provides over 40 percent of its employment.[128] It is vulnerable to climate change, as 60 percent of agricultural land in India is highly dependent on rainfall.[129] By 2100, $9–10 billion in annual losses are anticipated due to climate change, with major crops expected to see a 10–30 percent decrease in yield.[130]

A green transition is important but difficult. This section explores the features of the agricultural sector, outlines two possible ways forward for decarbonisation and suggests four big ideas to speed up the journey.

## A uniquely challenging sector

Agriculture is one of the highest GHG-emitting sectors in India.[131] Annual emissions of about 585 $MtCO_2e$ from agriculture account for nearly 20 percent of the country's overall GHG emissions (Exhibit 67).[132] Rice and livestock alone are responsible for 70 percent of these emissions.[133]

Unlike in other sectors, methane constitutes a large share of GHG emissions from agriculture, with over 70 percent of India's total methane emissions being driven by enteric fermentation in livestock and the standing water from rice cultivation. India is the second-largest rice producer in the world, and more than 80 percent of its rice fields practise continuous flooding.[130] Additionally, India is second only to China in terms of the over-application of nitrogen-based fertilisers at over 110kg/ha/year, more than double the European Union average of 52kg/ha/year.[134]

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[128] World Bank; International Labour Organisation.

[129] FAOSTAT.

[130] ICAR; USDA.

[131] FAOSTAT.

[132] Baseline emissions were calculated bottom-up based on agricultural activity levels in 2019 and corresponding emission intensities as estimated by the Food and Agricultural Organisation (FAO).

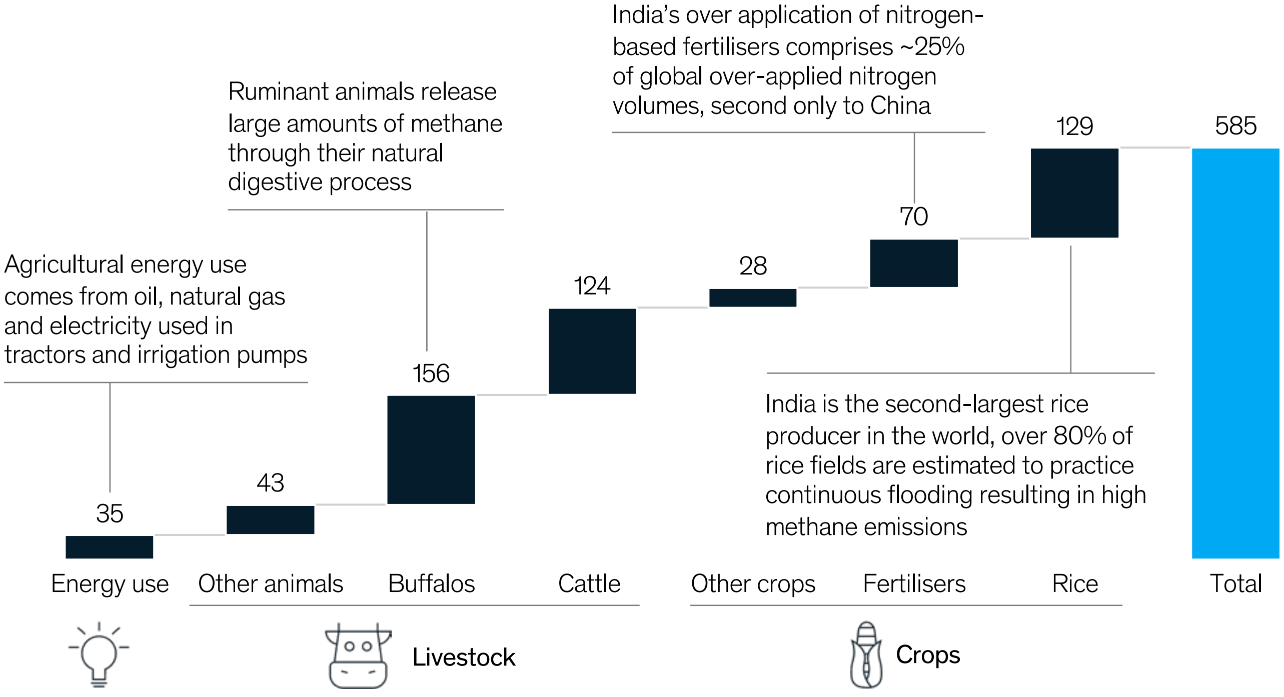
[133] World Bank.

[134] McKinsey analysis on data from FAOSTAT.

Exhibit 67

## Agriculture is one of the largest emitters of GHG in India.

**GHG emissions from agriculture in 2019 by category**
$MtCO_2e$



1. Includes goats, sheep and swine.

Source: Food and Agricultural Organisation; UNFCCC; McKinsey India Decarbonisation Model

Food demand is expected to increase by two or three percent per annum until 2070, with rice production expected to increase from around 170 Mt in 2020 to 320 Mt by 2050 and 360 Mt by 2070, and meat production expected to grow from 3 to 7 Mt by 2070, with exports continuing to drive production.[135] In the absence of abatement efforts, this ongoing demand would lead to a continued increase in emissions.

Unlike in the industrial sectors, abating emissions from agriculture would entail working with highly decentralised and fragmented production and regulations. The transformation would involve engaging with about 150 million farmers, over 95 percent of whom are small-hold farmers (owning less than five hectares of land). About a quarter of these farmers live below the poverty line.[136]

Despite these unique challenges, decarbonising the agriculture sector is possible. As we have done for other sectors, we examined two scenarios for how Indian agriculture could decarbonise: 1) an LoS scenario that aims to decarbonise by 2070 and 2) an Accelerated decarbonisation scenario that sets the decarbonisation target 20 years earlier to 2050.[137]

## The LoS scenario

With projected demand growth, current farmer and government actions in agricultural sustainability, total agricultural emissions in India are estimated to increase from 585 $MtCO_2e$ in 2019 to 650 $MtCO_2e$ by 2030 and then gradually decline to around 530 $MtCO_2$ by 2070. If current levels of carbon sequestration from croplands continue, net emissions from agriculture will likely be 258 $MtCO_2e$ by 2070 (Exhibit 68).

In this scenario, current efforts by the state towards sustainable production are assumed to continue at a steady pace. Promoting nano-fertilisers and bio-decomposers would eliminate nitrate overapplication by 2070. The practice of burning rice straws would be eliminated by 2070, but at a slow and uneven pace. The electrification of farm tractors and irrigation equipment would begin post-2030, with 60–65 percent adoption by 2070. This follows trends in the transportation sector, particularly relating to medium- and heavy-duty trucks. Food waste is anticipated to fall to 20 percent from the current levels of 30–40 percent.

Despite these positive developments, livestock rearing is expected to remain non-intensive, with minimal (10–20 percent) adoption of efficient feeding and manure management practices by 2070.

Croplands also sequester or remove carbon from the atmosphere with the application of manure or crop residues, as well as plantations and trees on croplands. Currently, India's croplands sequester 267 $MtCO_2e$/year.[138] In an LoS scenario, this is expected to remain at similar levels, reaching 274 $MtCO_2e$/year by 2070.[139] While incorporation of more sustainable practices like nano-fertilisers and bio-decomposers may increase sequestration, continued cultivation could minimise the sequestration effect in the LoS scenario.

## The Accelerated scenario

By our estimates, agricultural emissions in the Accelerated scenario could be reduced to 322 $MtCO_2e$ by 2050 (45–50 percent lower than the LoS scenario), leading to a cumulative abatement of 9 $GtCO_2e$ by 2070. With improved sequestration, net emissions from agriculture could be net negative by 2050, reaching almost –50 $MtCO_2e$ (Exhibit 68).

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[135] Outlook based on FAO; production estimated to follow population and GDP growth.

[136] National statistical offices survey.

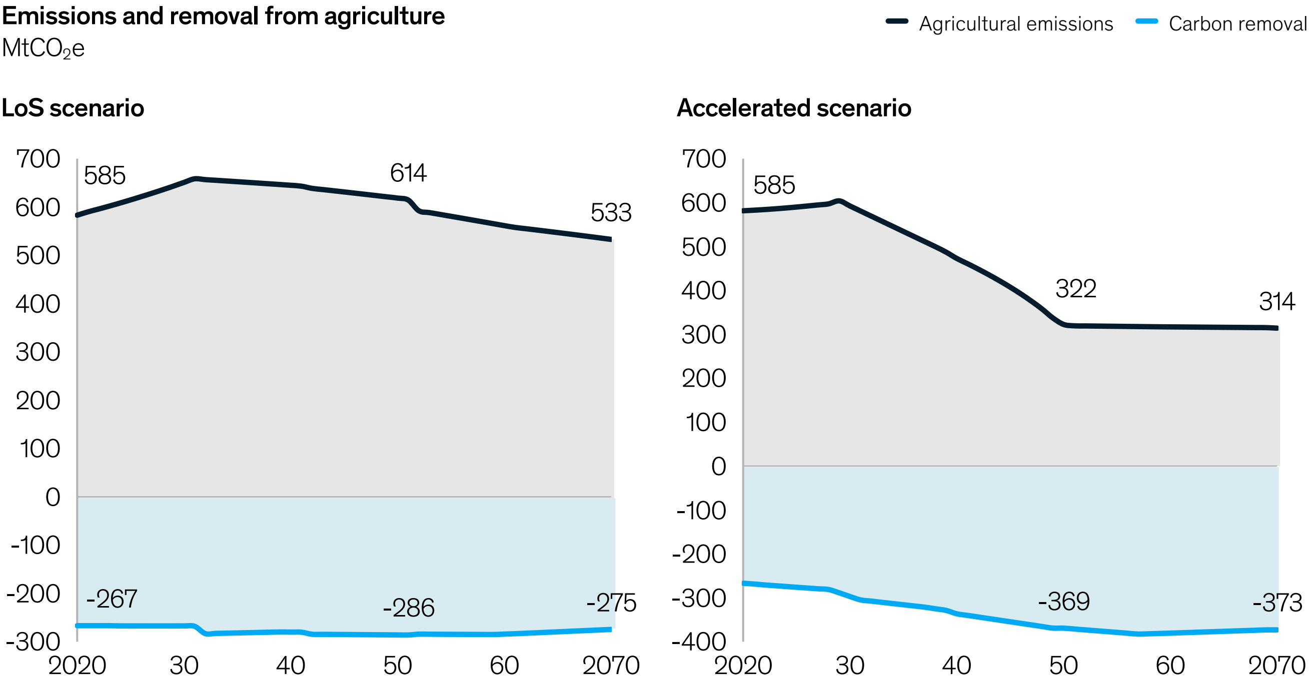
[137] The emissions trajectory is based on continued GDP and population growth. Emission intensity is estimated to reduce post-2030 with expanding policies to reduce nitrate fertilisers and drive yield improvements and electrification.

[138] UNFCCC.

[139] Current sequestration figures are retrieved from India's submission to UNFCCC and are mainly driven by Soil Organic Carbon (SOC). This is expected to decrease with inaction. In the LoS scenario, regenerative farming practices continue at current rates and thereby maintain current SOC levels.

Exhibit 68

## Improved sequestration could lead to net-negative emissions from agriculture by 2050.



Source: McKinsey India Decarbonisation Model; McKinsey Nature Analytics

Modernisation of rice production and electrification alone could account for nearly 40 percent of the emission abatement in the Accelerated scenario (Exhibit 69). Total electrification of tractors and irrigation pumps could abate all emissions from agricultural energy use. The cost savings from fuel and the declining expenditure on EVs could offset the costs.

Introducing slow-release fertiliser forms and nitrification inhibitors would reduce fertiliser-induced field emissions and fertiliser consumption, subsequently reducing emissions from production and transportation.

Still water in rice fields leads to methane release and additional fertiliser use. A shift to AWD fields, dry seeding and straw management could reduce these emissions and simultaneously lower costs. Improving feed digestibility, boosting additives to ruminant diets and managing manure would also reduce methane emissions from livestock.

The Accelerated scenario could see half of all rice cultivation taking place with efficient straw and water management practices, i.e., dry direct seeding and AWD. Straw burning could be completely eradicated by 2050, with residues used as biomass or organic fertiliser.

Nearly half of all livestock rearing could be improved with the implementation of efficient feeding practices, i.e., feed-mix optimisation and grain processing. Efforts toward efficient fertiliser use could be accelerated with nitrate over-application being eliminated by 2030. The Accelerated scenario could also see farmers being incentivised to use electric tractors and farm equipment, leading to complete farm equipment electrification between 2030 and 2050.

Arising from a combination of policies and consumer preferences, this scenario could also see a demand shift toward GHG-efficient diets. Less water-intensive crops like millets could replace 30–40 percent of rice consumption by 2050,[140] driven by a combination of consumer health preferences and government actions to promote alternatives. Meat consumption could decline by 30 percent due to increasing shifts toward alternative proteins. The food-waste ratio could also decline to five or ten percent from its current levels with improved supply-chain management.

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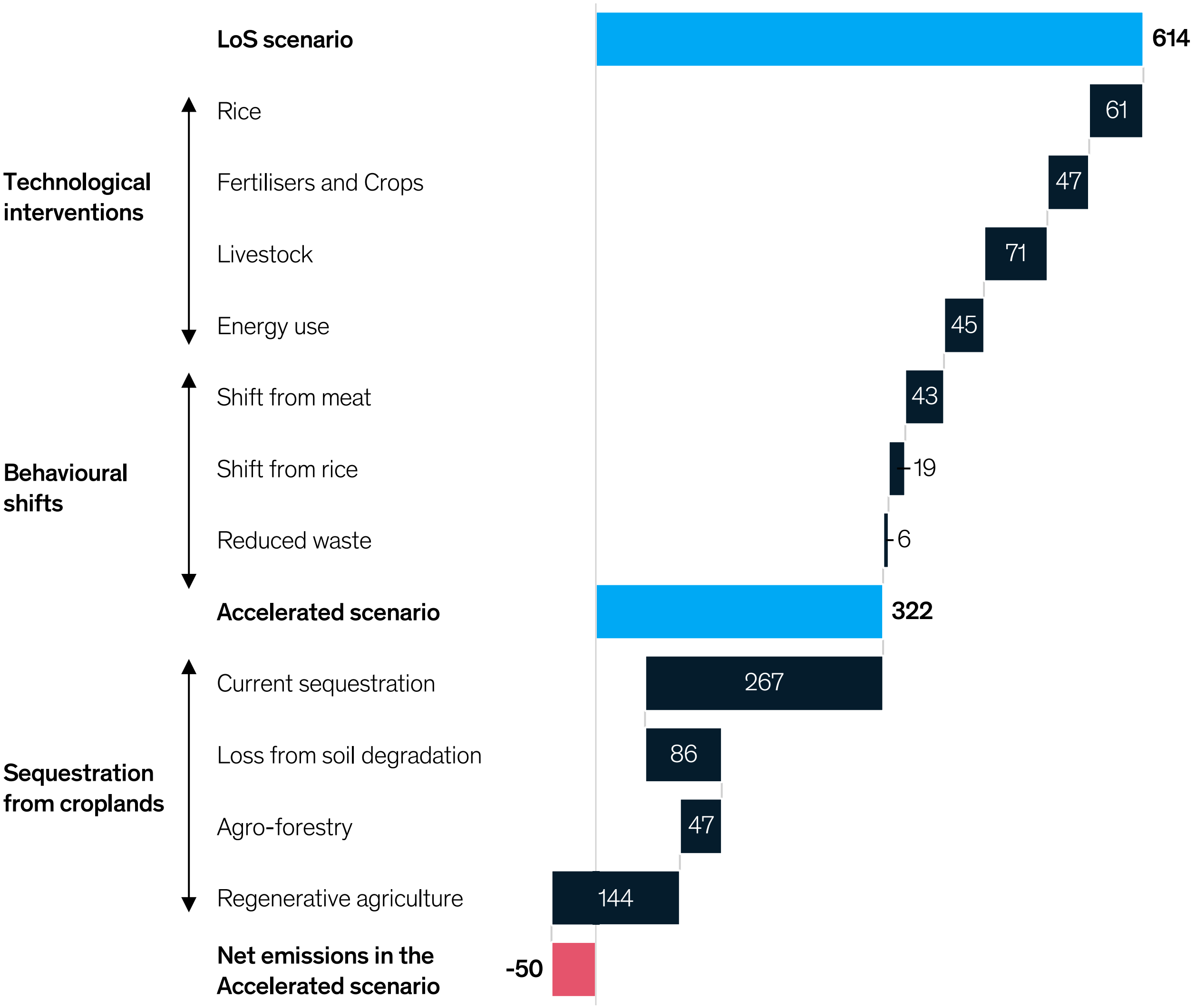
[140] C-Step

Exhibit 69

## Technological interventions alone contribute to over 75 percent of agricultural emissions abatement.

**Annual GHG emissions in 2050**[1]
$MtCO_2e$



1. The efficacy and adoption rates of the different levers are derived from various academic sources. Please refer to the technical appendix for more details.

Source: McKinsey India Decarbonisation Model

Given the structural challenges and technological limitations it faces, agriculture is estimated to emit 320 $MtCO_2e$ in 2070, despite accelerated decarbonisation. Three-quarters of these emissions would be in the form of methane from livestock,[141] whose abatement is incumbent on next-horizon technologies, i.e., direct methane capture, inhibition of enteric fermentation through vaccines or special additives and more viable forms of alternative proteins.

With current technologies, attaining net-zero emissions would require natural carbon offsets from croplands. With accelerated adoption of regenerative practices and plantations, India's croplands could sequester nearly 370 $MtCO_2e$/year by 2050, offsetting residual emissions.[142] Practicing low-tillage farming and planting trees on croplands and pasturelands alone can help sequester an additional 100 $MtCO_2e$ annually by 2050 (Exhibit 70).

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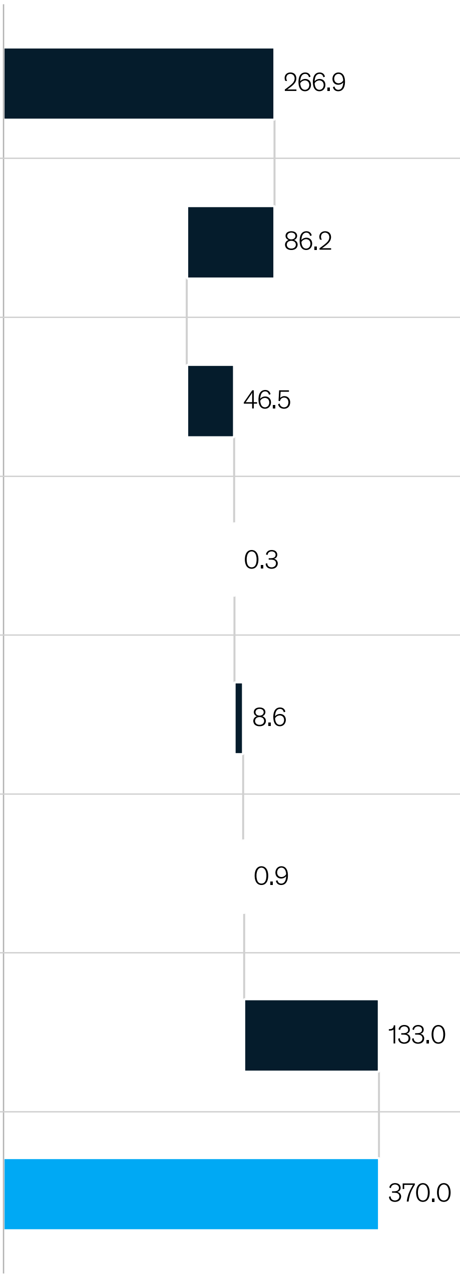
[141] World Bank

[142] Biophysical and economically feasible potential as estimated by McKinsey Nature Analytics using an NCS-specific geospatial modelling effort.

Exhibit 70

## India’s croplands could sequester nearly 370 $MtCO_2e$/year by 2050 to offset the residual emissions from agriculture.

**Carbon sequestration potential of croplands by lever**



| **Potential actions** | | **Description** | **Additional sequestration potential,** $MtCO_2e$ | **Required adoption,** million hectares |
|---|---|---|---|---|
| **Current sequestration from croplands**[1] | | Carbon absorption by agricultural soils and tree plantations in croplands | 266.9 | |
| **Loss from soil/croplands** | | Soil stock of carbon is expected to decline with increased cultivation | 86.2 | |
| **Agroforestry** | | Planting trees on croplands and pasturelands to provide shelter | 46.5 | 158.5 |
| Regenerative agriculture | **Cover crops** | Soil $CO_2$ sequestration by sowing cover crops outside the growing season | 0.3 | 0.3 |
| | **Legumes on grazing lands** | Additional soil $CO_2$ sequestration by sowing legumes that fix carbon | 8.6 | 7.2 |
| | **Optimising grazing land intensity** | Avoided $CO_2$ emissions by reducing grazing intensity | 0.9 | 3.5 |
| | **No or low tillage** | Shallow cultivation or fewer tillage operations to reduce topsoil disturbance | 133.0 | 102.6 |
| | | **2050 potential with accelerated action** | 370.0 | |

[1] As estimated by UNFCCC.

Source: UNFCCC; McKinsey Nature Analytics

## Proposed investments and implications

In an LoS scenario, implementing green interventions in agriculture may require total Capex spending of nearly $240 billion by 2070. Accelerating the transition by 2050 would likely require an additional spend of $240 billion over LoS (Exhibit 71).[143]

Significantly, nearly half the proposed green interventions could be carried out at net-negative lifecycle costs (Exhibit 72). Sustainable agriculture could also open up avenues for premium pricing, creating further economic gains.

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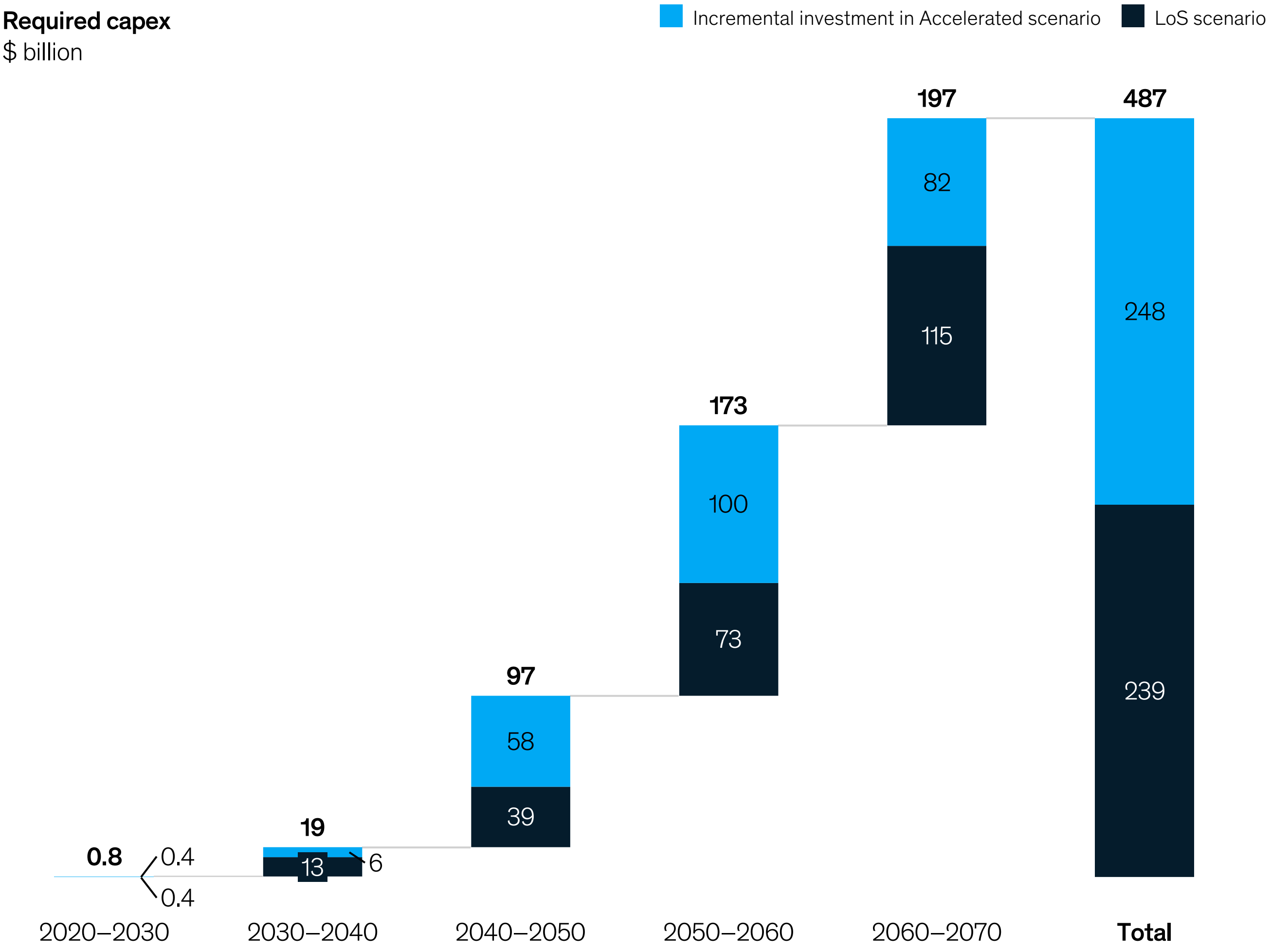
[143] Includes only the cost of decarbonisation levers as modelled in the scenarios, based on McKinsey's global agriculture lever library; please refer to the technical appendix for details.

Exhibit 71

### Accelerating decarbonisation would require an additional spend of over $240 billion.

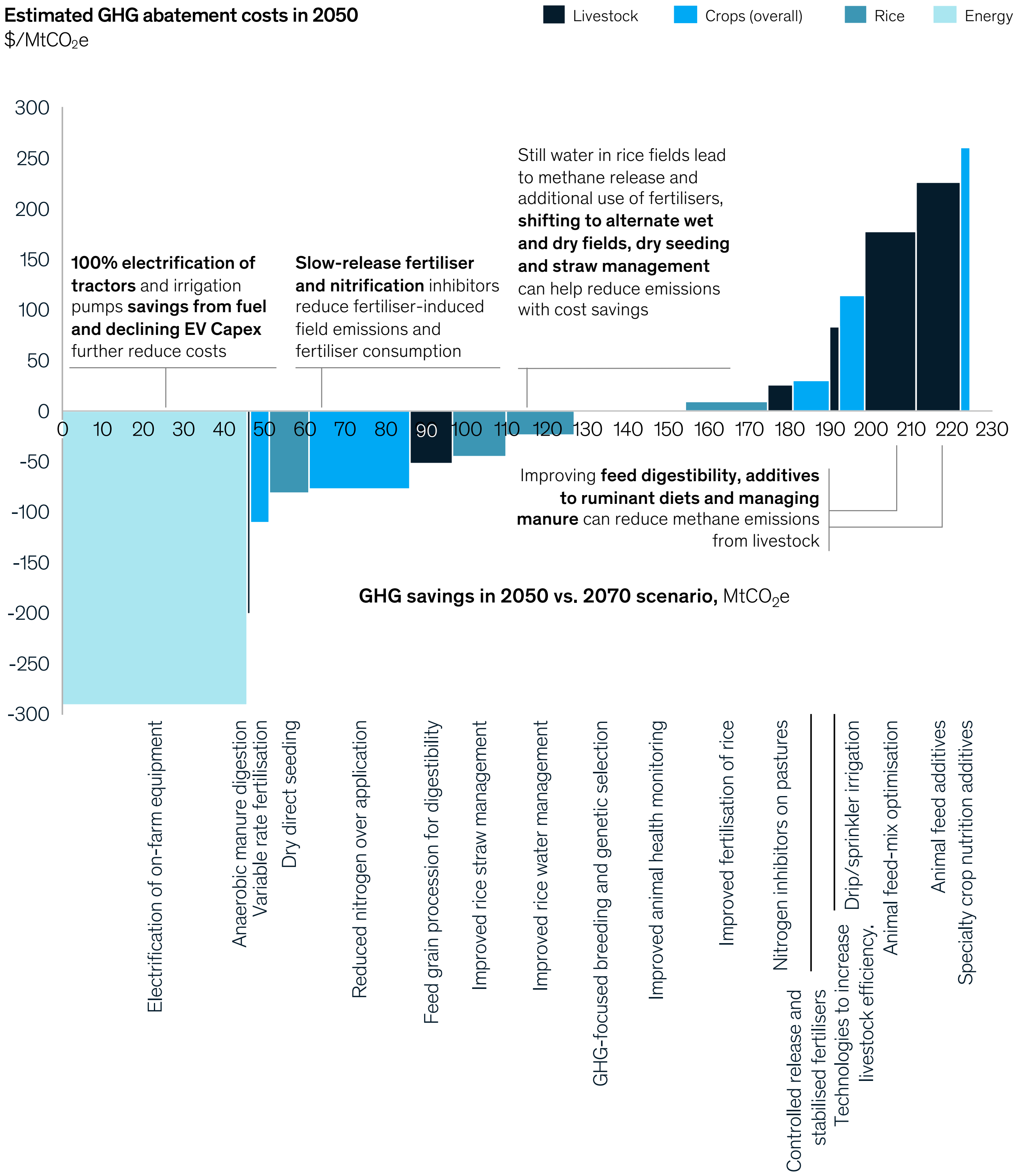


1. India's agriculture, forestry and fishing sector had Gross Value Added (GVA) of $473.6 billion in 2019, at current prices ($), as estimated by World Bank.
2. Only includes capex required for green levers; does not include overall production capex involved in agriculture.

Source: McKinsey India Decarbonisation Model

Exhibit 72

## Around half of the proposed green interventions could be carried out at net-negative lifecycle costs.



**Estimated GHG abatement costs in 2050**
$/MtCO$_2$e

**100% electrification of tractors** and irrigation pumps **savings from fuel and declining EV Capex** further reduce costs

**Slow-release fertiliser and nitrification** inhibitors reduce fertiliser-induced field emissions and fertiliser consumption

Still water in rice fields lead to methane release and additional use of fertilisers, **shifting to alternate wet and dry fields, dry seeding and straw management** can help reduce emissions with cost savings

Improving **feed digestibility, additives to ruminant diets and managing manure** can reduce methane emissions from livestock

Source: McKinsey India Decarbonisation Model

## Acceleration has considerable benefits

Accelerated decarbonisation could abate an additional 9 $GtCO_2e$ by 2070 (a quarter of global $CO_2$ emissions in 2019), compared to the LoS scenario, and lead to additional earnings worth $145 billion by 2070 (Exhibit 73).

In the LoS scenario, sustainable farming could generate additional earnings of roughly INR 3,400/ha/year in the form of cost savings from improved productivity and ancillary incomes from carbon credits and agroforestry. This could increase to INR 4,800/ha/year with acceleration—roughly eight to ten percent of the current average income of a farming household.[144] Excluding expenses incurred on adopting sustainable farming practices, gross revenues in an accelerated scenario could be over INR 8,000/ha/year.

Nearly all additional operating expenses involved in practicing sustainable farming could be offset by cost savings between 2020–2070.

Agroforestry and recycling crop residues rather than burning them could also create incremental earnings of $150 billion (2020–2070) in the form of carbon credits and the sale of by-products and residues.[145] Implementing a carbon-credit system in India would require overcoming the challenges of smallholder farming, i.e., the lack of support in planning and the need for credible accounting. Digitisation and creating farmer collectives that integrate multiple farmers and their sites could help address some of these challenges.

In addition to socioeconomic benefits, sustainable agriculture has several environmental benefits. It can help improve soil nutrients and sustainability, reduce water consumption and improve air quality (e.g., by mitigating pollution from straw burning). An improved yield from sustainable farming can also free up an additional five to six million hectares of land compared to the LoS scenario, which can help address land availability challenges.[146]

## Proposed enablers for agriculture decarbonisation

Targeted regulatory and policy interventions could be considered for abatement in the agriculture sector. Four moves could contribute to an accelerated transition by 2050:

1. **Incentivising GHG-efficient practices and technologies.** A green transition in agriculture is limited not only by capital but also by the challenge of fragmentation. India's farmers are widely dispersed and practise non-intensive farming, and there is often a lack of awareness about the practices and benefits of sustainable farming. A switch in farming techniques would, therefore, require support in the form of education, access to new methods and incentives.

   Education can be crucial in creating awareness of the downsides of conventional practices, for example, the deterioration of soil health caused by excessive fertiliser use. It can also highlight the benefits of sustainable farming. For instance, reducing the continuous flooding of rice fields could result in the use of 40 percent less water and reduce cultivation costs by at least 20 percent.[147] Since 85 percent of rural women in India are engaged in agriculture, their education is crucial.[148] Decarbonisation could improve the livelihoods and incomes of these women through increased savings from sustainable farming practices.

   Access to equipment and local dispensaries is a necessity for farmers trying to practice dry seeding and better livestock rearing. A lack of veterinary hospitals, for instance, has a huge impact on livestock health and productivity. Equipment for dry seeding and residue collection can also be made available for custom hiring across the country.

   Incentives can play an important role in encouraging the initial uptake of GHG-efficient fertilisers such as nano-fertilisers and bio-enzymes, as well as quality feed for livestock. Funding schemes for EVs can also be extended to farm tractors. These practices can be implemented effectively by prioritising specific high-impact crop ecosystems for sustainable agriculture, such as rice in Andhra Pradesh and Telangana and wheat in Uttar Pradesh and Punjab.

2. **Implementing a co-beneficial ecosystem for farmers.** Integrating farmers into carbon markets can speed up the adoption of sustainable practices while improving farmer resilience and income. This would also address challenges and drive the adoption of solutions for small farmers. Furthermore, carbon sequestration from sustainable farming, such as planting trees and cover crops, can be calculated, allowing the creation and sale of carbon credits. For example, planting trees on 80–90 percent of croplands can generate additional credits worth $60 billion by 2070, or $330/ha.

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[144] Calculated assuming average cropland of 190 million hectares in 2070, divided over 45 years.

[145] Refers to net revenue after costs incurred. The carbon price is assumed to be constant at $50 between 2030–70. The price of residue is assumed at INR 9,000/kg based on interviews with industry experts.

[146] Calculated based on the projected increase in crop yield per hectare of land that continues to meet expected demand.

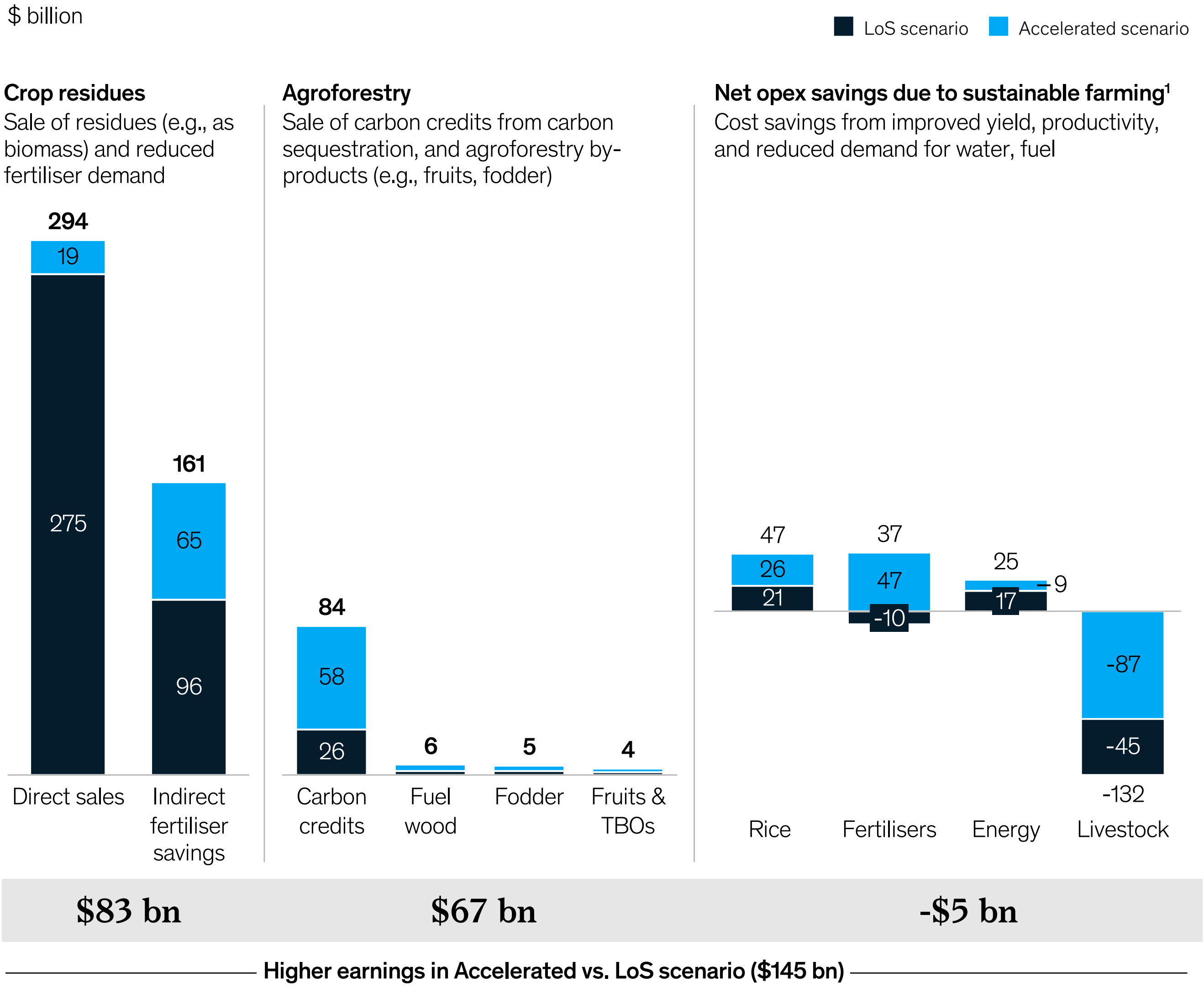
[147] International Rice Research Institute.

[148] Niti Aayog.

Exhibit 73

## Faster decarbonisation of agriculture could lead to additional earnings of $145 billion by 2070.

**Earnings (revenues minus cost) from decarbonising agriculture between 2020–70**
$ billion



1. Calculated as sum of total operating expenses incurred in adopting sustainable farming practices (e.g., rice intensification, controlled fertiliser use, etc.,) and the total savings accrued from such practices (e.g., reduced fertiliser demand, improved productivity, etc.,). Negative sign in Livestock indicates that expenses are higher than total savings, driven by higher cost of feed additives and technologies.

Source: McKinsey India Decarbonisation Model

Exhibit 74

## Case study: Australian farmers earn credits for reducing carbon emissions.

| | |
|---|---|
| **Action** | Carbon Farming Initiative (CFI) 2011—Landowners could earn carbon credits by changing land-use or management practices to store carbon or reduce greenhouse gas emissions<br>Emissions Reduction Fund (ERF) 2015—building on CFI, expanded coverage to encourage emissions reductions across the economy |
| **Objective** | Emissions reduction targets:<br>• 5% below 2000 levels by 2020<br>• 26-28% below 2005 levels by 2030<br>• 80% below 2000 levels by 2050 |
| **Details** | Economy-wide budget of $4.55 billion, initially $2.55 billion; this budget was increased in 2019 to ramp up ambition<br>Farmers enter into a contract where they earn credits for carbon-reduction activities on farm; these credits can then be sold to the Australian government or to businesses wishing to offset their emissions<br>Eligible activities include:<br>• Increasing fertiliser efficiency<br>• Enhancing soil carbon through practices like cover cropping and no-till agriculture<br>• Storing carbon in biomass<br>• Reducing livestock emissions<br>• Collecting methane off effluent dams use to generate biogas |
| **Impact** | Projects in Queensland and New South Wales have received more than $800 million in carbon-farming credits<br>So far, the ERF has bought contracts to abate 180 Mt of carbon for up to 10 or 20 years<br>ERF has delivered income $239 million annual revenue for landholders |

Source: Australian Government, Department of Climate Change, Energy, the Environment and Water; Department of Agriculture, Fisheries and Forestry

Implementing a carbon-market ecosystem is complex and would involve overcoming several challenges, for instance, awareness of carbon programmes and operations. Farmers will require end-to-end support from planning practices and implementation to collecting the correct information and submitting verification paperwork. These challenges are further exacerbated in a primarily smallholder Indian agriculture sector.

Integrating several farmers owning a few hectares of land through the support of Farmer Producer Organisations can address some of these challenges. Such projects could also consider leveraging digital platforms and various data sources to accelerate and reduce the cost of validation or verification. The government may also need to create a comprehensive framework for intermediaries and other stakeholders.

3. **Creating links with other sectors.** The creation of links to other sectors that can upcycle agricultural and crop waste is another initiative that could accelerate this transition. Such collaborations would reduce straw burning and crop-residue mismanagement. The waste, once upcycled, could be used for packaging material or as carbon-neutral biomass in industry. The use of bio-decomposers breaks down residue into organic fertiliser, leading to reduced fertiliser manufacture and use. In addition, strong supply networks could ensure easy collection, transportation and usage of residues.

4. **Instigating demand shifts**. To achieve maximum abatement, there is also a need for demand-side shifts. A shift in demand from meat and rice requires investments in sustainable consumer alternatives such as plant-based or lab-grown protein and the promotion of coarse cereals. The promotion of water-efficient cereals like millets can also make India a global hub for sustainable staples.

******

Operationalising these moves would require support at different governmental levels. Multiple, targeted missions that address the challenges in rice, dairy, meat and fertilisers would be needed to design solutions, lay out transition roadmaps, provide the necessary resources and integrate all of these into the wider agri-development programmes. Part of the solution would lie in involving the private sector and civil society in the implementation.

# 3. Cross-cutting enablers

# 3.1 Green hydrogen

## Key takeaways

**Green hydrogen[149] will likely become increasingly cost competitive** with declining electrolyser Capex and reducing renewable energy costs, getting to \$2/kg in our LoS scenario and \$1.8/kg in the Accelerated scenario by 2030. Additionally, government support (capital subsidies, power banking, PLI schemes, transmission charge waivers) and regulations (specifically, carbon price) can accelerate their competitiveness against the relevant alternatives which include grey hydrogen, coking coal and diesel.

**In the LoS scenario,** green hydrogen becomes progressively competitive – 2030 in chemicals and refinery; 2035 in long-haul trucking; 2040 in power storage applications; and 2045 in steel. In this scenario, India could stop building blast furnace-based steel capacity by 2045 (instead building green hydrogen-based steel capacities), thus cumulatively abating 1.9 Gt of emissions by 2050 and 12.5 Gt by 2070.

**In our Accelerated scenario,** with a carbon price of \$50 per tonne, green hydrogen becomes competitive for all major uses in the 2030s. This unlocks three times the LoS use of green hydrogen in the hard-to-abate sectors that are also new users of hydrogen (i.e., steel, trucking and power) by 2040, and leads to accelerated investment in low carbon assets. For example, 211 Mt of new steel capacity could shift to the green hydrogen steel route in this scenario between 2030 and 2045 (instead of the high carbon blast furnace steel route as in LoS). This cumulatively abates 5.7 $GtCO_2e$ by 2050 and 18.8 $GtCO_2$ by 2070.

**The green hydrogen transition could be kickstarted early by blending mandates for current grey hydrogen uses.** About 5–6 Mt of grey hydrogen is currently used in refining, methanol and ammonia as feedstock.[150] This can be decarbonised by using green hydrogen through appropriate blending mandates, thus creating demand for green hydrogen in India in this decade. This could accelerate the cost reduction of green hydrogen, opening up uses in hard-to-abate sectors like steel, trucking, marine mobility and power storage, as it becomes cheaper than the current fuel (i.e., diesel for trucks, coal in blast furnaces). Moving early on green hydrogen helps a growing India avoid locking into carbon-intensive assets for the next half century (e.g., for steel production) and leads to lower imports (e.g., ammonia, coking coal, crude oil).

**Early unlock of low carbon assets through green hydrogen in the Accelerated scenario would have many benefits.** These include cumulative Forex savings of \$420 billion in oil and gas and \$280 billion in coking coal by 2050. In addition, by 2040, green hydrogen can be a new industry with revenues of \$30–35 billion per annum. While the domestic opportunity matures over time, India could be one of the most competitive global producers of green hydrogen (and its derivatives) by 2030, creating an annual export opportunity of \$5–6 billion to energy-short markets that already have a carbon price. This can serve to incubate green hydrogen for India as domestic demand develops.

**The investment needed** (till 2050) is estimated to be in the region of \$430 billion across green hydrogen production (i.e., electrolysers and renewable energy – accounting for \$316 billion), midstream (i.e., storage and pipeline infrastructure – accounting for \$114 billion) in the Accelerated scenario. The comparable investment by 2050 in the LoS scenario is \$242 billion.

Beyond the already stated measures, policy interventions could be considered for i) creating blending mandates across the ammonia and refinery sectors; ii) introducing carbon pricing through compliance carbon markets; iii) introducing PLIs or subsidies to strengthen local production and build technological capabilities locally; iv) initiating bilateral MoUs with importing countries like Japan, the UK, South Korea and the EU for hydrogen and hydrogen-based products.

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[149] Hydrogen produced with renewable power sources.
[150] TERI, Niti Aayog.

## Context

Green hydrogen, made from renewable energy, is essential for India's decarbonisation — as a replacement for grey hydrogen for fertilisers and refineries and for newer uses like green steel and trucking. By 2070, green hydrogen could account for 15–20 percent of India's primary energy mix, helping to abate 12–18 $GtCO_2e$ of cumulative emissions. Local production of green hydrogen also offers India a path to energy independence, reducing the need for crude oil, gas, ammonia and urea imports.

Globally, there is momentum toward a hydrogen economy as more than 30 governments have announced hydrogen strategies (Exhibit 75). India also announced its green hydrogen policy in February 2022 which promises lower cost power with inter-state transmission charges waived, banking for in the grid and a green hydrogen mission.[151]

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[151] Ministry of Power.

Exhibit 75

## Overview of global green H2 policies.

| | | Policy | Description |
|---|---|---|---|
| **Domestic production and imports** | Europe | IPCEI Programme[1] | $8 billion investment package for 60+ large-scale hydrogen projects. IPCEI HyTech (41 projects, 35 companies) was awarded $5.4 million, backed by 15 EU states, in July 2022 |
| | | Electrolyser Capacity target | Target of 17.5 GW by 2025 and 40 GW by 2030 committed in 2022 |
| | Germany | Hydrogen Republic of Germany | $700 million technology support for scaling and mass production |
| | | Offshore electrolysis tender (expected 2022) | World-first offshore electrolyser tender; land in the special economic zone has been reserved for wind-powered electrolysis, supported with EUR 50 million in public funding |
| | France | PNRR & Future Investment Plan (PIA4) | $9.2 billion budget dedicated to national green H2 plan, which includes subsidies for production of electrolysers, H2 for industrial use, mobility[2] and R&D grants |
| | USA | Investments and Inflation Reduction Act (IRA)- 45 V | Investments of $9.5 billion for hydrogen; subsidy on hydrogen production up to $3/kg, commensurate with $CO_2e$ emissions |
| **End-uses** | Europe | Carbon Contracts for Difference (expected 2022) | Companies are compensated for difference between actual emission abatement cost and price of carbon to reduce decarbonisation risk for industry |
| | Germany | Innovation Programme Hydrogen and Fuel Cell (Phase II) (2016) | $1 billion for fuel cell applications in transport and mobility |
| | | Decarbonisation of Industry Funding programme (2021) | Up to $3 billion for reduction of process-related emissions in energy-intensive industries |
| | Spain | MOVES II & III Plan (2021) | $400-800 million for providing purchase incentives on alternative energy vehicles |
| | | FCEV Production Incentive | $25 million to incentivise orientation of existing automotive industrial capacities towards public and private renewable hydrogen transport modes |

1. Important Projects of Common European Interest eligible for government funding under EU rules.
2. Includes France govt's allocation towards IPCEI.
3. Plan National de Relance et de Résilience.

Green hydrogen demand will be generated by substituting grey hydrogen for existing uses such as crude-oil refining, methanol production, fertiliser and city-gas blending. New uses in hard-to-abate sectors such as long-haul trucking, steel production and power storage replacing current fuels can unlock much bigger demand. Green hydrogen replaces different fuels or feedstocks in each case – grey hydrogen, coking coal or diesel– and hence needs to become competitive against each one. Currently, all the hydrogen produced in India (5–6 Mt) is grey, for fertilisers, refining and chemicals.[152] In addition, India imports about 2 Mt of grey hydrogen embedded in fertilisers.[153]

This section addresses four important themes for the development of green hydrogen – what it will take for green hydrogen to become competitive versus relevant alternatives in both the LoS and the Accelerated scenarios; how the demand will develop; what the benefits and costs of acceleration are; and what it will take to drive adoption at scale.

The LoS scenario assumes that the technology costs for electrolysers and green power costs decline as expected and current policies continue. The Accelerated scenario assumes a somewhat faster decline in green hydrogen production costs ($1.8/kg by 2030 versus $2/kg in LoS) with a $50 carbon price and blending mandates.

## Competitiveness of green hydrogen

Currently on-site steam methane reformer (SMR)-based grey hydrogen is used in most downstream processes such as refineries and ammonia production. The current production cost of $1.90/kg will increase with natural gas prices. In contrast, green hydrogen production costs are expected to decline by 55 percent over the next decade, becoming cost competitive against grey hydrogen by around 2030 (Exhibit 76).

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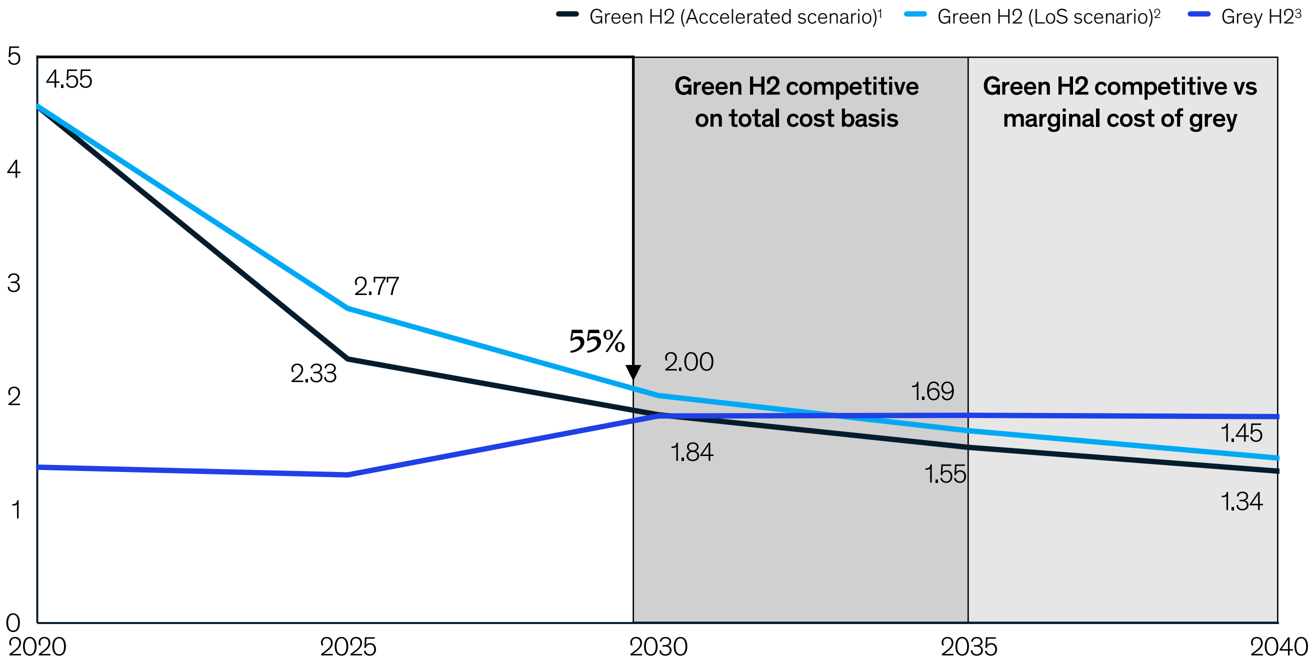
[152] TERI, Niti Aayog.
[153] Fertecon.

Exhibit 76

## Green hydrogen likely to be the most competitive production route by 2030–2035.

**Cost of production of Hydrogen**

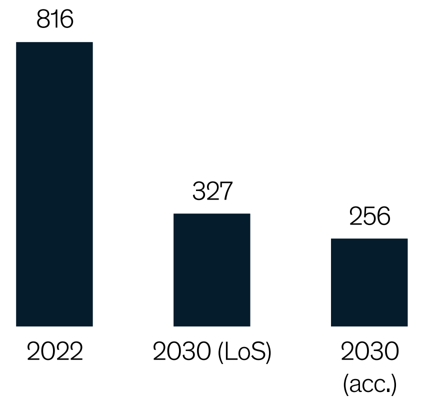
($/Kg); PV solar based with onsite hydrogen storage



**Key factors driving green hydrogen competitiveness by 2030-2035**

**Decline in electrolyser capex costs**

$/kW



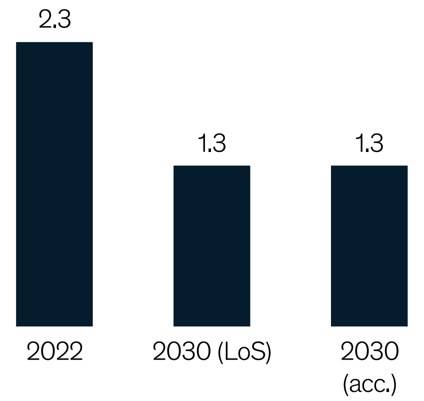
i. Scale-up/automation of electrolyser mfg.

ii. Larger electrolyser module sizes

iii. Ramp-up of local electrolyser production

**Decline in renewable electricity costs**

INR/kWh



i. Decrease in capex and project finance costs

ii. Increase in efficiency[4] and LCOE improvements

**Government support**

i. Improving cost economics for green hydrogen production (T&D waivers for RE, capital subsidy for electrolyser, PLI schemes, etc.)

ii. Sector-wise mandates for green H2 adoption

iii. Infra investments to enable distribution

---

1. Assuming an accelerated decline in electrolyser costs.
2. Includes on-site storage cost of $0.25-0.35/ kg.
3. Assuming natural gas cost of 7 $/mmbtu in 2020, rising to 10-11 $/mmbtu by 2040.
4. AC PLF varies from 26-32% for PV solar year on year.

Source: McKinsey Hydrogen Cost Model

Hence, existing use-cases – refinery, ammonia, methanol, natural gas blending – for green hydrogen will be in-the-money by around 2030 in both scenarios. With a carbon price of $50 per tonne, new use-cases in long haul trucking and steel making are also expected to be in-the-money by 2030. Green hydrogen usage in power storage is expected to be the last to become cost competitive (Exhibit 77).

In the LoS scenario, when green hydrogen gets to $2/kg enabled by current policies, it is expected to become progressively competitive against alternatives – 2030 for chemicals and refinery; 2035 for long-haul trucking; 2040 for power storage applications; and 2045 for steel. In our Accelerated scenario, with a carbon price of $50 per tonne, green hydrogen is expected to become competitive for the majority of uses by 2030[154] (Exhibit 78).

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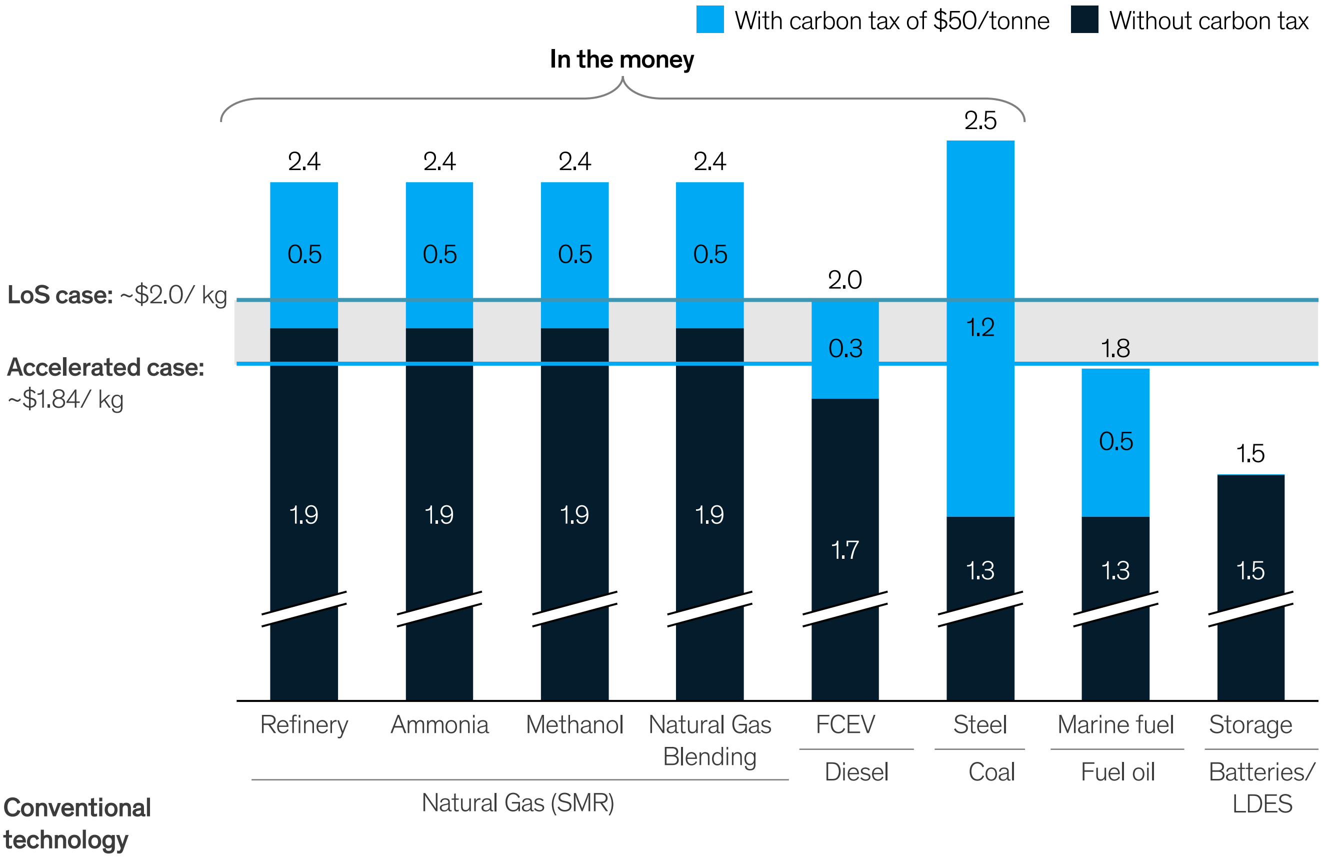
[154] Exception of power storage.

Exhibit 77

## Green hydrogen could become competitive for a majority of the use-cases by 2030.

**Required hydrogen production costs for breakeven against conventional technologies**

$/ kg in 2030



Source: McKinsey Hydrogen Insights: Breakeven Analysis

Exhibit 78

## In the Accelerated scenario, most use cases become cost competitive in 2030 with a carbon price of $50 per tonne.

Competitiveness of green hydrogen in different use-cases

1. Includes ammonia production, refining, methanol production and natural gas blending.

Source: McKinsey Analysis

### Demand development for hydrogen in the LoS and Accelerated scenarios

Green hydrogen demand is expected to first emerge as a replacement for grey hydrogen in use cases like refining, ammonia and methanol as it becomes more competitive by 2030. Demand is somewhat higher in the Accelerated scenario, but not by much, and in fact declines over time, with the accelerated reduction of refining demand (Exhibit 79).

Exhibit 79

## Existing hydrogen use-cases are likely to be early adopters.

MMTPA; sector wise projections

**Demand forecast**

| | | 2030 Green H2 demand | | 2050 Green H2 demand | | | |
|---|---|---|---|---|---|---|---|
| **Use-case** | **Description** | **LoS** | **Accelerated** | **LoS** | **Accelerated** | **Current alternative** | **Global pilots** |
| Refineries | Desulfurisation of crude oil to meet emission norms | 0.05 | 0.05 | 1-1.5 | 0.1 | On-site SMR based production (grey) | REFHYNE<br>bp |
| Methanol production | Use of hydrogen as feedstock | 0.13 | 0.15 | 3-3.5 | 0.2 | On-site SMR based production (grey) | INERATEC<br>RUB |
| Fertiliser production | Use of hydrogen as feedstock for ammonia production | 0.4 | 0.4 | 7 | 7 | On-site SMR based production (grey) | YARA |
| Blending with city gas | 15-20% blending by volume with city gas (CNG) | <0.1 | <0.1 | <0.1 | <0.1 | | 🇫🇷 🇩🇪<br>🇪🇸 |
| **Total** | | 0.6-0.7 | 0.6-0.7 | 11-12 | 7-7.5 | | |

1. More economical than opting for RE + storage solutions.
2. Potentially direct air capture/ biomass.

Source: Expert interviews, TERI

In the Accelerated scenario, hydrogen demand in the 2030s and 2040s is expected to be much higher for the hard-to-abate sectors of steel, trucking and power (8X of demand in the same sectors in 2040 and 3X in 2050) (Exhibit 80). In each of these hard-to abate sectors, different dynamics could be at play:

- **Steel** could be one of the largest consumers of green hydrogen from 2030 onwards in the Accelerated scenario. This is because even a relatively small carbon price makes hydrogen-based steel-making much more competitive relative to the blast furnace-coking coal route.
- **Automotive:** Hydrogen fuel cell based long-haul trucking[155] is expected to become progressively more cost competitive in lifecycle value terms versus the internal combustion engine as well as battery EVs. This could be another big consumer of hydrogen post-2030.
- **Power:** Hydrogen is a small part of the storage solution with other options being much more economic. Power storage could be the last to adopt green hydrogen since the current alternatives will likely be 40–50 percent lower cost. Nevertheless, as India moves to in firm renewable sources, hydrogen would play a key role in grid balancing and energy storage.

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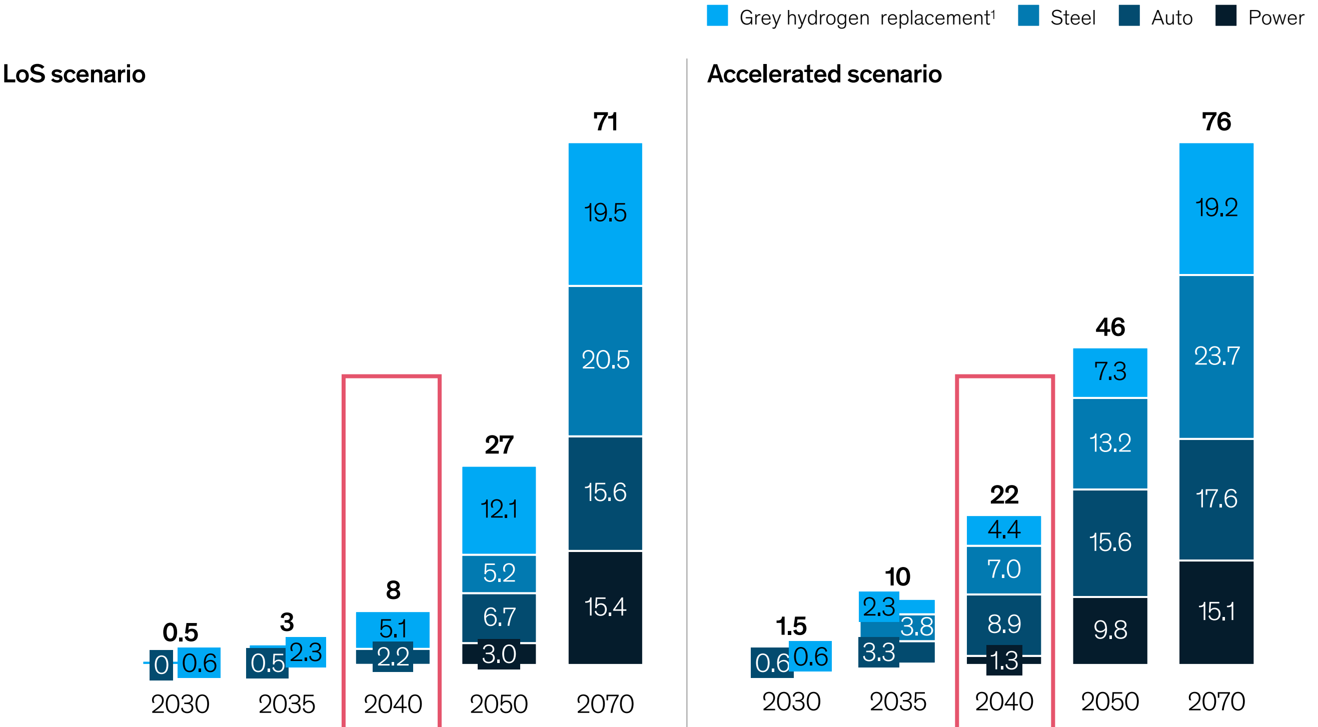
[155] Over 300 km distance.

Exhibit 80

## Hard-to-abate sectors drive disproportionate demand for hydrogen in the Accelerated scenario.

**Green H2 Demand,** MMTPA; bottom-up sector wise projections



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **CO₂ abated** MMTPA | 5 | 27 | 71 | 302 | 810 | 20 | 155 | 310 | 535 | 903 |
| **$ billion** | 1.2 | 4.8 | 10.6 | 33.0 | 64.1 | 3.1 | 16.2 | 31.5 | 56.0 | 68.3 |

1 Includes refineries, methanol production, fertiliser production and city gas blending

## Benefits from accelerated adoption of green hydrogen

— **Building India right, first time.** Accelerating hydrogen adoption in steel-making could help India build the right assets, reduce the risk of being left stranded and create additional carbon space. Growing steel demand means rapid and continued capacity addition in the 2030s and 2040s. In the LoS scenario, almost 249 Mt of BF-based steel capacity is expected to be added over the coming 25 years. By contrast, in the Accelerated scenario, this would be 14 Mt, with the balance being hydrogen-based green steel. Steel assets last for 40 to 50 years.[156] Hence, the LoS scenario implies locking into high carbon assets for much longer. This is an investment of about $265 billion in steel-making, which could also be at the risk of getting stranded in case of climate shock or early closure, even with India's 2070 net-zero NDC (Exhibit 81).

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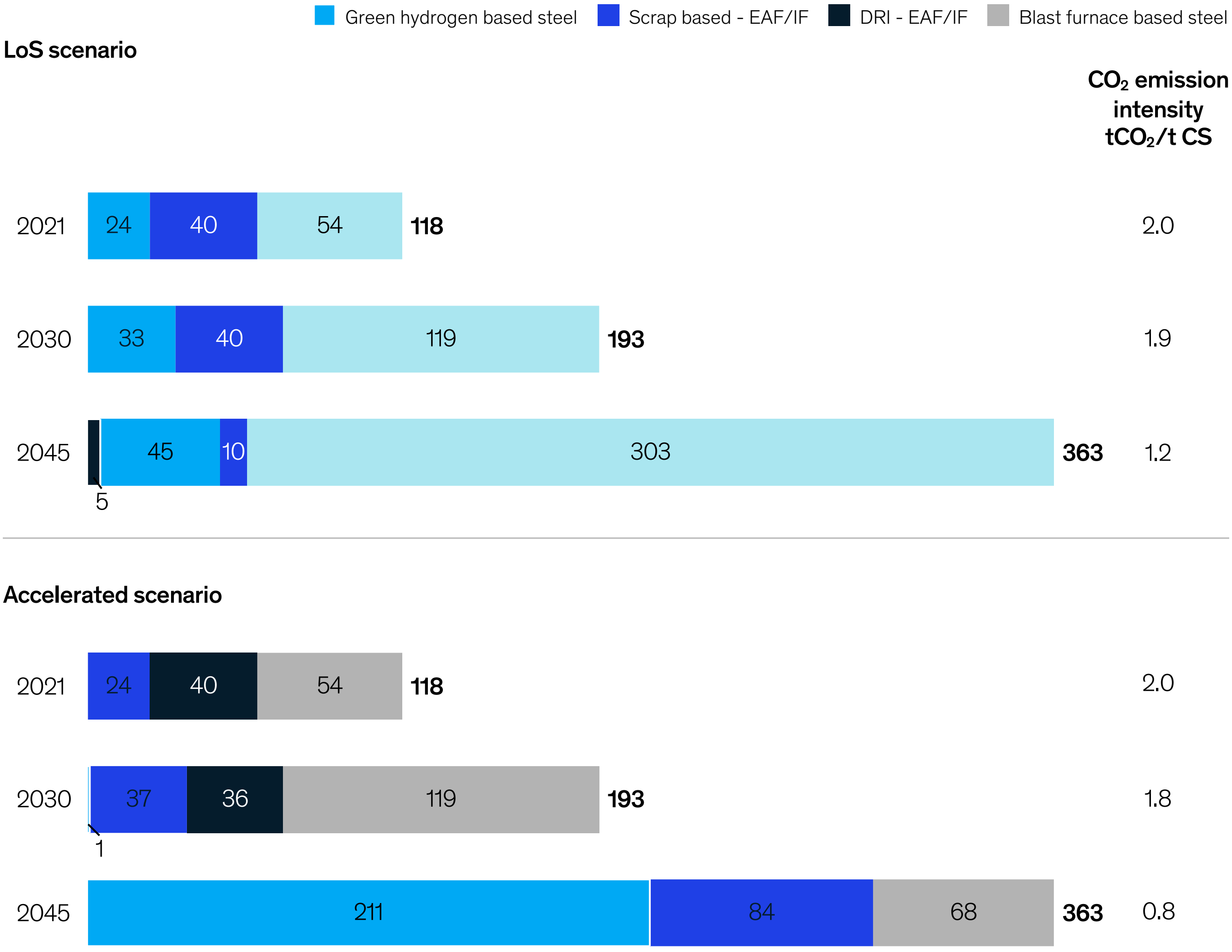
[156] Vdeh plantfacts, Posco newsroom.

Exhibit 81

## Crude steel capacity by route.

MMTPA



Note: Assumes scrap rate increasing from ~10% currently to 20% in BF-BOF by 2040; Scrap rate in green hydrogen based EAF at 10%; DRI usage in EAF Scrap at 10% of total metallic mix.

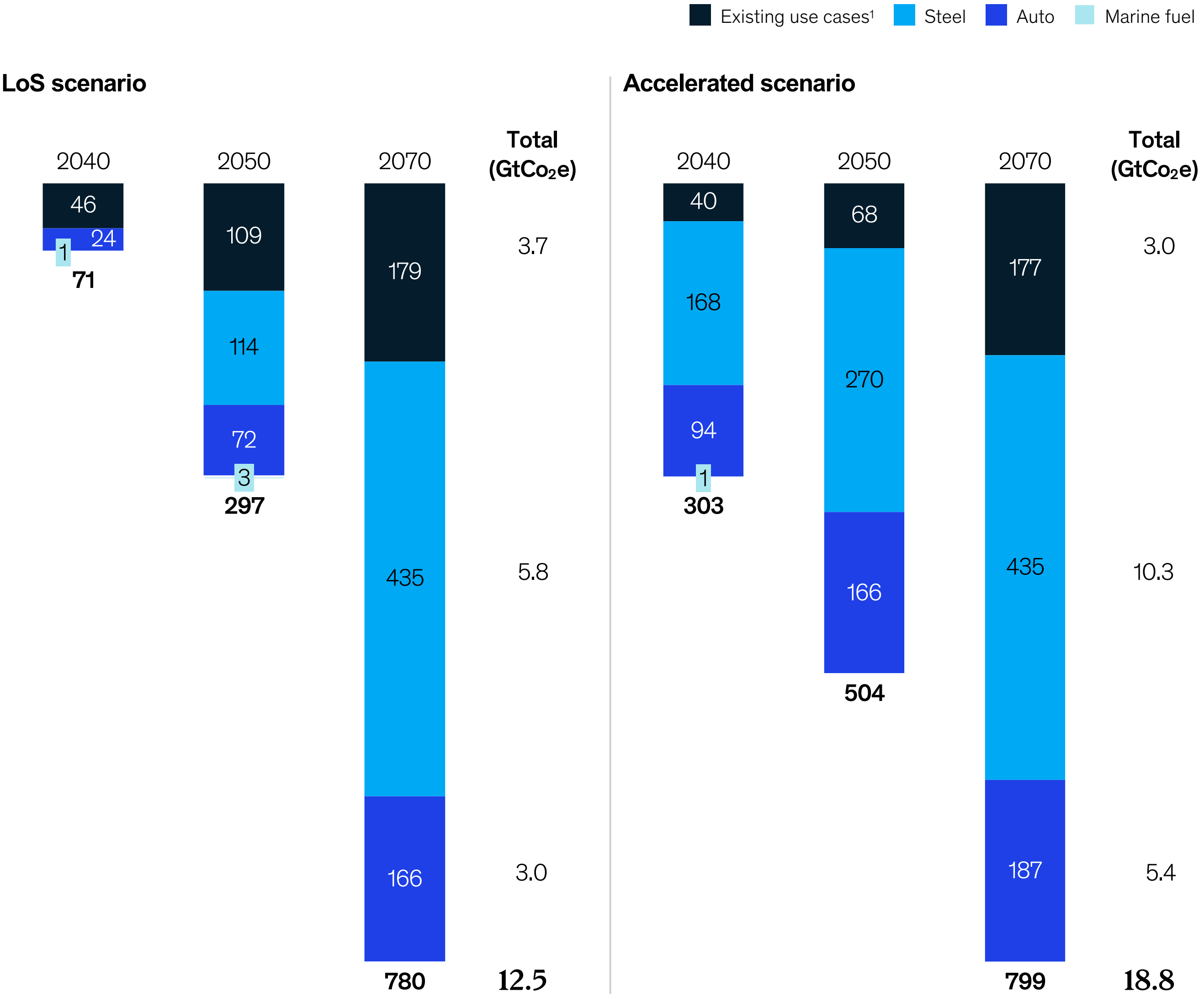
Source: McKinsey decarbonisation TCO model v14, Metal Bulletin

- **Creating carbon space in both the LoS and Accelerated scenarios.** In the LoS scenario, 12.5 $GtCO_2e$ is abated cumulatively till 2070 (1.9 $GtCO_2e$ by 2050 and an additional 10.6 $GtCO_2e$ by 2070), while in the Accelerated scenario, this increases by 6.3 $GtCO_2e$ (3.8 $GtCO_2e$ by 2050 and an additional 2.5 $GtCO_2e$ by 2070) (Exhibit 82).
- **Increasing Forex savings and energy security.** In the LoS scenario, India reduces its energy import reliance by $42 billion annually till 2050, through the reduction of crude oil, natural gas and coking coal imports. This increases in the Accelerated scenario to $64 billion annually by 2050 (Exhibit 83).

Exhibit 82

## Annual $CO_2e$ abatement potential from Green hydrogen.

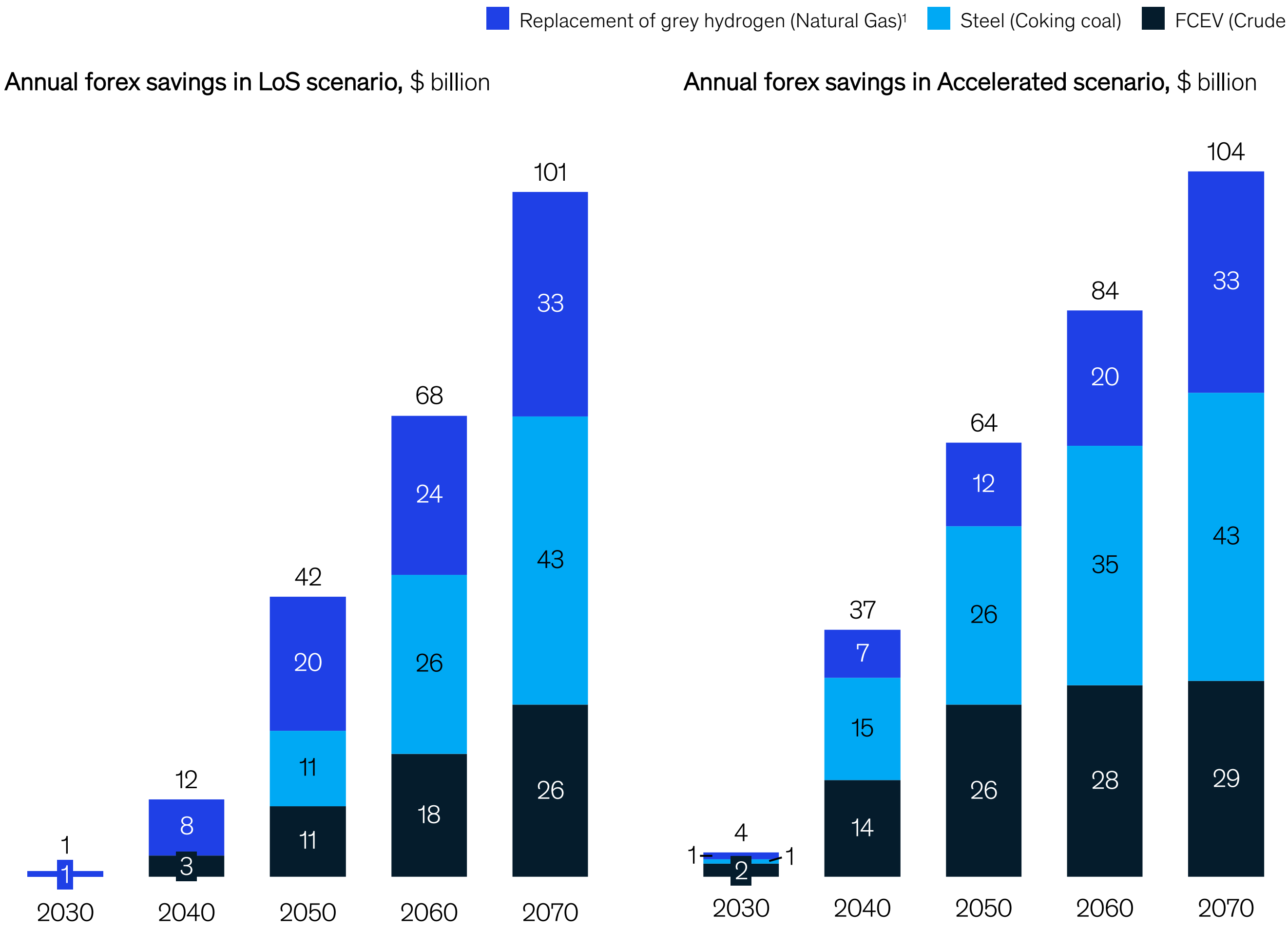
$MtCO_2e$ p.a.



1. Includes ammonia production, refining, methanol production and natural gas blending.

Exhibit 83

## Forex savings on account of green hydrogen.



1. Includes ammonia production, refining, methanol production and natural gas blending.

**Exporting green hydrogen-based products, also to incubate the hydrogen economy in India.** India can also be one of the most competitive producers of green hydrogen (and its derivatives). This creates an opportunity for India to export $5–6 billion worth of green hydrogen derivatives exports (e.g., green hydrogen-based DRI and ammonia) by 2030 to energy-short markets that have set high targets for decarbonisation (e.g., South Korea, Japan, the EU) (Exhibit 84). More importantly, this provides India with the opportunity to start participating in the hydrogen economy quicker.

## Proposed investment required for green hydrogen

The Accelerated scenario would likely require $430 billion in investment for green hydrogen by 2050, roughly twice what will be needed in the LoS scenario. This would be split across solar-power and electrolyser capacity and midstream for setting up new pipelines and retrofitting existing natural-gas pipelines for hydrogen distribution (Exhibit 85).

Exhibit 84

## India likely to be a strong contender to meet the import demand for Japan and South Korea.

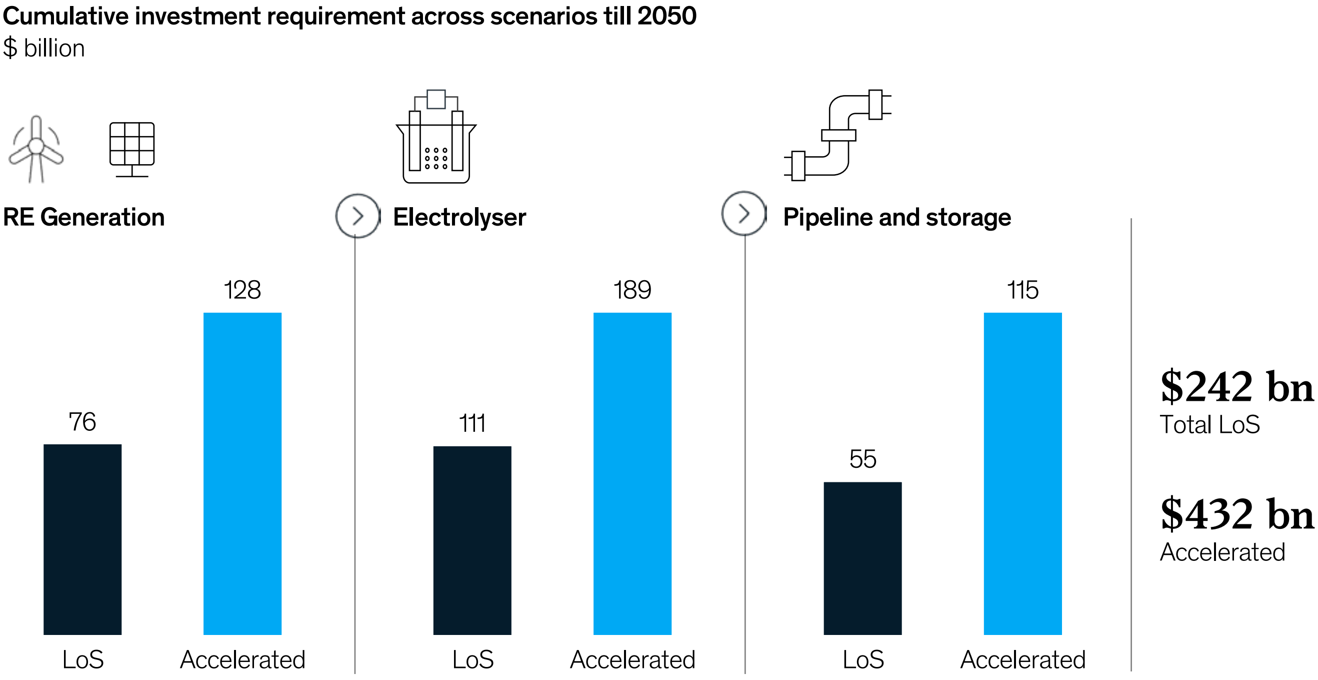
**Landed cost of Green Hydrogen to Japan**
2030 ($/Kg); LoS scenario[1]

[1] Excluding on-site storage.

Source: McKinsey Hydrogen Cost model

Exhibit 85

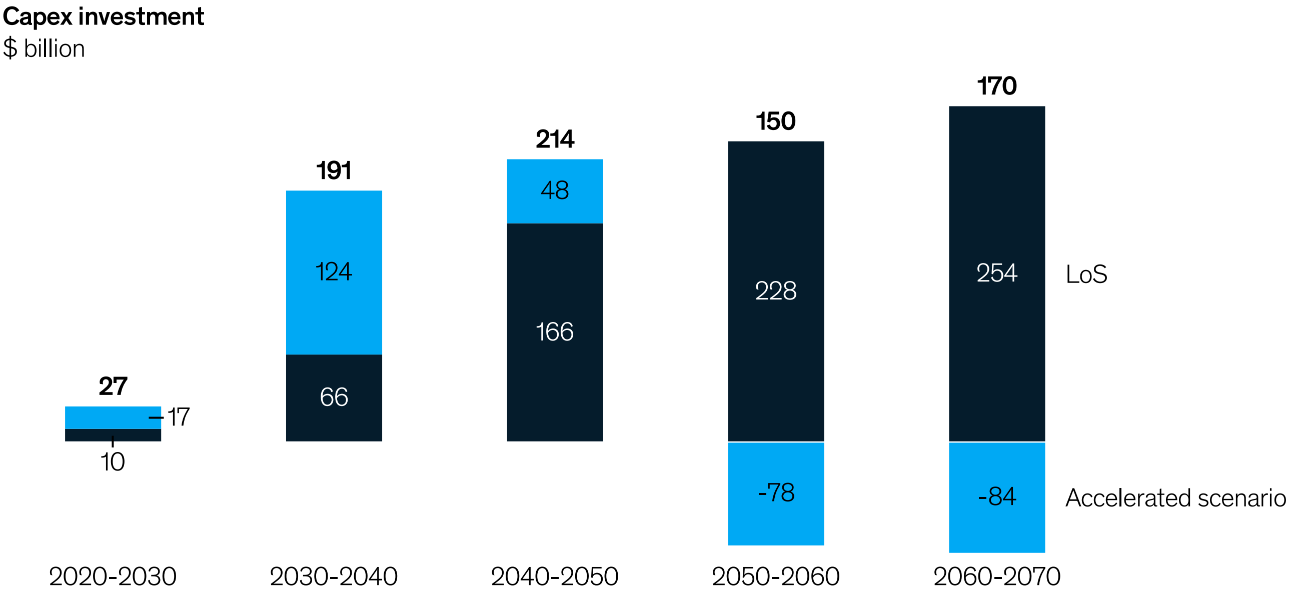
## $432 billion would be needed in investment in the green hydrogen value chain in the Accelerated scenario by 2050, 1.8x of LoS scenario.



The investment is front-loaded, particularly in the Accelerated scenario (~30 percent by 2040 and ~60 percent by 2050 vs. ~10 percent by 2040 and ~33 percent in the LoS scenario) (Exhibit 86).

Exhibit 86

## Decade-wise investment needed in green hydrogen value chain.



## Proposed enablers to accelerate hydrogen adoption

The following measures could be considered for accelerating the hydrogen economy in India:

**1. Creating blending mandates across ammonia, refinery and fertiliser,** which would likely kickstart the adoption of green hydrogen (and derivatives) as a replacement for grey hydrogen. Similar steps are being taken globally. For example, in Japan, co-firing of ammonia for power production is under consideration.[157] A market-making mechanism through innovative auctions such as the Hydrogen Global Initiative (Exhibit 87) in the EU could also be considered (similar to the tenders that India's Solar Mission launched to spur on renewable demand).[158]

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[157] Japan hydrogen roadmap.

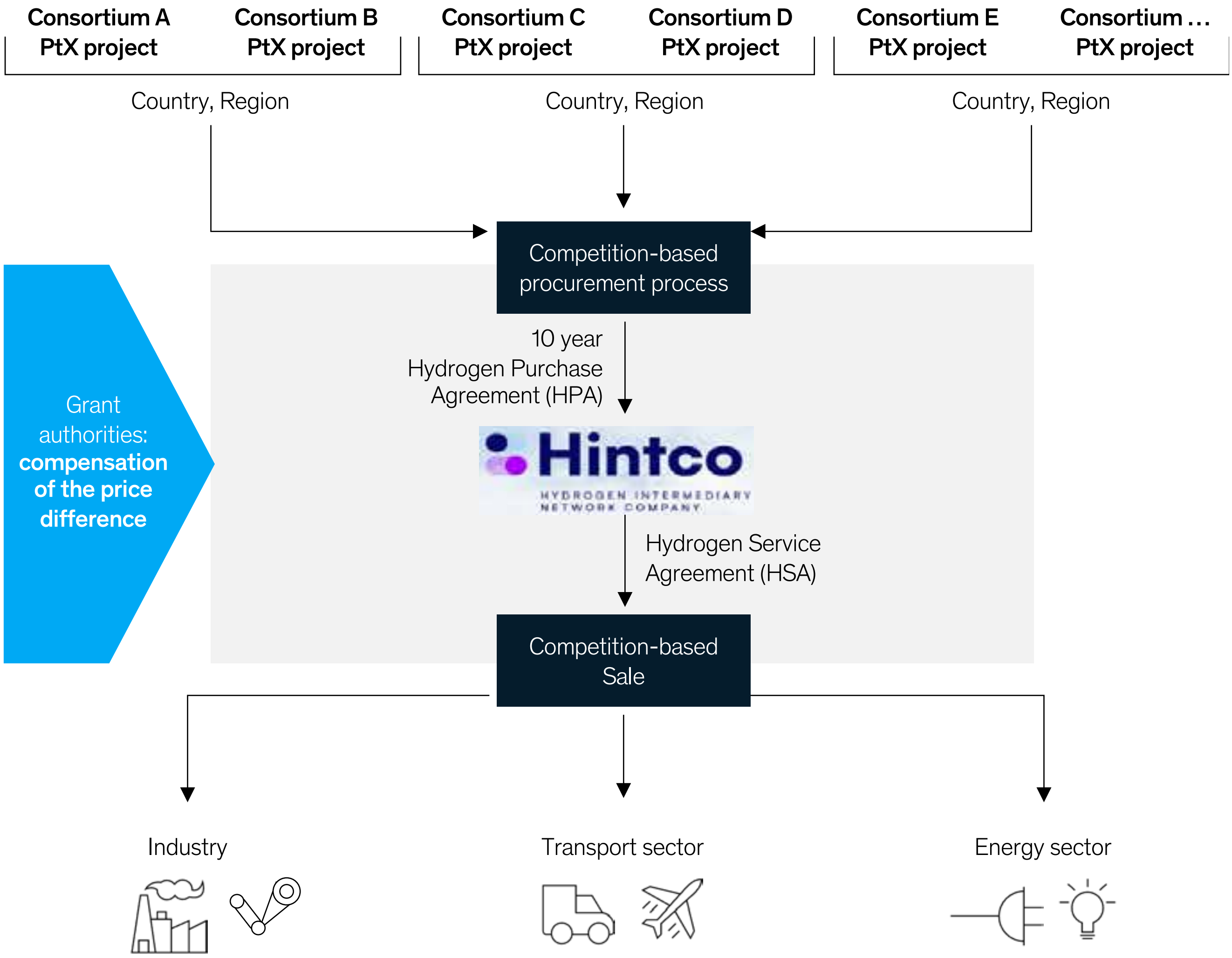
[158] Mercom India.

Exhibit 87

## Germany's H2 Global scheme: €900 million investment to incentivise global players through double auction mechanism for imports.

H2Global Stiftung

**Context** H2Global scheme launched in March 2021 to support global low-cost green hydrogen production by eliminating price/demand uncertainty; raised €900 million till date towards price offsets



**2. Introducing carbon pricing through compliance carbon markets** in a calibrated but accelerated manner, providing steel makers with the policy-certainty to be able to invest. This will need to be accompanied with appropriate carbon border adjustment mechanisms to ensure the global competitiveness of India's steel and manufacturing industry. A $50 per ton carbon price can accelerate hydrogen-based steel-making by 15 years.

**3. Building a local equipment industry** by instituting actions such as PLIs[159] to induce local manufacturing for electrolysers and the balance of plants. For example, a subsidy of $60–80/KW in electrolyser manufacturing can accelerate green versus grey hydrogen competitiveness by five years. Investing in R&D for developing indigenous, hydrogen-based electrolysers, fuel cells and hydrogen DRI would provide the necessary thrust for domestic production. Additionally, attracting global technology players to India will be important.

**4. Initiating bilateral MoUs with importing countries such as Japan, the UK and South Korea for green hydrogen-based products**. Australia, for example, has agreements with South Korea and Japan to establish an international hydrogen supply chain.[160] India could attempt something similar to incubate a green hydrogen and hydrogen-based product industry even as local demand develops.

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[159] Production Linked Incentives.
[160] H2 Insights.

# 3.2 Material circularity

## Key takeaways

**India currently generates 750–800 Mt of waste annually.** Of this, 500 Mt is crop-residue waste, of which 72 percent is recycled. Of all other types of solid waste—such as municipal, C&D and plastic—only 13 percent is recycled.[161]

**Our LoS scenario** assumes increasing recycling rates to 39 percent by 2050 for non-agricultural waste streams, and 87 percent for crop residue. This level of material circularity is supported by current policies and leads to a cumulative reduction of 22 $GtCO_2e$ by 2070.

**The Accelerated scenario** could see increased recycling levels to 58 percent across non-agricultural waste streams and 100 percent across agricultural waste streams by 2050 leading to an additional cumulative reduction of 12 $GtCO_2e$ by 2070. This would likely require accelerated implementation of existing policies, e.g., EPR for plastic waste, e-waste and tyre waste, and new policies and blending mandates, such as 50 percent recycled plastics in packaging (as opposed to a 30 percent target for select plastics today) and 20 percent recycled concrete as a clinker substitute (does not exist today).

**Material circularity could generate benefits beyond abatement.** Actions in the LoS scenario could reduce emissions by 1.2 $GtCO_2e$ per annum by 2070, whereas the Accelerated scenario could abate 1.45–1.5 $GtCO_2e$ of emissions per annum by 2070. Overall, material circularity could generate net savings by improving closed-loop production. For instance, recycling hubs for new waste streams such as EV batteries could drive domestic production and create cumulative precious-metals import savings of $720–730 billion by 2070, with a 50 percent reduction in virgin material imports.

**Significant capital and operational expenditure** will likely be needed for collection, sorting and processing of waste to accelerate material circularity. Capex investment of $660 billion would likely be required by 2070 in the Accelerated scenario ($220 billion more than in the LoS scenario), with the majority going towards recovery and recycling infrastructure for construction (one percent recycled) and plastic waste (25 percent recycled).

**The accelerated transition would likely need demand signals and policy support** from the government in the form of landfill levies, EPR frameworks included with blending mandates, carbon pricing on emission heavy products. Further investment in technology like chemical recycling and infrastructure like mobile waste sorting vehicles would be required.

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[161] World Consumer research report; UNDP Plastic Waste Management Program; CPCB Solid Waste Management Reports; Indian Textile Journal; Indian Council for Agricultural Research; Ministry of Steel; FAO; National Policy on Crop Residue Management by Ministry of Agriculture

## Context

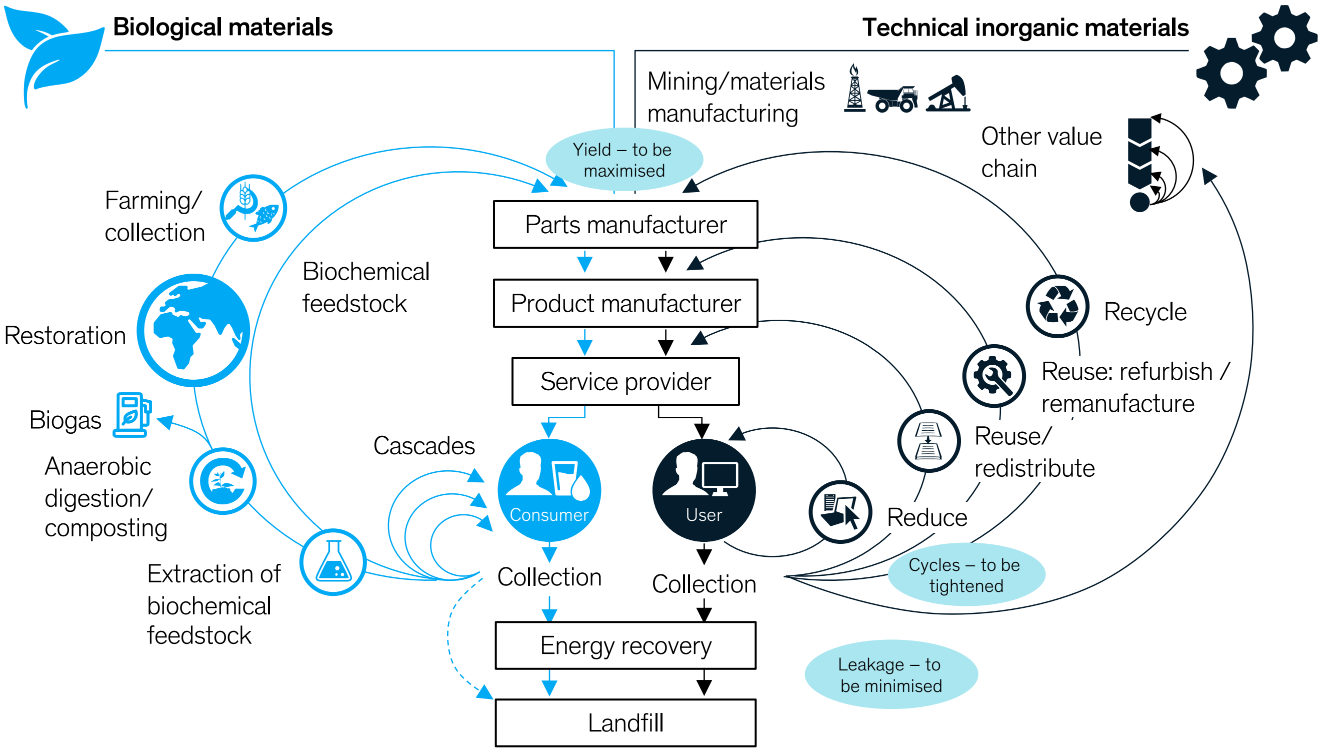
Our current economy is based on a linear, 'take-make-waste' system of production. This leads to significant waste generation and a loss in value of materials and components. In a circular economy, closed (or partially closed) loop systems of production minimise waste. By reusing raw materials and implementing looped production systems, waste consumption can be driven without being limited by finite resources, and value from materials can be maximised (Exhibit 88).

A linear-economy system is not sustainable and leads to resource depletion, waste and increasing emissions. Material circularity, by contrast, can help regenerate nature, while minimising resource depletion and waste generation. It is also a cost-efficient way to reduce carbon emissions: production from recycled raw materials can reduce emissions by between 50 and 98 percent versus virgin raw materials (Exhibit 89).

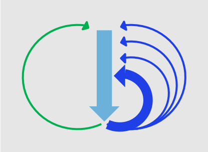
Exhibit 88

## Circularity requires a holistic value-chain transformation.

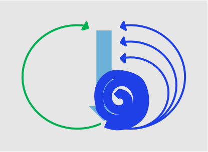
**There are two ways to think about circularity: biologically and technologically**



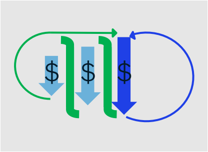
There are four ways to create value from circularity



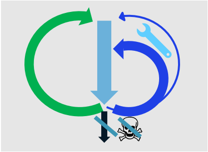
Tighten the recirculation circle: the tighter the circles, the larger the savings



Recirculate longer: longer usage times of products and materials



Cascade use of products: reuse an old product as new product in different application



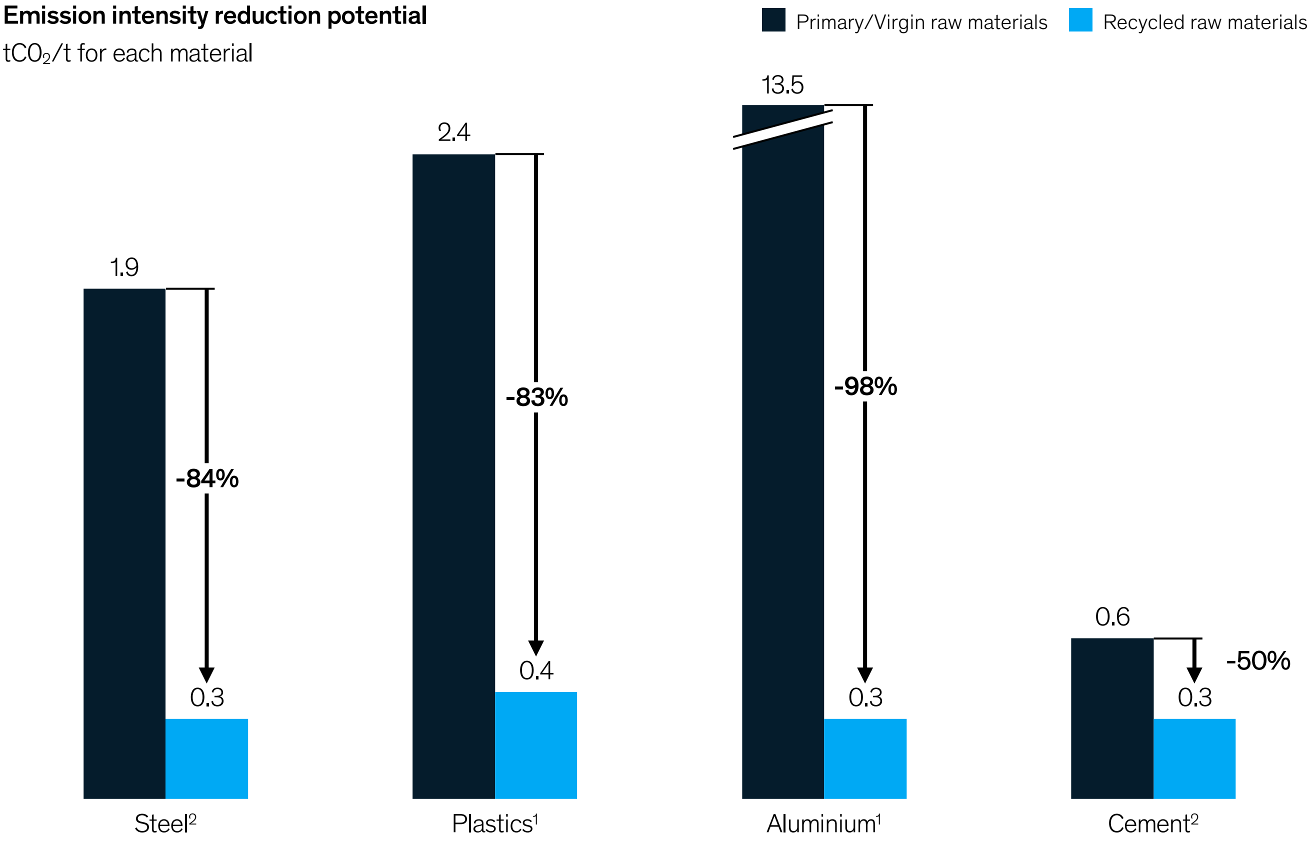
Improve reusability of products, parts and materials: improvements through original design of products

Source: Ellen MacArthur Foundation – Circular economy systems diagram

Exhibit 89

## Substantial emission reduction potential in using recycled raw materials vs. virgin materials across sectors.

**Illustrative**



1. Emission intensity for EU as calculated by Material Economics.
2. Emissions intensity for India with material-recycling based production.

Source: Material Economics: The Circular Economy Report for EU

India currently generates 750–800 Mt of solid waste annually across various waste streams, with recycling rates mostly varying between one and 30 percent.[162] Some waste streams, such as construction, textile and tyre waste are recycled at rates as low as one to seven percent (Exhibit 90).

**Low recycling rates are driven by three main factors:**

- **Weak demand signals.** Globally, many leading consumer players in sectors like fast-moving consumer goods (e.g., Unilever has committed to halve the amount of virgin plastic they use in packaging and P&G has committed to 100 percent reusable packaging by 2030), textiles (e.g., H&M) and tyres (e.g., Continental Tyres) have announced ambitious plans for using recycled content in their products.[163] However, Indian players have not made similar commitments, given low consumer awareness and limited economic incentives.
- **Inadequate enforcement of regulations** such as EPR guidelines. While waste-management rules across multiple waste streams have been in effect since 2016, implementation remains a challenge. For example, recycling of e-waste stands at 14 percent, against EPR guidelines of 40 percent. [164]

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[162] World Consumer research report; UNDP Plastic Waste Management Program; CPCB Solid Waste Management Reports; Indian Textile Journal; Indian Council for Agricultural Research; Ministry of Steel; FAO; National Policy on Crop Residue Management by Ministry of Agriculture.

[163] Unilever, P&G, H&M and continental tyres company websites.

[164] CPCB.

Exhibit 90

## Current scenario and recycling targets assumed in the LoS scenario for India's 750-800 million tons of annual waste generation.

| | **Waste, 2019** Mt | | **Recycling rates** percent of total waste | | | | |
|---|---|---|---|---|---|---|---|
| **Waste stream** | **Generated** | **Recycled** | **Current recycling** | **Global bench marks** | **LoS scenario (2050)** | **Current regulation** | **Current applications** |
| **Construction & demolition (C&D)** | 150 | 2 | 1% | 80% (Norway) | 30% | C&D Waste-management Rules 2016 | Mostly mismanaged;<br>limited steel recovery |
| **Plastics** | 15 | 4 | 25% | 66% (EU – packaging waste) | 66% | Plastic ban (state & central level);<br>EPR on plastic waste<br>(70-90% recycling by 2030) | Some types of plastics recycled (e.g., PET to polyester and rPET) |
| **Municipal solid waste** | 62 | 20 | 32% | 67% (Germany) | 47% | Solid-waste management<br>rules, 2016 | RDF, waste-to-energy |
| **Fashion / textile** | 1.0 | 0 | ~0% | 75% (Germany) | 16% | NA | Downcycled into blankets, etc. |
| **E-waste** | 1.1 | 0.2 | 14% | 47% (Sweden) | 29% | EPR* on e-waste<br>(70% recycling by 2030) | Precious metal recovery<br>Refurbishment |
| **Automotive (end-of-life vehicles)** | 5.8[1] | 4[1] | 70% | 96% (Sweden) | 75% | Vehicle scrappage policy, 2021 (21 million vehicles by 2025) | Metal – recycled steel, aluminium, etc. |
| **Tyres and rubber** | 1.4 | 0.1 | 7% | 100% (Sweden, Germany, Norway) | 23% | EPR on tyre waste | CRMB in road construction |
| **Agriculture (crop residue)** | 500 | 360 | 72% | N/A | 87% | National policy for management of crop residues, 2014 | Paddy straw – incinerated;<br>Others – cattle feed, biomass, etc. |

[1] 2021 estimate.

Source: World Consumer research report; UNDP Plastic Waste Management Program, CPCB Solid Waste Management Reports, Indian Textile Journal, Indian Council for Agricultural Research, Ministry of Steel, Building Material Promotion Council, FAO, Steel recycling, Ministry of Steel – Steel Scrap recycling policy, National Policy on Crop Residue Management by Ministry of Agriculture.

India is dependent on the unorganised sector for waste collection, which means only high-value waste is collected. As a result, recycling rates are higher in waste streams with strong economic incentives such as steel (vehicle recycling rates in India are greater than 70 percent) and PET bottles (80 percent recycling, including conversion to rPET and polyester), and much lower for construction and e-waste.[165]

— **Insufficient investment in infrastructure** for collecting, sorting and processing waste streams. For example, there are only four waste-management facilities in Delhi, compared to Tokyo with 19 facilities for a similar population.[166] The lack of data collected at waste-stream level regarding the collection, sorting and recycling of post-consumer waste also poses challenges.

## The LoS scenario

While policies exist (Exhibit 90), due to a lack of infrastructure, the country is not able to reach target recycling rates. We estimate that with continuous improvement in the necessary infrastructure for collection, sorting and recycling of all waste streams, recycling rates can be increased to 38 percent (currently at 13 percent) for non-agricultural waste streams, and 87 percent (currently at 72 percent) for crop residue by 2050. This level of material circularity could help abate emissions of 440 $MtCO_2e$ per annum by 2050 and 1.16 $GtCO_2e$ per annum by 2070 across all sectors.

These gains will likely require significant investment. Moreover, distributed waste generation, high recovery costs for remote locations and long lead times to drive consumer-habit changes could lead to delayed achievement of EPR targets for waste streams like e-waste, plastic and tyres, even though recycling technologies for these exist.

Use of recycled materials as feedstock can lead to emission reductions in the steel, cement, agriculture, chemicals and aluminium industries, as well as lower emissions from landfills (Exhibit 91). Exhibit 92 shows examples of cross-sector utilisation of recycled materials across waste streams.

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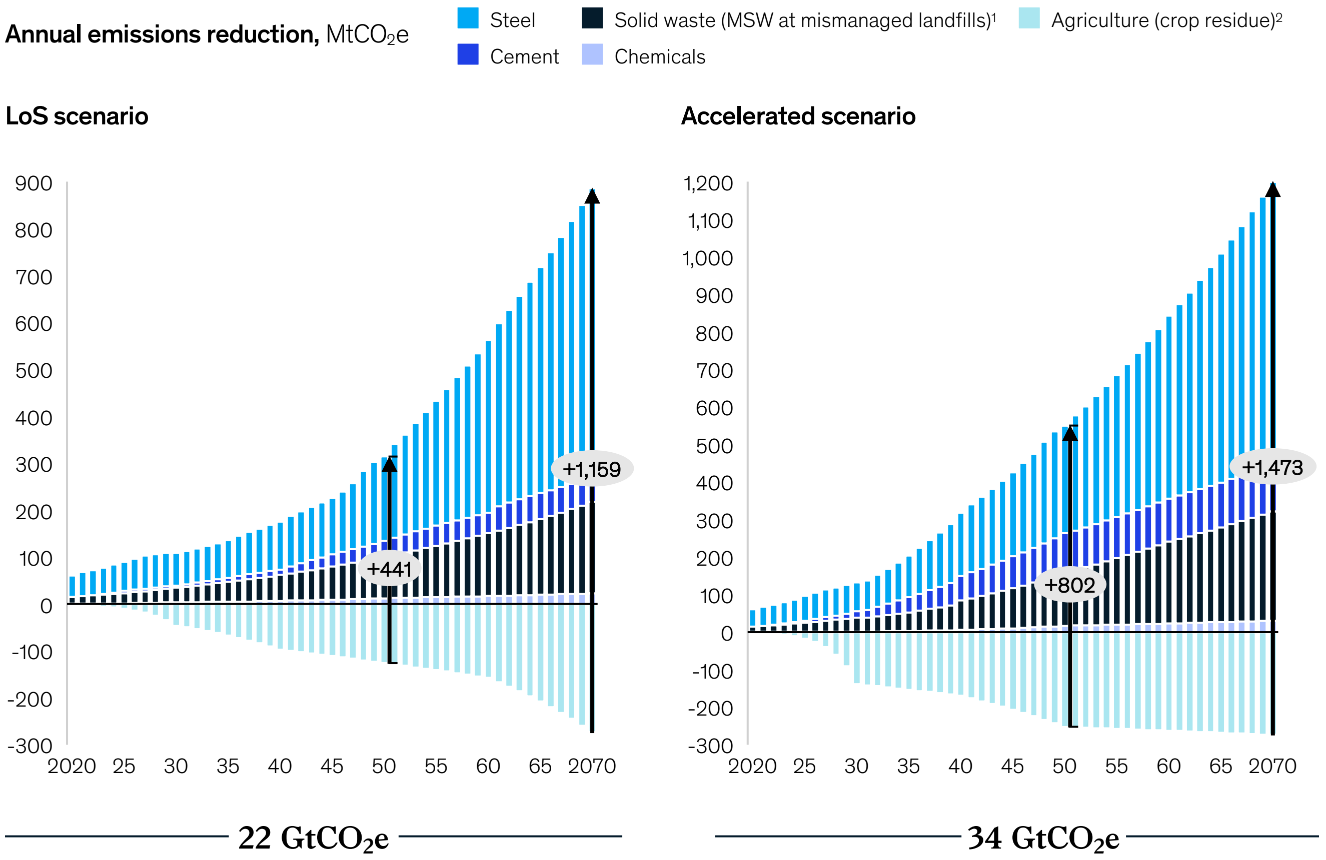
[165] CPCP; PlastIndia foundation.

[166] DPCC, Japan government - WTE plants comparison.

Exhibit 91

## Emissions reduction by driving material circularity across sectors.



1. Emissions from mismanaged landfills from MSW (Municipal Solid Waste) containing organic and inorganic waste including paper, plastic, textiles among others
2. Sequestration through non incineration-based uses of crop residue (e.g., paddy straw).

Source: World Consumer research report; UNDP Plastic Waste Management Program, CPCB Solid Waste Management Reports, Indian Textile Journal, Indian Council for Agricultural Research, Ministry of Steel, Building Material Promotion Council, FAO, Steel recycling, Ministry of Steel – Steel Scrap recycling policy, National Policy on Crop Residue Management by Ministry of Agriculture.

Exhibit 92

## Cross-sector utilisation of recycled raw materials could accelerate material circularity across waste streams.

**Illustrative**

| Waste stream | Annual waste generation | Examples of cross-sector applications |
|---|---|---|
| **Construction and demolition waste** | 150 MTPA | • Steel from scrap<br>• Recycled concrete, artificial limestone, clinker replacement, limestone replacement in cement<br>• Recovered plastics, other materials reused for chemicals<br>• Glass recycling<br>• Recycled aggregates for construction |
| **Plastics** | 15 MTPA | • Alternative fuel (not carbon neutral) for cement<br>• Liquid fuel through pyrolysis for use in generators Mechanical recycling-based applications such as construction material, roads etc. |
| **Municipal solid waste (mixed)** | 62 MTPA | • Alternative fuel – Refuse Derived Fuel (not carbon neutral) for cement<br>• Organic MSW for SAF |
| **Fashion/textile** | 1 MTPA | • Post-consumer cotton as natural cellulosic feedstock for chemicals industry<br>• Post consumer cotton as natural cellulose input for recycled paper manufacturing |
| **E-waste** | 1.1 MTPA | • Steel from scrap<br>• Plastic components of e-waste as alternative fuel (not carbon neutral)<br>• Recovery of e-waste batteries for second life applications and stationary storage<br>• Recycled plastics as feedstock for chemicals |
| **Automotive (end-of-life vehicles)** | 5.8 MTPA[1] | • Steel from scrap<br>• Reusable parts/ refurbished cars |
| **Tyres and rubber** | 1.4 MTPA | • Alternative fuel (not carbon neutral) for steel<br>• Road construction (CRMB)<br>• Recycled/sustainable carbon black production for chemicals |
| **Agriculture (crop residue)** | 500 MTPA | • Biomass- alternative fuel for steel and cement<br>• Bio-ash - clinker replacement in cement and steel<br>• Plastic packaging/ tableware alternatives in steel<br>• SAF feedstock |

1. 2021 estimate.

Source: CPCB Waste Management Rules for C&D waste, Plastic waste, Solid waste (MSW), E-waste and Tyre waste; Extended producer responsibility on Plastics, E-waste, Tyres by Ministry of Environment (MoEFF , Steel recycling, Ministry of Steel – Steel scrap recycling policy, National policy on Crop residue management by Ministry of Agriculture, Team Analysis

## The Accelerated scenario

There is an opportunity to accelerate material circularity further and drive improvements in recovery and recycling. Dedicated policy, technology and infrastructure efforts could increase recycling rates across waste streams (Exhibit 93).

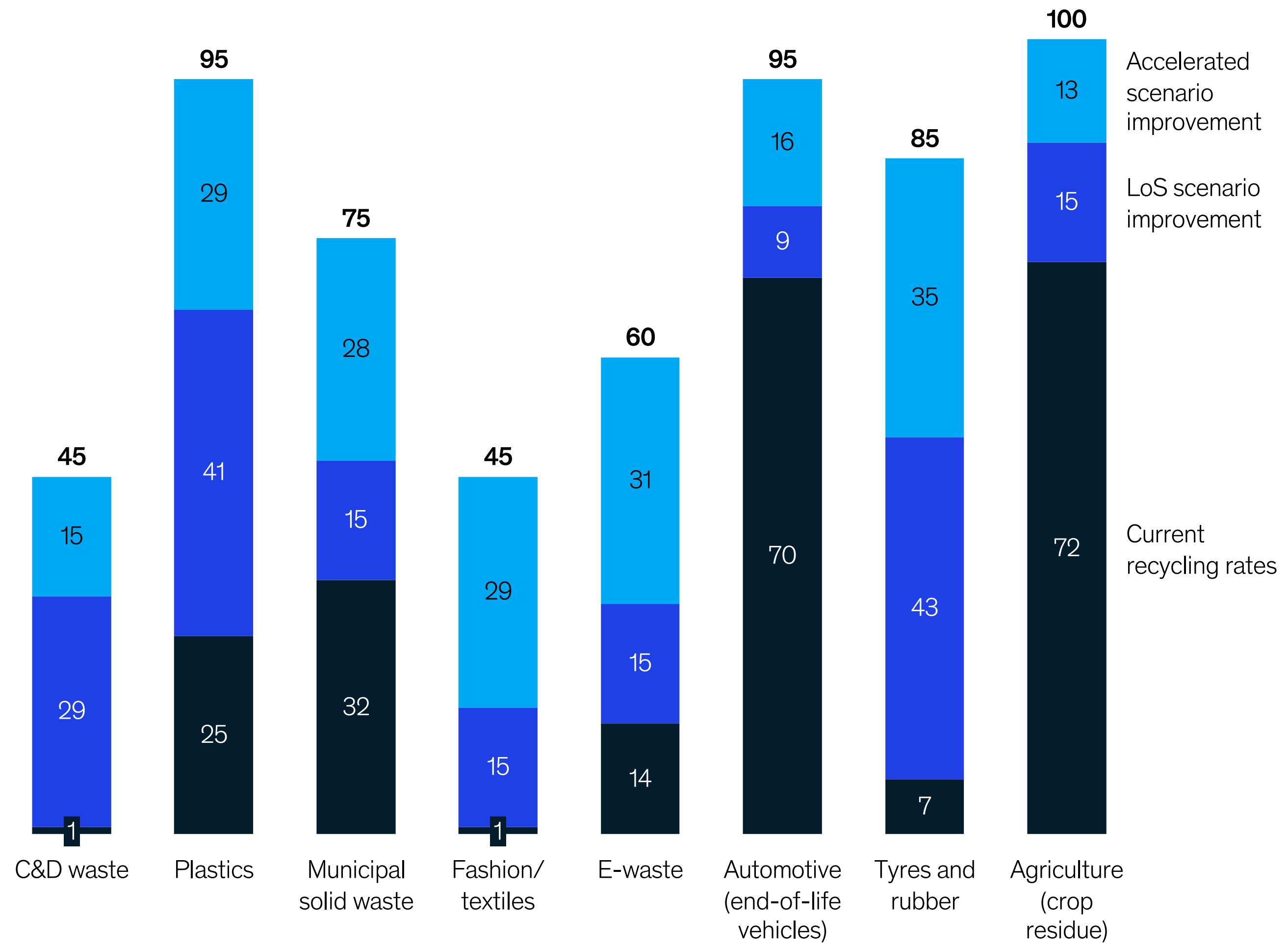
This acceleration could help abate 800 $MtCO_2e$ per annum of emissions by 2050, and 1.47 $GtCO_2e$ per annum by 2070, leading to a 50 percent higher abatement versus the LoS scenario (Exhibit 91).

This acceleration would likely require unlocks in waste-management policy, demand creation for recycled materials and improvements in recycling technology (Exhibit 94). It would also require an exponential increase in consumer awareness through collaborative efforts by the government, civil society and waste management organisations, to ensure waste segregation at source and the sustainable consumption of recyclable materials.

Exhibit 93

### Recycling rates can be improved across waste streams in India.

% Recycling



Source: UNDP, CPCB Annual Waste Reports, Indian Textile Journal, Indian Council for Agricultural Research, FAO, EAI

Exhibit 94

## Unlocks across demand drivers, waste management and technology needed for material circularity to reach full potential.

| | **Current** | **Accelerated scenario** | | | |
|---|---|---|---|---|---|
| **Waste stream** | **Current recycling** | **2070 target recycling %** (Accelerated Scenario) | **Key unlock: demand drivers** | **Key unlock: waste management** | **Key unlock: technology/process** |
| **Construction & demolition waste** | 1% | 75% | BIS standard revision on use of recycled concrete in cement & aggregates<br>Construction norms on recycled C&D waste; optimized cement use | Mandated targets on C&D recovery and recycling<br>Landfill levies | Material segregation automation<br>Decentralised/mobile material segregation units<br>Recycled concrete technology |
| **Plastics** | 25% | 95% | Labeling guidelines on recycled content<br>Carbon price on virgin plastics use | Phasing out of multi-layered plastics & other hard to recycle plastics<br>Labeling guidelines on recycled content | Chemical recycling<br>Food contaminated plastics recycling<br>Multi-layered plastics recycling |
| **Municipal solid waste (Mixed)** | 32% | 100% | Demand signals for Refuse Derived Fuel use as fuel<br>Demand signals for organic MSW as feedstock for biogas, SAF, co-processing etc | Mandated segregation at source<br>Landfill levies for bulk waste generators<br>Decentralized waste management mandates | Refuse Derived Fuel<br>Energy recovery efficiency improvement |
| **Fashion / textile** | ~0% | 75% | Eco-labels guidelines<br>Mandated transparency on labels, communication of chemical, water & carbon footprint | Circularity policy for textiles, pre & post consumer waste<br>Design for circularity: guidelines on blending fabrics; guidelines on recycled fabric use | Fiber level recycling<br>Dye removal technologies<br>Blended fabric recycling |
| **E-waste** | 14% | 80% | Carbon price on virgin materials use<br>Refurbishment guidelines for second life use | Mandated EPR targets on all e-waste<br>Landfill levies | Multi-stream recycling facilities (precious metals, plastics both can be recycled vs. only metal recovery) |
| **Automotive (end-of-life vehicles)** | 70% | 95% | Carbon price on virgin material use<br>Guidelines on refurbished cars quality & emissions | Vehicle scrappage policy implementation<br>Authorised recycler regulations & checks | Design for circularity<br>Scrap metal recovery techniques |
| **Tyres and rubber** | 7% | 85% | Carbon price on virgin materials use<br>Refurbishment guidelines for second life use e.g. Re-treading | EPR on tyre waste, rubber waste<br>Guidelines on recycled content & labelling of recycled content | Tyre recycling technologies<br>Technology for production of carbon black, other raw materials from waste tyres |
| **Agriculture (crop residue)** | 72% | 100% | Alternate uses of collected crop residue such as molded products (packaging/ tableware), carbon neutral biomass applications etc. | Biodecomposer incentives<br>Subsidies, awareness incentives for collection of crop residue vs incineration | Bio-decomposer<br>Innovative farm equipment to collect paddy straw (eg: Takachar)<br>Disposable packaging solutions / tableware (eg: Bio-lutions, Zume) |

Source: CPCB Waste Management Rules for C&D waste, Plastic waste, Solid waste (MSW), E-waste and Tyre waste; Extended producer responsibility on Plastics, E-waste, Tyres by Ministry of Environment (MoEFF) , Steel recycling, Ministry of Steel – Steel scrap recycling policy, National policy on Crop residue management by Ministry of Agriculture, Team Analysis

## Material circularity investment and implications

The acceleration of material circularity will likely require significant capital and operational expenditure (Capex and Opex) for collection, sorting and processing of waste (Exhibit 95). An estimated Capex investment of $660 billion would likely be required by 2070 in the Accelerated scenario ($220 billion more than in the LoS scenario), with the majority going towards recovery and recycling infrastructure for construction (one percent recycled) and plastic waste (25 percent recycled).[167]

Opex costs for collection, sorting and processing of waste are projected to be an average $74 billion annually till 2070; cumulatively $3.7 trillion in the Accelerated scenario ($820 billion more than LoS). However, there is already a demand for high-quality recycled raw material across sectors like steel, aluminium and plastics, which could help absorb the Opex and Capex costs of recycling.

Moreover, with the right enablers (such as blending mandates, percentage recycled material and carbon pricing), the creation of demand signals for recycled raw material could enable a green premium. This is already happening in markets such as the EU, where recycled raw materials sell at a 15–30 percent premium over virgin materials.[168] Additionally, imported materials, particularly precious rare-earth materials, scrap steel and aluminium can be reduced.

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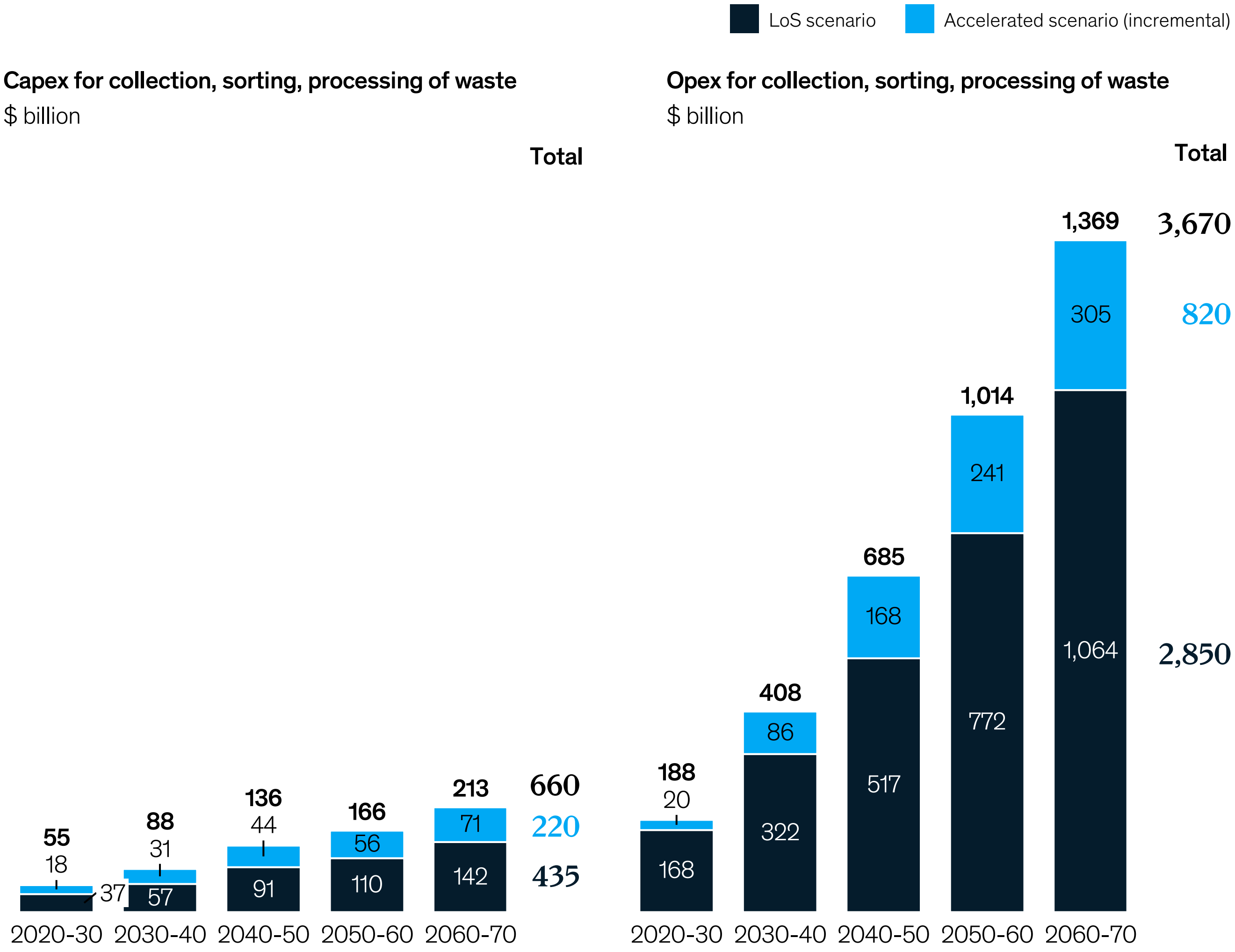
[167] Analysis based on data from CPCB, CSE, UNDP and Indiastat.

[168] Breakthrough energy; Forbes; McKinsey analysis.

Exhibit 95

### Capex investment and opex would be needed to accelerate the recycling infrastructure set-up.



Source: CPCB data, Press search, McKinsey CI Circular, CEIC Cost of paddy cultivation, Profound Market Research for Construction Waste, Expert interviews, Team analysis

There is the potential to save $720–730 billion in imports by 2070 by creating recycling hubs for new waste streams such as EV batteries. By investing early in technology, regulations (for both waste management and demand signals) and infrastructure for cell-level recycling of end-of-life batteries, up to 90 percent of precious raw materials could be recovered. This could help meet the growing demand for precious-metal batteries—lithium iron phosphate (LFP) and nickel manganese cobalt (NMC) due to growth in EVs, consumer electronics and long-duration storage (Exhibit 96). Once EV battery recycling occurs at the right quality, India could also recycle the world's end-of-life EV batteries.

## Proposed enablers for accelerating material circularity

Driving material circularity across all waste streams will likely require shifts in policy and regulation, significant investment in infrastructure and support for technological innovation.

**Demand signals to encourage recycling of waste could include:**

- Landfill levies to reduce waste generation and promote reuse of material and circularity in production.
- EPR frameworks that include blending mandates to create demand signals for recycled raw-material use, similar to current policies for plastics. Mandates and recommended targets, similar to the EU's Circularity Action Plan, could be considered.[169]
- Signals for recycled and low-carbon

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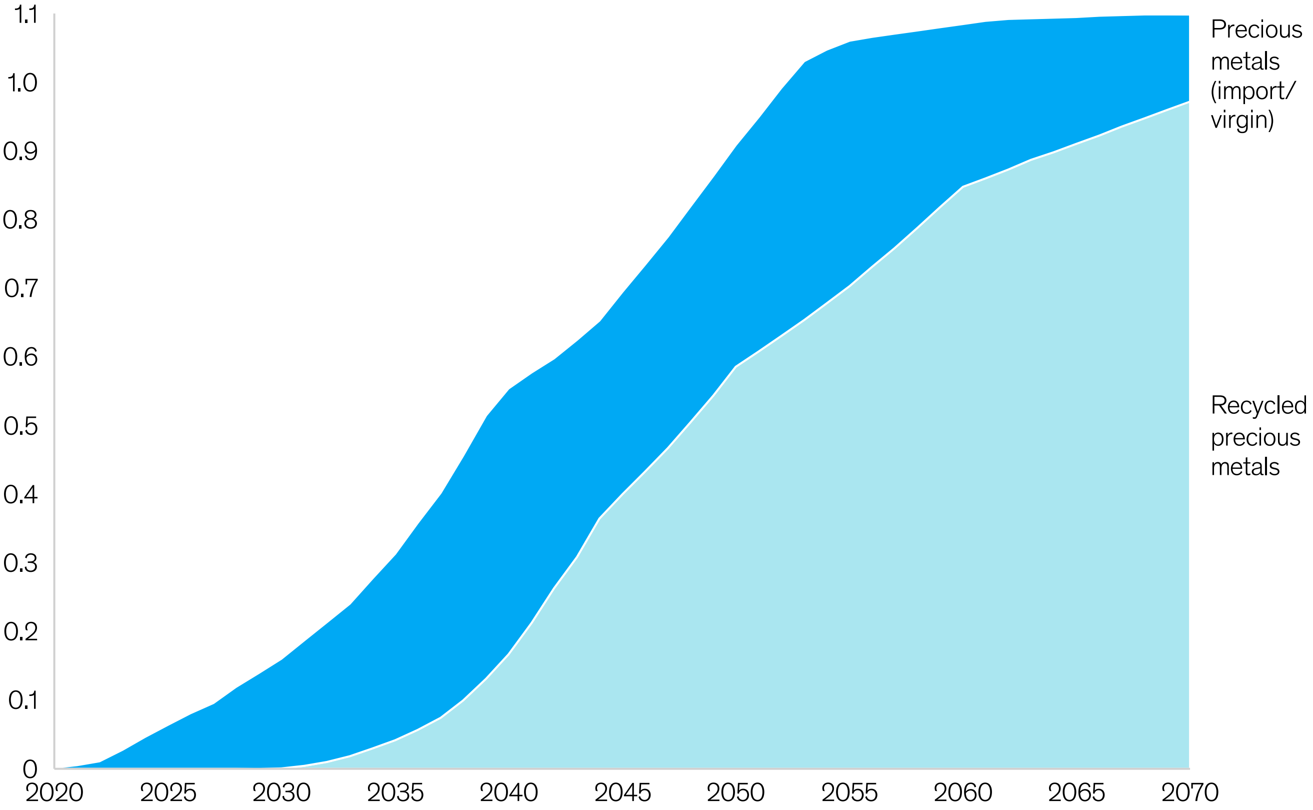
[169] EU circular economy action plan.

Exhibit 96

### Circularity for precious metals can reduce import dependence for batteries (LFP, NMC).

**Contribution of recycled precious metals to total precious-metal demand for batteries in Accelerated scenario**

MMTPA



1. 60-65% of precious metals demand can be met by recycled metals by 2050 (80-90% by 2070)
2. Second-life usage of batteries for stationary purposes can help utilise remaining battery life. Recommended second-life usage at 5-7 years of usage life
3. End-of-life recycling at cell level can help recover lithium, nickel, manganese and cobalt from NMC and LFP batteries.
4. Investment in battery recycling technology is crucial to help achieve up to 90% recycling rates.

Source: McKinsey Battery Insights, Press Search, Expert interviews, team analysis products. For example, carbon pricing on emission-heavy, virgin, raw-material-based products can help create demand signals for recycled raw materials.

**Policies and regulations for waste management could include:**

- Stringent enforcement and accelerated implementation of existing EPR regulations and waste-management rules (e.g., for plastic waste, tyre waste and e-waste) could achieve specified recycling targets much faster than in LoS.
- New policies could be considered for existing mismanaged waste streams (such as textiles and construction waste) and upcoming ones (EV batteries, solar panels and windmill blades). India can take inspiration from material-recovery and circular-economy strategies successfully adopted by the EU, Australia, China and the US (Exhibit 97).[170]
- Policies for registration and operation of recycling facilities could be considered to ensure quality and safety standards.

**Investment in technology** for improved recycling and waste management:

- Technological innovations and scale-ups, such as chemical recycling, could help to manage waste across multiple streams, such as plastics, textiles, windmill blades and solar panels.
- Digitisation of waste-collection information, especially for post-consumer waste, could significantly improve collection and sorting rates across streams in a cost-effective and efficient manner.

**Investment in setting up infrastructure** for collection, sorting and processing of waste could be considered:

- Innovations such as mobile waste-sorting vehicles to improve construction waste collection rates, and for sorting and reuse on-site; static sorting centres to manage remaining construction waste, reducing transportation costs.
- Dedicated zones for recovery and recycling across multiple waste streams. This could reduce recycling facilities' Capex and Opex investments by up to ten percent (versus distributed facilities) and facilitate transportation from one stream to another—plastics from e-waste, for example, could be transported to a plastic-recycling facility in the same zone.

With these enablers in place, India can move away from the current waste-generating production system toward a closed-loop, circular economy that maximises value in a sustainable manner.

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[170] EU Circular economy action plan; Waste Levy under Environmental Protection Act, Australia; China Scrappage Program; US Car Allowance Rebate System.

Exhibit 97

## Global policies & steps taken to drive material circularity.

| Waste stream | Regulations in other countries/ regions | Countries/regions | Potential action for India |
|---|---|---|---|
| **Construction & demolition waste** | Waste Framework Directive in EU –C&D waste is a priority waste stream | EU | Landfill levies for C&D waste; maximize reuse at point of waste generation through distributed material recovery |
| **Plastics** | Plastic bans on single-use plastics<br>Extended producer responsibility | UK, EU, Australia, China | Strict implementation of bans and EPR<br>Consumer awareness |
| **Municipal solid waste (Mixed)** | Waste levy under Environmental Protection Act in Australia | Australia | Incentivise resource recovery |
| **Fashion/ textile** | EU strategy for sustainable and circular textiles | EU | Ecodesign & ecolabels for clothes<br>Bans on destruction of unsold products |
| **E-waste** | Waste from Electrical and Electronic Equipment (WEEE) in EU | EU | Product as a service to ensure end-of-life recovery |
| **Automotive (end-of-life vehicles)** | US car allowance rebate system, Germany - 'Umwelt pramie' scheme, China's scrappage program, Canada's "Retire Your Ride" program | US, Germany, China, Canada | Incentive on new cars post scrapping– partly by government, partly by OEMs |
| **Tyres and rubber** | EPR on tyre waste, landfill directives and levies | EU | Guidelines on retreading, design for circularity and longer use, repair<br>Technology investments |
| **Agriculture (crop residue)** | Bio-energy (62 countries)<br>Compost production in China, SE Asia, Nepal | China, SE Asia, Nepal | Alternatives offered to farmers – bio-energy, bio-ethanol, short-duration paddy |

Source: EU Regulations, Australia Environment Protection Act, Press Search

# 3.3 Natural climate solutions

## Key takeaways

**Natural climate solutions can help avoid, reduce and sequester GHG emissions** through the conservation, restoration and improved management of natural or modified ecosystems. Currently, India's forests, wetlands and croplands sequester an estimated 345 $MtCO_2e$ annually.[171]

**In the LoS scenario, this sequestration could increase to roughly 411 $MtCO_2e$ by 2050.** Over 95 percent of the carbon removal and emission avoidance would come from land-based solutions, not accounting for less-explored coastal or blue-carbon solutions.

**In the Accelerated scenario, India's NCS potential could increase to 644 $MtCO_2e$ by 2050,** leading to additional cumulative sequestration of 3 $GtCO_2e$ between 2020–2050, and over 7 $GtCO_2e$ by 2070. Nearly 85 percent of sequestration in the Accelerated scenario would come from forests, agroforestry and regenerative agriculture. This would require restoring an additional 8 million hectares of forests (over ten percent of current forest cover) and practising regenerative agriculture, such as low-till farming, in at least half of India's croplands.

**New solutions would be needed to sequester the remaining emissions** (~400 $MtCO_2e$ per year in 2050 in the Accelerated scenario) and achieve net zero. India will likely have to explore emerging and nascent blue-carbon solutions, such as seaweed farming and ocean fauna. This would require investment in research and comprehensive marine protection policies.

**Accelerating NCS offers several upsides.** Cumulative carbon credits from sequestration could amount to more than $480 billion by 2070. NCS would also have numerous social and environmental co-benefits, such as biodiversity protection; air, water and soil sustainability; and mitigation and adaptation to climate hazards.

**Accelerating adoption in a fast-growing economy will be challenging.** It could require a total investment of around $160 billion by 2070—$110 billion more than in the LoS scenario. Incentivising investments in NCS would require structural interventions, such as setting up domestic carbon markets and creating natural capital solutions to convert natural resources into investible assets. Regional road maps could also drive implementation to deliver high-impact NCS projects.

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[171] TERI.

## Context

NCS have a major role to play in avoiding, removing and sequestering GHG emissions, while offering benefits for society and the environment.

The different facets of the Indian economy are expected to continue emitting around 1.4 $GtCO_2e$ annually till 2050, even in an Accelerated scenario. Abating this would require carbon removal through technologies like CCUS, DAC and NCS.

NCS refers to the conservation and restoration of natural ecosystems to increase their carbon-storage potential and avoid GHG emissions. This includes the protection of a range of natural resources such as forests, mangroves and peatlands. Compared to other sequestration methods, NCS are cost-effective; support biodiversity, water and soil sustainability; and can help climate adaptation, e.g., with mangrove restoration helping to mitigate the impact of floods.

NCS can contribute to mitigating emissions in two ways: through the avoidance and reduction of emissions (caused by, for example, deforestation) and through the removal of emissions already in the atmosphere, such as reforestation and mangrove restoration. Both land-based and coastal- or ocean-based solutions, such as conserving saltmarshes and seagrass beds, can help with climate change mitigation.

Globally, net-zero pathways rely on the sequestration of carbon through natural solutions. In fact, NCS are estimated to have the potential to deliver up to one-third of the global net emissions-reduction requirements by 2030. Countries such as the United Kingdom have already formulated comprehensive NCS road maps and achieved early wins (Exhibit 98).

## Natural solutions

Maximising carbon sequestration involves both conserving existing resources and restoring those that are depleted. India hosts some of the world's most biodiverse ecosystems, such as the Himalayas and the Western Ghats and is home to several natural resources that can be leveraged to maximise carbon sequestration. The country has the tenth-largest forest area globally, with 72 million hectares of forested land.[172]

Despite ongoing deforestation, India's forest cover has historically seen net growth, increasing from around 20 percent of total area in 2000 to nearly 22 percent in 2020.[173] India's coastal mangrove forests amount to a total area of about 350,000 hectares.[173] The country also has a continuous coastline of about 5,500 km on the mainland and a total coastline of over 7,500 km.[174]

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[172] FAO.

[173] Our world in data.

[174] Ministry of external affairs.

Exhibit 98

### The United Kingdom has comprehensive NCS commitments across key segments.

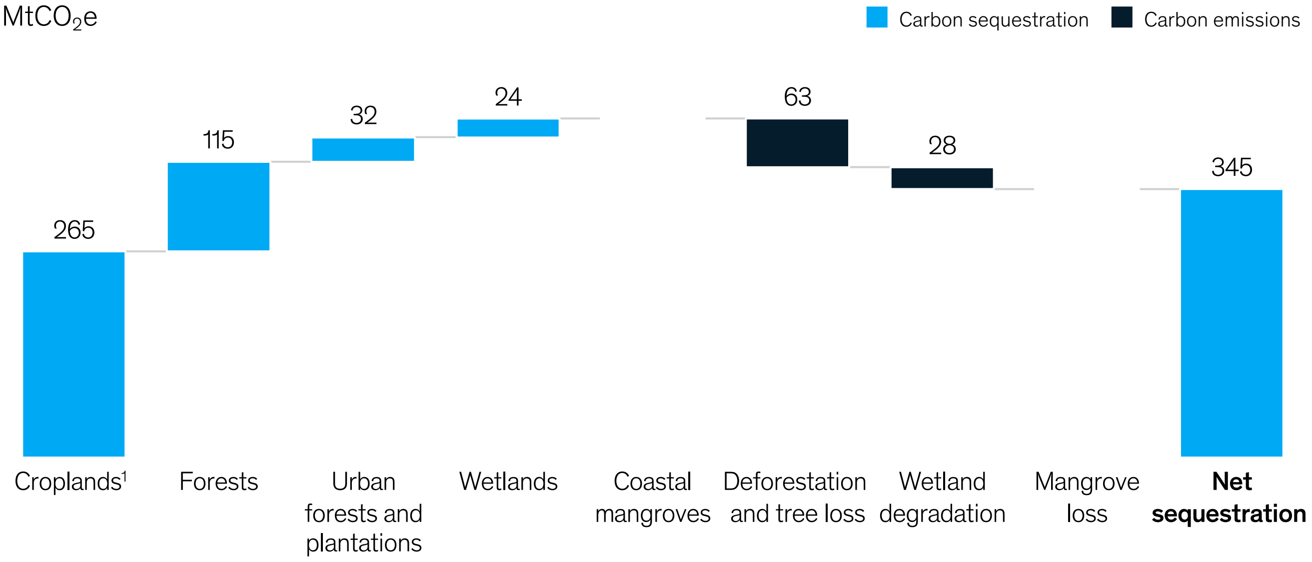
| Segment | | Key commitments | Interventions |
|---|---|---|---|
| **Land-based solutions** | **Forests and tree cover** | • Plant 30,000 ha/year by 2025<br>• Halt and reverse forest loss and land degradation by 2030 | • **'Landscape Recovery'** scheme to support large-scale tree and peatland restoration projects. Planned projects to cover 20,000 ha by 2024<br>• Subsidies for low-carbon farming under a **'Sustainable Farming Incentive'** scheme<br>• Phase out sales of horticultural peat by 2024<br>• **Nature for Climate Fund –** public funding for tree planting and peat restoration<br>• **'Local Nature Recovery'** scheme to support nature recovery projects which deliver local environmental priorities. Will map 50 'strategies areas' across England |
| | **Croplands** | • 60% of agricultural soil under sustainable management by 2030<br>• 85% of farmers practicing low-carbon farming by 2035 | |
| **Blue carbon** | **Peatlands** | • Restore 280,000 ha of peatland by 2050; at least 35,000 ha by 2025 | |
| | **Oceans** | • Establish at least 30% of marine areas for nature by 2030 | |

Source: UK parliament; press search

Exhibit 99

## India's forests and croplands act as key natural carbon sinks.

**Estimated annual $CO_2$ emissions and sequestration by India's natural resources in 2019**



1. Potential as estimated in India's submission to UNFCCC

Source: Global Forest Watch; TERI; UNFCCC; World Resources Institute

India's forests, wetlands and mangroves currently remove more carbon than they emit, leading to a net annual sequestration of 345 $MtCO_2e$ (Exhibit 99). However, the country's rapidly growing cities and farmlands are threatening these natural ecosystems. Despite net increase in forest cover, between 2001 and 2021, India has lost over two million hectares of tree cover, a 5.3 percent decrease since 2000, resulting in cumulative emissions of 1 $GtCO_2e$.[175]

## The LoS scenario

In the LoS scenario, India's annual carbon sequestration from NCS could increase to roughly 411 $MtCO_2e$, assuming historical growth rates of forest and agroforestry.[176] Over 95 percent of this removal would come from land-based solutions; coastal or blue-carbon solutions are typically less mature and more expensive, and thus are not widely explored beyond currently available technologies.

Agroforestry would play a big role, accounting for nearly half of the total NCS potential. India's agroforestry policy could see nearly a third of croplands used for regenerative farming practices, with the opportunity to create tree plantations on more than half of the country's crop and pasture lands by 2050.[177] This would replenish and augment the current stock of soil organic carbon.

While the solutions for the LoS scenario are known, focused implementation will still be required to deliver them. Policies such as the Green India Mission (GIM) and India's Paris commitments would see both forest restoration and deforestation continuing at current rates, with positive actions undertaken only in areas that are economically feasible and not suited for agriculture.

## The Accelerated scenario

In this scenario, conservation and restoration of natural sources could result in an additional 233 $MtCO_2e$ sequestered annually by 2050.[178] This translates to additional sequestration of around 2.5 $GtCO_2e$ to 3$GtCO_2e$ between 2020–2050, and over 7$GtCO_2e$ by 2070. Much of this is through land-based solutions—driven by forest conservation and large-scale adoption of agroforestry. These would contribute nearly 85 percent of the total NCS potential in the Accelerated scenario (Exhibit 100).

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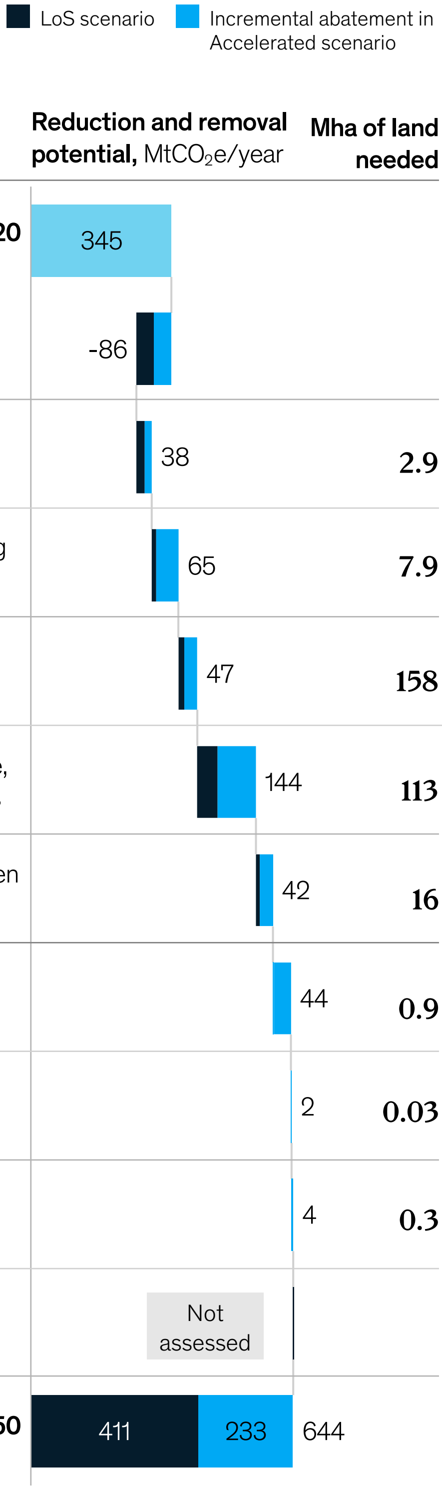
[175] Global forest watch.
[176] Calculated as the restoration potential of forests and croplands in economically feasible zones and based on historical growth rates.
[177] Our world in data.
[178] Assumes a scenario where the maximum theoretical potential for restoration is achieved, including in areas that are less economically feasible.

Exhibit 100

## Regenerative agriculture and restoration of forests could lead to nearly 85% of the NCS potential.

|  | Segment | Solution | Description | Reduction and removal potential, $MtCO_2e$/year | Mha of land needed |
|---|---|---|---|---|---|
|  |  |  | **Abatement in 2020** | 345 |  |
|  |  |  | Expected decline in soil sequestration potential with increasing cultivation[1] | -86 |  |
| **Land-based solutions** | **Forests** | Avoided deforestation | Avoiding emissions by preventing deforestation and forest conversion | 38 | 2.9 |
|  |  | Reforestation | Densifying current forests and reforesting recently deforested lands | 65 | 7.9 |
|  | **Agroforestry** | Trees in cropland, pastures | Integrating trees into croplands, creating above-and below-ground biomass | 47 | 158 |
|  |  | Regenerative agriculture | Soil $CO_2$ sequestration by reducing tillage, planting cover crops and sowing legumes | 144 | 113 |
|  | **Urban settlements[2]** | Tree plantations | Plantations along roads and creating green spaces in urban areas | 42 | 16 |
| **Blue carbon** | **Coastline** | Wetlands | Restoring fresh- and saltwater wetlands such as peatland and tidal marshes | 44 | 0.9 |
|  |  | Mangroves | Restoring degraded mangroves and avoiding degradation of existing mangroves | 2 | 0.03 |
|  | **Oceans** | Seagrass | Avoiding seagrass degradation and restoring degraded seagrass beds | 4 | 0.3 |
|  |  | Other ocean sequestration | Next-gen technologies and other unexplored blue carbon sinks | Not assessed |  |
|  |  |  | **Abatement in 2050** | 411<br>233<br>644 |  |



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1. Estimated based on soil sequestration rates in India's UNFCCC submission.
2. Based on estimates from Forest Survey of India's Technical Information Series.

Source: McKinsey Nature Analytics, based on: FAO FRA (2015), FAOSTAT, Global Mangrove Watch, Bastin et al. (2019), Busch et al. (2019), Chapman et al. (2020), Cook-Patton et al. 2020, Griscom et al. (2017), Griscom et al. (2020), Poeplau & Don (2015), Runck et al. (2020), Pendleton et al. (2012), Veldman et al. (2019), Li et al. (2020), Leifield & Menichetti (2018), Joosten (2009), Xu, Jiren, et al. (2018), Prestele et al., (2018), Ogle et al., (2019), Santoro, (2018); Buchhorn et al., (2020); Ramankutty et al., (2008), Shulze et al. (2018), Henderson et al. (2015); Copernicus Global Land Service, 2019; WRI Aqueduct; Portmann et al., 2010

— **Deforestation:** Deforestation has caused nearly 50 $MtCO_2e$ per annum in emissions since 2000 in India.[179] Five states combined—Assam, Mizoram, Nagaland, Arunachal Pradesh and Manipur—contributed to 60 percent of all forest loss. Over 90 percent of deforestation is driven by the forestry sector (wood and non-wood products).[180] In an economically feasible scenario, given that cropland conversion is an inevitable consequence of population growth, India could prevent at least half of its projected deforestation through conservation efforts.

— **Reforestation and densification:** Countries that are closer to the equator (i.e., tropical biomes) are most efficient at removing $CO_2$ through reforestation. India's forest sequestration potential is eighth-highest globally. Efficient reforestation would likely require the restoration of eight million hectares of forests—over ten percent of India's current forest cover.[181] To achieve this, the growth in forest cover would need to double as compared to the last decade (Exhibit 101). India made a commitment in Paris to increase total forest and tree cover to 33 percent by 2030.[182] Given the current forest cover of around 22 percent and historical growth rate of 0.2 percent per annum from 2010–2020, India is currently not on track to meet this goal.[183]

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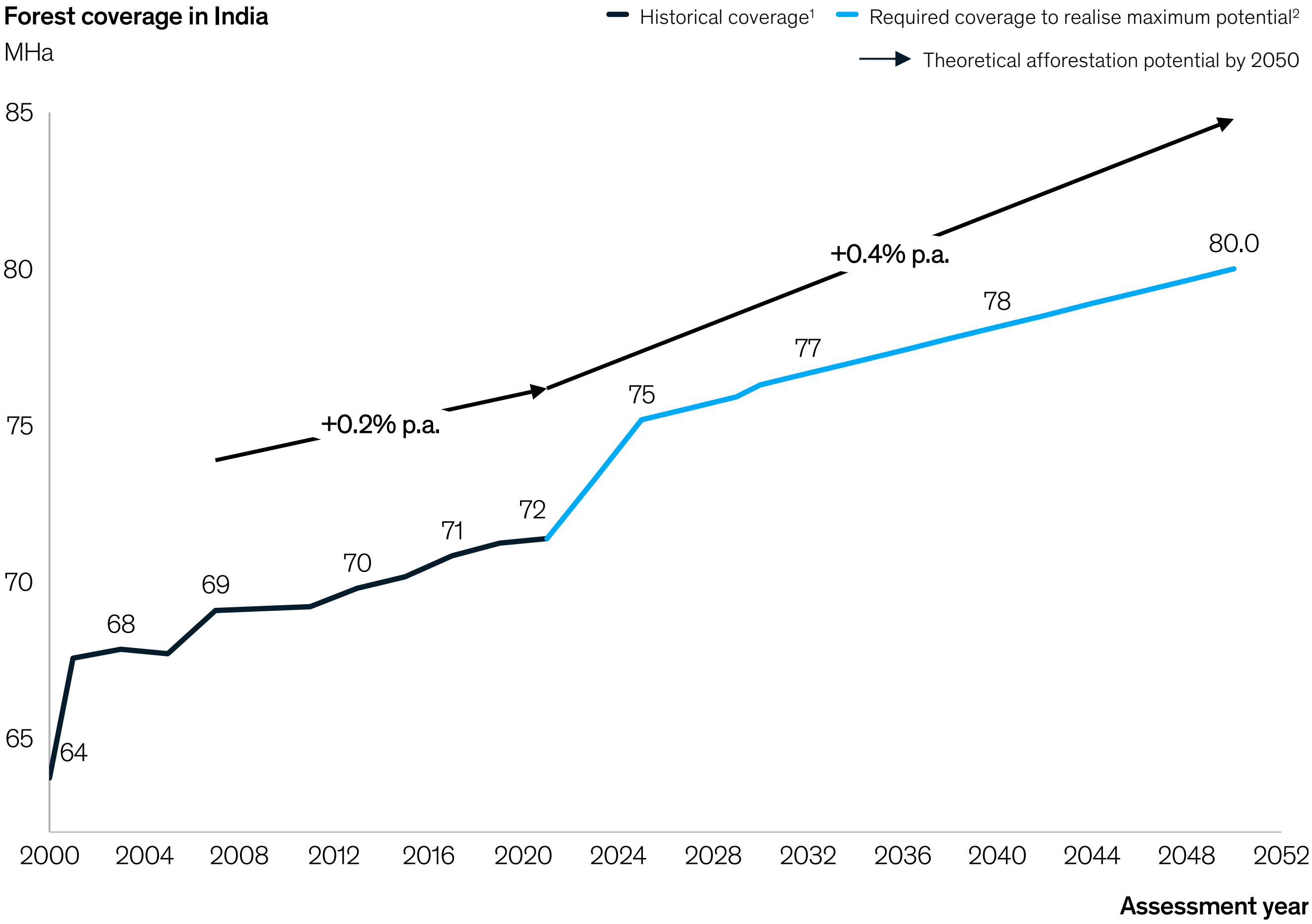
[179] There has been around 1 $GtCO_2e$ in emissions from 2001 to 2020 due to deforestation.
[180] Global forest watch.
[181] Our world in data.
[182] India's NDC.
[183] Global forest watch.

Exhibit 101

## Efficient reforestation would likely require doubling forest-coverage growth.



1. Spike from 2000-04 is due to revised forest accounting standards.
2. 2025 increase is assumed based on India's **Green India Mission (GIM)** target to reforest **5MHa by 2025.**

Source: Forest Survey of India Technical Information Series; India State of Forest Reports; McKinsey Nature Analytics

Densifying existing forests will play a crucial role, as moderately dense and very dense forests together constitute only half of India's current forests.[184] However, this has the potential to increase to 60 percent by 2050.[185]

- **Agroforestry:** Planting trees in over 80 percent of India's croplands could sequester around 45 $MtCO_2e$ to 50 $MtCO_2e$ per year by 2050. Farmers could plant trees on croplands and pasturelands to reduce carbon emissions, provide windbreaks and shelter for crops, prevent erosion, diversify production and maintain soil moisture levels. Agroforestry can also increase farmer incomes and improve rural livelihoods by producing useful by-products, such as tree-borne oilseeds, fuel wood and animal fodder.
- **Regenerative farming:** Using cover crops, sowing legumes on pasturelands and adopting zero or low tillage can help preserve soil biodiversity and improve soil organic-carbon stock. Adopting zero- or low-soil tillage in half of India's croplands could remove 134 $MtCO_2e$ (over 40 percent) of the remaining 322 $MtCO_2e$ emissions from agriculture by 2050 in the Accelerated scenario (Exhibit 102). Custom hiring of zero-tillage seed drills and tractors compatible with small farmers could help mitigate capital constraints.
- **Coastal and ocean-based (blue-carbon) solutions:** Blue-carbon solutions offer many co-benefits in addition to carbon sequestration. For example, mangroves preserve coastal habitats and enable nutrient retention in soil. They protect against climate adversities, such as storms, and have many socioeconomic benefits. Peat and other wetlands also have high value as wildlife habitats and preserve water quality, especially in cropland regions and downstream locations of fertilised croplands.

  India has unique potential here, with several emerging blue-carbon solutions, such as farming seaweed and ocean fauna (Exhibit 103). Tapping into this opportunity would

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[184] ISFR.

[185] Forest survey of India – technical information series.

Exhibit 102

## Zero- or low-soil tillage in half of India's croplands could remove >40% of remaining agricultural emissions by 2050.

**Regenerative agriculture in the Accelerated scenario**

| **Solutions** | **Description** | **Abatement potential by 2050,** $MtCO_2e$/year | **Required adoption,** MHa |
|---|---|---|---|
| **Cover crops** | Soil $CO_2$ sequestration by sowing cover crops outside the growing season | 0.3 | 0.3 |
| **Legumes on grazing lands** | Additional soil $CO_2$ sequestration by sowing legumes that fix carbon in pastures | 8.6 | 7.2 |
| **Optimising grazing land intensity** | Avoided $CO_2$ emissions by reducing grazing intensity | -0.9 | 3.5 |
| **No or low tillage** | Shallow cultivation or fewer tillage operations to reduce topsoil disturbance | 133.6 | 102.6 |
| **Total regenerative agriculture** | | **143.5** | **113.5** |

Source: McKinsey Nature Analytics based on: Griscom et al., 2017; Henderson et al. 2015; Prestele et al., 2018; Ogle et al., 2019; Copernicus Global Land Service, 2019; WRI Aqueduct; Portmann et al., 2010; FAO

Exhibit 103

## There are several blue-carbon solutions emerging in India.

● High ○ Low

| Category | Subcategory | Description | Scope in India |
|---|---|---|---|
| **Established NCS** | **Salt marsh** | Widely understood solution-conserving peatlands and salt marshes from degradation | ◕ >15 Mha of wetlands with high scope for conservation |
| | **Mangrove** | Avoiding mangrove loss and restoring mangrove plantations for sequestration | ◕ Plantations present across most coastal states; receives high attention |
| | **Seagrass** | Restoring seagrass beds for ocean sequestration | ◕ Present across the coastline; there are existing projects for conservation |
| **Emerging NCS** | **Kelp forests** | Kelp forests are made up of fast-growing plants capable of storing carbon | ○ Suited only for cold weather, deep oceans; no scope for India |
| | **Bottom-trawled sediments** | Fishing method of dragging weighted nets; better management can improve sequestration | ◑ Trawling is pervasive in India; reasonable scope for avoidance |
| | **Seaweed farms** | Protection restoration and extension of seaweed farms | ◕ Already moderately established in India; high potential for restoration |
| **Nascent NCS** | **Predators** | Support carbon stocks by maintaining ecological balance | ◑ Moderate shark populations offer reasonable potential |
| | **Mesopelagic fauna** | Support deep-sea sequestration by exporting biomass from surface layers | ◔ Migratory in nature. Not reliable for India |
| | **Whales** | Support deep-sea sequestration by enhancing phytoplankton carbon absorption | ◔ Whale populations are largely migratory; hard to evaluate impact |

Source: McKinsey Nature Analytics; McKinsey report - Blue carbon: The potential of coastal and oceanic climate action

require investment in nascent technologies and a ramp-up of efforts in marine conservation, such as a comprehensive marine protected areas (MPA) policy.

### Investments and other implications

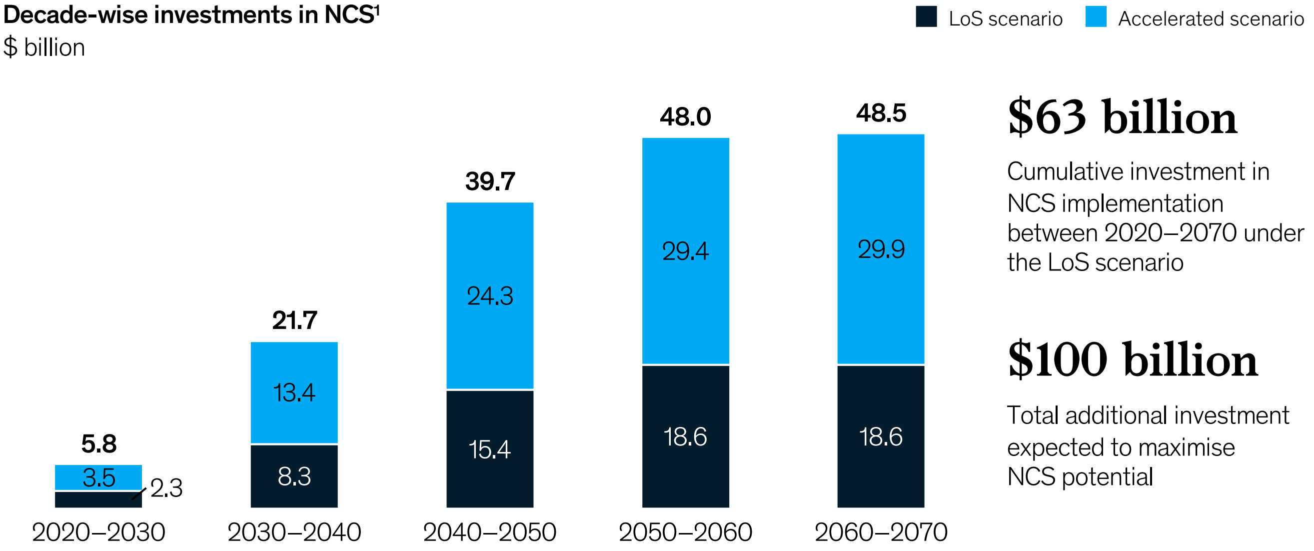
In the Accelerated scenario, implementing NCS to the maximum potential will likely require a total investment of $160 billion by 2070—almost two-and-a-half times the expected investment in the LoS scenario (Exhibit 104).

Accelerating NCS could help sequester additional carbon emissions of nearly 12 $GtCO_2e$ cumulatively by 2070—7.2 $GtCO_2e$ higher than in the LoS trajectory (Exhibit 105). This also offers numerous social and environmental benefits: biodiversity protection; air, water and soil sustainability; and mitigation of climate hazards like floods and storms.

Exhibit 104

## Maximising the potential of NCS will likely require an expected $160 billion in cumulative investments by 2070.

**Decade-wise investments in NCS**[1]
$ billion



**$63 billion**

Cumulative investment in NCS implementation between 2020–2070 under the LoS scenario

**$100 billion**

Total additional investment expected to maximise NCS potential

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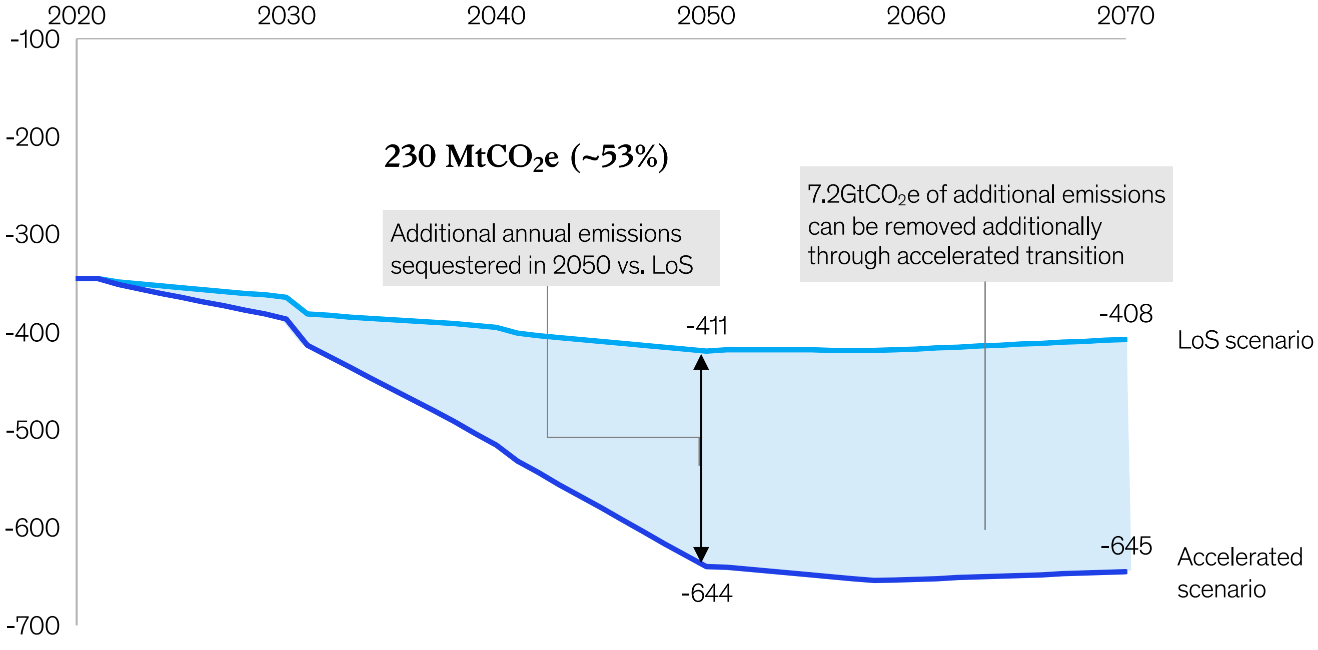
[1] Only considered Opex and investments, therefore investments will increase with an increase in the extent of NCS

Source: Modelled based on McKinsey Nature Analytics

Exhibit 105

## Accelerated NCS could sequester an additional 12 $GtCO_2e$ by 2070.

**GHG removal in NCS under different decarbonisation scenarios**
$MtCO_2e$



230 $MtCO_2e$ (~53%)

Additional annual emissions sequestered in 2050 vs. LoS

7.2$GtCO_2e$ of additional emissions can be removed additionally through accelerated transition

Source: McKinsey

Although acceleration may require additional investments—a total of $100 billion by 2070—all sequestration through NCS can be achieved at less than $50/tCO$_2$e, assumed as the carbon price in 2030 in the Accelerated scenario, making NCS an economically feasible and attractive investment (Exhibit 106).[186]

Accelerated action could generate carbon credits worth a total of $480 billion from 2030–2070, making it a net-positive opportunity if it is integrated well into domestic carbon markets.[187]

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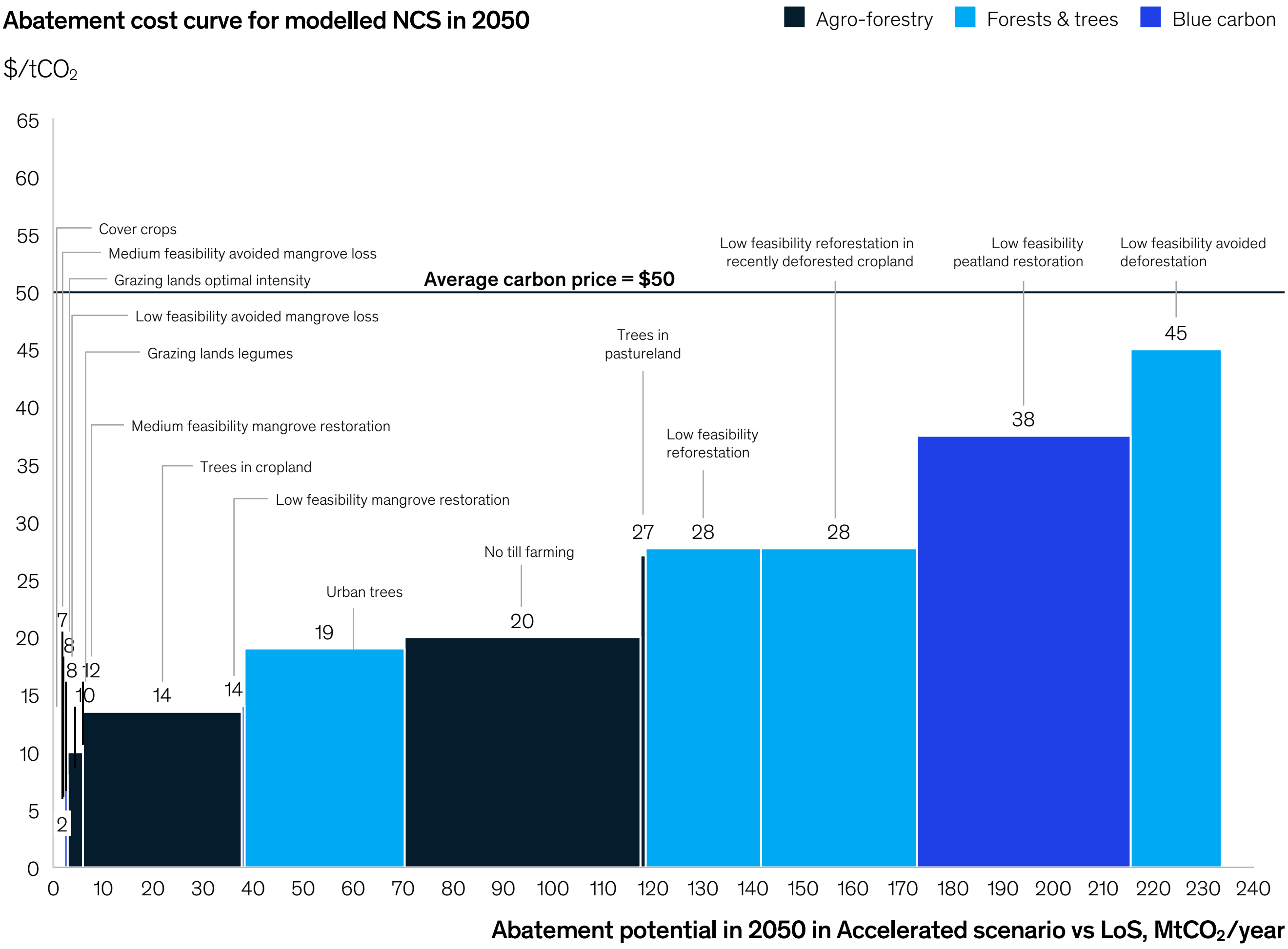
[186] Additional cost incurred due to incorporation of less economically feasible projects.

[187] Carbon price assumed to be $50 from 2030–2070.

Exhibit 106

## CO$_2$ abatement through NCS can be achieved below a carbon price of $50/tCO$_2$e.



Source: McKinsey Nature Analytics

## Actions to accelerate NCS

In addition to carbon sequestration, NCS have many environmental co-benefits (for example, mangroves offer protection against storms) which require unlocks (Exhibit 107).

Exhibit 107

### Proposed unlocks and corresponding benefits of specific natural climate solutions in India.

🔴 Low
🟠 Medium
🔵 High

| | | | Benefits (value derived from the solution) | | | Implementation score[1] (difficulty in implementing the solution) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Segment | Solution | Carbon sink | Bio-diversity | Soil and water health | Economic feasibility | Maturity | Resource availability | Proposed state-led unlocks |
| **Land-based solutions** | Forests | Avoided deforestation | 🟠 | 🔵 | 🔵 | 🔵 | 🔵 | 🔵 | Creating certifications like FSC to prevent commodity-led deforestation[2] |
| | | Reforestation | 🔵 | 🔵 | 🟠 | 🔵 | 🟠 | 🟠 | Leveraging NCS to attract investments in restoration projects |
| | Cropland | Trees in cropland, pastures | 🔵 | 🟠 | 🔴 | 🔵 | 🟠 | 🔵 | Integrating farmers into carbon markets to create incentives |
| | | Regenerative agriculture | 🔵 | 🔴 | 🟠 | 🔵 | 🔴 | 🔵 | Providing capital (cooperatives) and custom hiring low-till equipment |
| | Urban settle-ments | Tree plantations | 🟠 | 🟠 | 🔴 | 🔵 | 🔵 | 🔵 | Mandating green cover, e.g., smart city projects |
| **Coast and ocean-based solutions** | Coastline | Wetlands | 🟠 | 🔵 | 🔵 | 🟠 | 🟠 | 🔴 | Focusing on conservation programmes like existing mangrove initiatives |
| | | Mangroves | 🔴 | 🔵 | 🟠 | 🔵 | 🔵 | 🔴 | Establishing mangroves as legal 'forests' (e.g., Maharashtra) |
| | | Seagrass | 🔴 | 🟠 | 🔵 | 🟠 | 🟠 | 🟠 | Providing funded research to identify potential areas for seagrass cultivation |
| | Oceans | Other ocean sequestration | 🟠 | 🔵 | 🟠 | 🔴 | 🔴 | 🔵 | Developing a comprehensive MPA policy to maintain marine ecological balance |

1. **Economic feasibility** refers to current costs of implementing the solution. Low score is assigned to high-cost solutions. **Maturity** refers to available technologies and tools to implement the solution. **Resource availability** is the extent of natural occurrence of the resource. E.g., mangroves are assigned a low score as the availability and potential for mangroves is limited compared to forests.
2. Forest Stewardship Council: Ensures that forest products come from responsibly-managed forests that provide environmental, social and economic benefits.

Source: McKinsey Nature Analytics

NCS represent an attractive investment opportunity for both public and private stakeholders. Globally, large corporates are increasingly investing in NCS, motivated by various factors, including compliance with voluntary carbon targets, corporate social responsibility and consumer demand for green products.

India has seen a growing interest in NCS, with several corporations driving mangrove-restoration and forest-conservation projects. However, accelerating conservation and restoration, against the backdrop of a fast-growing economy, will likely require institutional intervention and systemic enablers. These could include:

— **Setting up a domestic carbon market:** NCS projects can be integrated with carbon exchanges, where credits from sequestered carbon are traded (Exhibit 108). This would create positive value for all stakeholders and act as an important enabler in implementing projects. Setting up a domestic exchange is crucial for India to retain both the carbon-offset and economic benefits of trading credits. Please refer to the section "Develop a national carbon-exchange market" in the Sustainable Finance chapter for further details.

— **Establishing natural capital solutions as an investible asset class:** NCS represent a new asset class with the potential to capture the intrinsic value of the natural world, and there are several examples to build on (Exhibit 109). Natural resources could become investible assets that provide financial capital; NCS projects could thus be leveraged as an asset class that generates economic value for investors. While various solutions are already being pioneered, India would likely require a regulatory and policy road map to establish natural capital as an accessible and valuable asset class.

Exhibit 108

## A domestic carbon market could enable India to retain both the carbon offset and economic benefits of trading credits.

**Carbon-reduction project development process**

| | **Design project** | **Fund project** | **Develop project** | **Certify impact** | **Sell offsets** |
|---|---|---|---|---|---|
| **Example: a reforestation project in Colombia with 'VCS' label**[1] | South Pole designed a reforestation project of >1,000 ha in an area degraded by extensive cattle grasing and mining in Colombia; independent third-parties, CCBA and VCS, validated the project design | Being a larger project developer, South Pole used the cashflow generated by the sale of carbon credits from earlier projects to fund this new carbon-reduction project | During the project's development, local workers were trained to prepare the soil and plant >20 local tree species to stimulate the ecosystem's regeneration | After 5–7 years of forest growth, the impact and additionality (i.e., sequestered carbon) was certified by CCBA and VCS, which then issued carbon credits; every 5–7 years a new assessment will yield additional carbon credits (until full growth) | South Pole sold carbon credits (i.e., offsets) to end buyers that want to reduce their net carbon footprint; the offset was then retired (so it could no longer be traded) and the end buyer claimed the impact |

[1] Verified Carbon Standard, the world's largest carbon standard for voluntary market, from Verra.

Source: McKinsey research

Exhibit 109

## Natural resources could become investible assets.

### Examples of NCS

| Investment products | Underlying asset class | Example | Country | Players | Description |
|---|---|---|---|---|---|
| **Convertible forest bonds** | Forestry and land use | Kasigau Corridor Reforestation | Kenya | IFC | Convertible forest bonds to protect forest areas<br>IFC created a $152 million forests bond that allows investors to be paid in cash or carbon credits. IFC will purchase CCs from UN Kenya scheme and BHP Billiton will provide the cash coupon, if selected, and offtake the carbon credit created by the scheme 5-year bond investors include CalSTRS and QBE[1] |
| **Stormwater Retention Credit (SRC)** | Natural flood defences | Storm Water Credits | USA | Prudential Financial | Investments in cities resilient to urban flooding in Washington, DC<br>Prudential Financial invested $1.7 million in a collaboration between NatureVest and Encourage Capital which underpins the US's first SRC trading market. Prudential will finance the development of green infrastructure projects that reduce stormwater run-off, which will create credits that can be traded on the SRC market[2] |
| **Green municipal bonds** | Freshwater resources | Blended finance for wastewater treatment | USA | dc water is life | Bonds to finance green stormwater infrastructure in Washington, DC<br>DC Water and Sewer Authority invested $25 million in the first US Environmental Impact Bond (EIB). The EIB used innovative financing and risk structures to make investing in green infrastructure attractive for the government via a 'pay for success' model using municipal bonds[3] |
| **Blended finance investment** | Freshwater resources | Blended finance for wastewater treatment | India | HINDUSTAN ZINC | Blended finance to improve wastewater treatment in Udaipur<br>The Udaipur Municipal Corporation developed a public-private partnership with Hindustan Zinc (HZ) to finance investment in wastewater management technology. HZ will cover most financing and operating costs for 5 years for 2 fecal sludge treatments, and in return is afforded rights to water supply from treated wastewater and revenue from by-products |
| **Sustainability -Linked Loan (SLL)** | Sustainable agriculture | China SLL | China | ING<br>BBVA | SLL to incentivise sustainable agriculture<br>A consortium of 20 banks, led by ING, BBVA and Rabobank have provided a $2.1 billion SLL to COFCO International. Interest paid FCO will fall if COFCO hits certain sustainability targets, which will be monitored by Sustainalytics[5] |

1. IFC pressroom.
2. Storm Water Solutions.
3. American Flood Coalition.
4. OECD (2019), Making Blended Finance Work for Water and Sanitation: Unlocking Commercial Finance for SDG 6 (Annex C), OECD Studies on Water.
5. COFCO International.

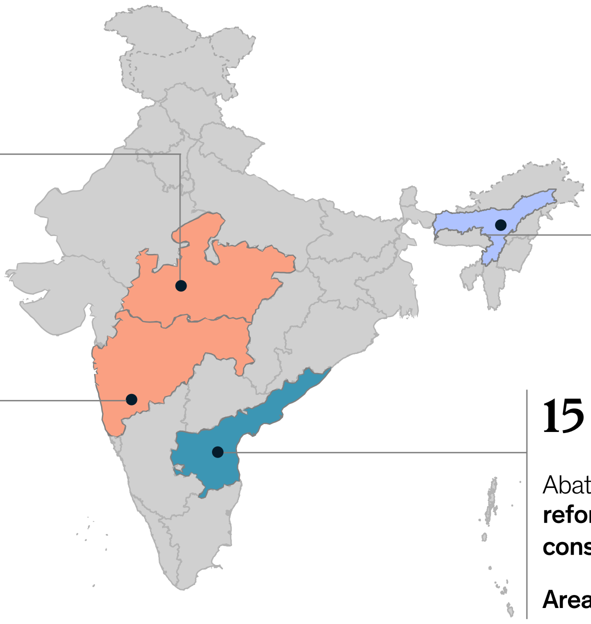
- **Creating regional and local road maps:** While India's state governments and city corporations have local environmental policies, targeted NCS action and road maps could be considered. For example, four mega projects, which together have the potential to deliver over a quarter of the total expected abatement from NCS by 2050, have been identified: agroforestry projects in Madhya Pradesh and Maharashtra, a peatland restoration project in Assam and a reforestation and forest conservation project in Andhra Pradesh (Exhibit 110). Likewise, city-level road maps are crucial for creating local carbon sinks and improving liveability and climate adaptability.
- **Unlocking blue carbon:** Attaining complete decarbonisation will likely require unlocking the full potential of India's oceans. India is in prime position to become a front-runner in blue carbon. This would likely require regulatory support in the form of a comprehensive MPA policy to ramp up conservation efforts, increase investment in blue-carbon research and development and facilitate startups.

NCS could play a key role in India's pathway to decarbonisation as they offer several benefits in addition to carbon sequestration. Although accelerating adoption in a fast-growing economy will likely be challenging, India could leverage NCS to fully reap the benefits of its natural resources through investments and project road maps.

Exhibit 110

## Four states could deliver >25% of the total expected abatement from NCS by 2050.

**Top 4 states in India with highest NCS potential**



**24 $MtCO_2e$**

Abatement potential from **agroforestry in Madhya Pradesh**

**Area required:** 28Mha

**28 $MtCO_2e$**

Abatement potential from **agroforestry in Maharashtra**

**Area required:** 35Mha

**24 $MtCO_2e$**

Abatement potential from **peatland restoration in Assam**

**Area required:** 0.5Mha

**15 $MtCO_2e$**

Abatement potential from **reforestation and forest conservation in Andhra Pradesh**

**Area required:** 1.8Mha

Source: McKinsey Nature Analytics

# 3.4 Carbon capture, utilisation and storage

## Key takeaways

**India's residual gross emissions will likely persist at around 1.4 $GtCO_2e$ annually till 2050 in the Accelerated scenario,** particularly from the hard-to-abate sectors, i.e., agriculture, cement, chemicals and steel. CCUS can help reduce these emissions by 329 $MtCO_2e$ per annum by 2050 and 403 $MtCO_2e$ per annum by 2070.

**Globally, CCUS is emerging as a viable solution, with 40 Mt per annum capture and storage capacity plants operational** at pilot level and further capacity of 90 Mt per annum announced, despite the fact that it is currently not economically viable.[188] In India, the viability of CCUS could be improved by creating hubs for large emitters close to storage locations.

**We estimate that India could develop as many as five storage hubs that are within 500km of 70 percent of India's point-source emissions**. The captured carbon can be transported through pipelines to existing oil fields for storage. India's cumulative storage capacity in oil fields is 3 $GtCO_2e$, which is about a quarter of the storage requirement of 11.3 $GtCO_2e$ by 2070.[189]

**A preliminary analysis suggests that 3 $GtCO_2e$ cumulative CCUS would require Capex of $1.3 trillion by 2070,** of which about $0.5 trillion would be for carbon capture and the balance for transportation and storage in the hub model.[190]

**Enablers for creating substantial CCUS capacity include carbon pricing to compensate for high CCUS Opex ($49–$55/$tCO_2$).** R&D investments to improve the efficacy and costs of CCUS will be important. Some governments—like Australia—have led the way in providing investment subsidies.[191] Technologies may need to be scaled up to use captured carbon in cement, chemicals and synthetic fuels. Finally, exploration investments may be required to identify and develop the storage potential in saline aquifers. This could unlock an additional cumulative carbon storage potential of around 60 $GtCO_2e$ for India.[189]

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[188] Global CCS Institute 2021 Status Report.

[189] British Geological Survey; European Commission; Global CCS Institute 2021; $CO_2$ Storage Resource Catalogue; Wood Mackenzie O&G site database.

[190] Utilisation costs have not been included in the financial estimates.

[191] Global CCS Institute.

## Context

In our LoS scenario, India will likely still emit roughly 1.4 $GtCO_2e$ per annum in 2050. This makes it imperative for India to explore carbon capture technologies like CCUS.

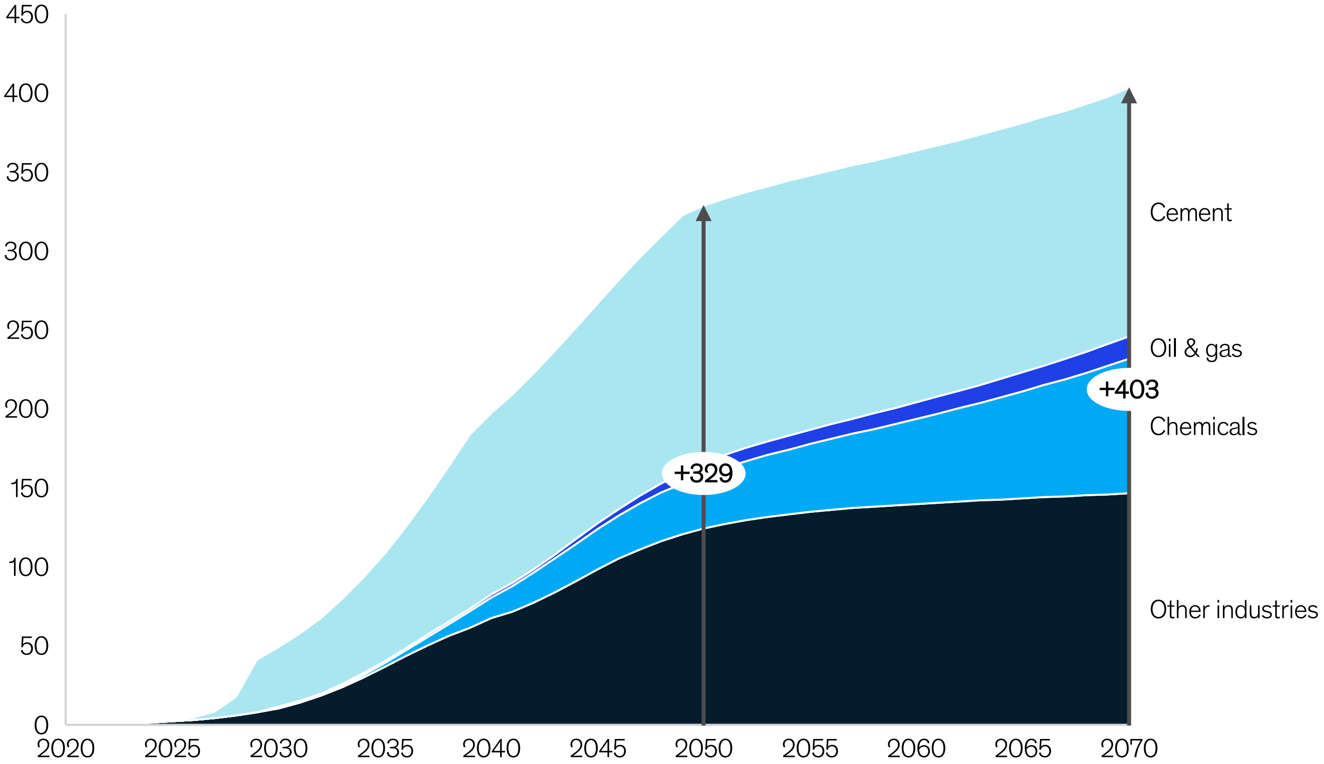
Demand for CCUS is growing globally—with an announced capacity of 90 Mt per annum (two-and-a-half times the current installed capacity). To reach decarbonisation goals across countries, CCUS capacity must increase one-hundredfold by 2050. Over the past 20 years, natural-gas processing has been the primary industry using CCUS. However, new projects are extending CCUS into other industries, like chemicals, cement, steel and power. In addition, storage in subsurface hubs is being explored.

In India, CCUS could capture 329 $MtCO_2e$ per annum by 2050 and 403 $MtCO_2e$ per annum by 2070, particularly from hard-to-abate sectors such as cement, chemicals and oil and gas (Exhibit 111).

Exhibit 111

## CCUS could capture almost 330 $MtCO_2e$ per annum by 2050 and help achieve decarbonisation.

**CCUS capture potential (demand): by sector in Accelerated scenario,** $MtCO_2e$ p.a.



Assumption: 65% fugitive emissions captured across cement, oil & gas refineries. Chemicals primarily include ammonia and other industries primarily include lime.

Source: CEEW Study on the role of CCUS in India; Sector Deep Dives for 2050 Aspirational scenario; McKinsey Sustainability Insights

To achieve this, action steps across all four CCUS could be considered (Exhibit 112).

There are three types of carbon-emission sources[192] based on the purity of $CO_2$ in their flue gas:

- **High-purity point sources (50–90 percent flue gas):** ethanol, ammonia and natural gas processing;
- **Low-purity point sources (5–15 percent flue gas):** power stations and cement factories—classified as hard-to-abate sectors;
- **Diffuse sources or DAC**: low-concentration $CO_2$ captured from ambient air; also required for negative emissions.

The concentration of $CO_2$ in the carbon source determines the technological requirements and chemistry for carbon capture (Exhibit 113).

Exhibit 112

## Four key steps required to deliver CCUS.[1]

| 1. $CO_2$ sources | 2. $CO_2$ capture | 3. $CO_2$ compression & transport | 4. $CO_2$ use/storage |
|---|---|---|---|
| $CO_2$ from the atmosphere, sustainable biomass, or point sources which generate anthropogenic $CO_2$[2] | Techniques to capture $CO_2$ during pre-combustion, combustion and processes[4] | Mode of transporting $CO_2$ from point of emission to point of use or storage | Ways by which we can use or store $CO_2$, including long-term surveillance to ensure permanence |
| Characteristics of $CO_2$ will vary by type of source[3] | Ability to capture varies depending on the type of source and characteristics of $CO_2$ | | Ability to use $CO_2$ will depend on the characteristics and volume of captured $CO_2$ |
| Relevant point sources include: power generation, cement, refining, chemical, metals and other industrial processes (e.g., ceramics, glass) | | | |

1. All four steps of the value chain are not required to create a CCUS project.
2. Includes immobile material point sources.
3. Pressure, temperature, quality, concentration.
4. Includes direct air capture.

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[192] Global CCS Institute.

Exhibit 113

## Purity of $CO_2$ in source determines the technology requirements and capture chemistry.

Non-exhaustive

● High ○ Low

**$CO_2$ sources and associated capture technologies**

High

$CO_2$ concentration

Low

| Source of emissions | Chemistry needed | Mechanism | Description | Maturity level |
|---|---|---|---|---|
| ① **High-purity point sources (50–90% flue gas)**<br>Emissions from ethanol, ammonia, natural gas processing | ✗ | Dehydration equipment | Need dehydration and compression equipment which is ‘low cost’ | ● |
| ② **Low-purity point sources (5–15% flue gas)**<br>$CO_2$ emissions from large point sources such as power stations and cement factories—required for hard-to-abate industries | ✓ | Solvent | High performance chemical that selectively dissolves $CO_2$ from effluent stream | ● |
| | | Sorbents | Typically solid materials that “adsorb” $CO_2$ from effluent stream | ◔ |
| | | Membranes | “Filter-like” technology that separates gasses from industrial streams | ◑ |
| | | Novel concepts | Broad range of approaches targeting a step-change process enhancement | ◔ |
| ③ **Direct air capture**<br>$CO_2$ is captured from ambient air at low concentrations—required for ‘negative emissions’ | ✓ | HT aqueous solution | Basic aqueous solution, absorbs $CO_2$ and is then regenerated | ○ |
| | | LT solid sorbent (TSA) | Solid chemical that adsorbs $CO_2$ and is regenerated by heating | ○ |
| | | LT liquid solvent (MSA) | Liquid absorption of $CO_2$ with regeneration by microwaves | ○ |

Source: Global CCS institute

**Carbon capture.** By using the right carbon-capture technology based on the $CO_2$ concentration at point sources, India can capture an estimated 11–11.5 $GtCO_2e$ cumulative emissions by 2070.

The current cost of carbon capture is high (\$30–\$90/$tCO_2$; \$600 for DAC) but is expected to decline with advances in capture technologies (Exhibit 114). From 2014–2020, more than ten capture technologies have matured to a Technology Readiness Level (TRL) of more than seven, which is typically required for concept deployment (Exhibit 115).[193] Numerous CCUS solutions based on wide-ranging technologies are also rapidly being tried, and multiple vendors have recently focused on modularisation and containerisation of CCUS technology and business models, e.g., CCUS-as-a-service, which accelerate adoption and hence accelerate learning.

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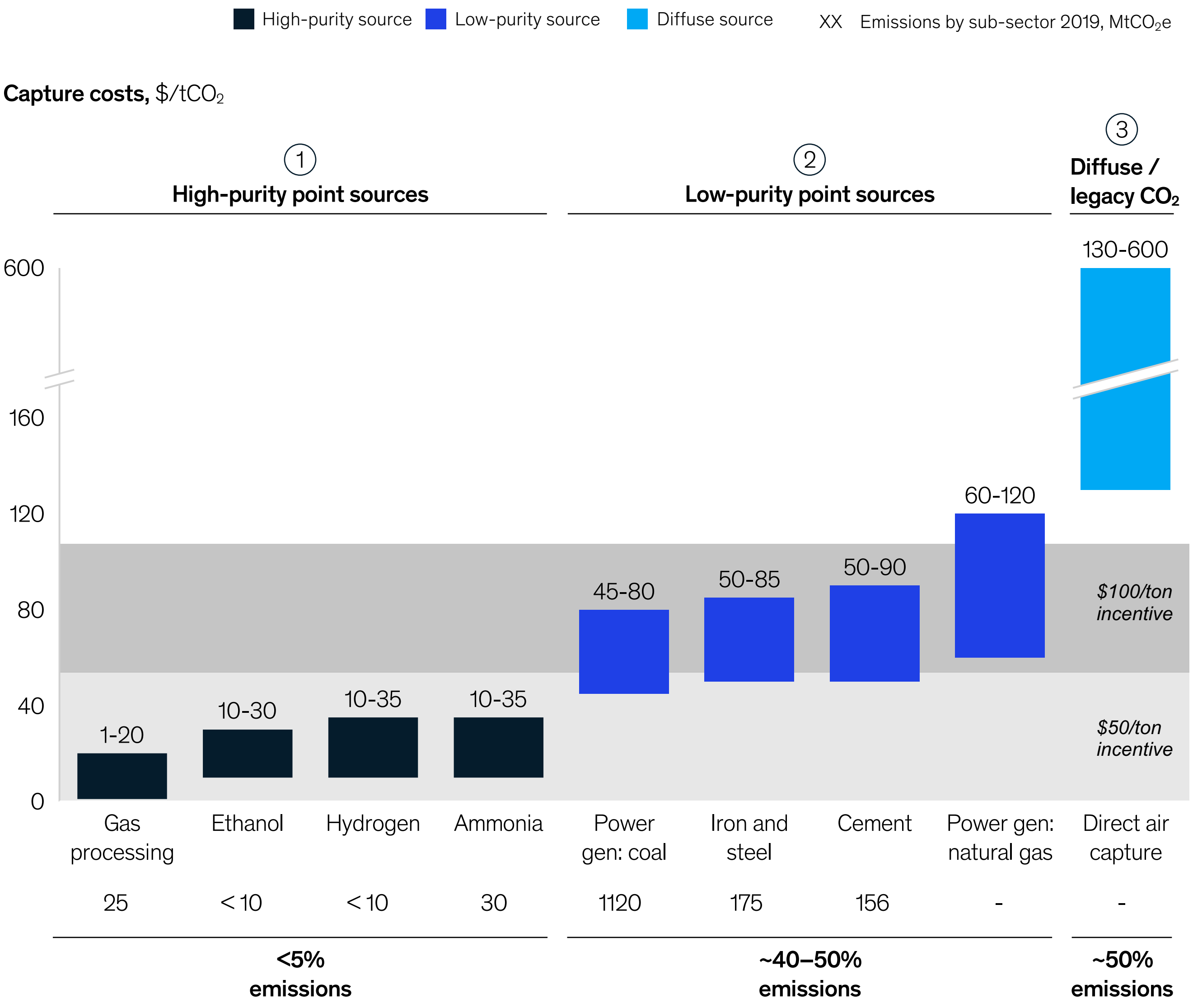
[193] Global CCS Institute.

Exhibit 114

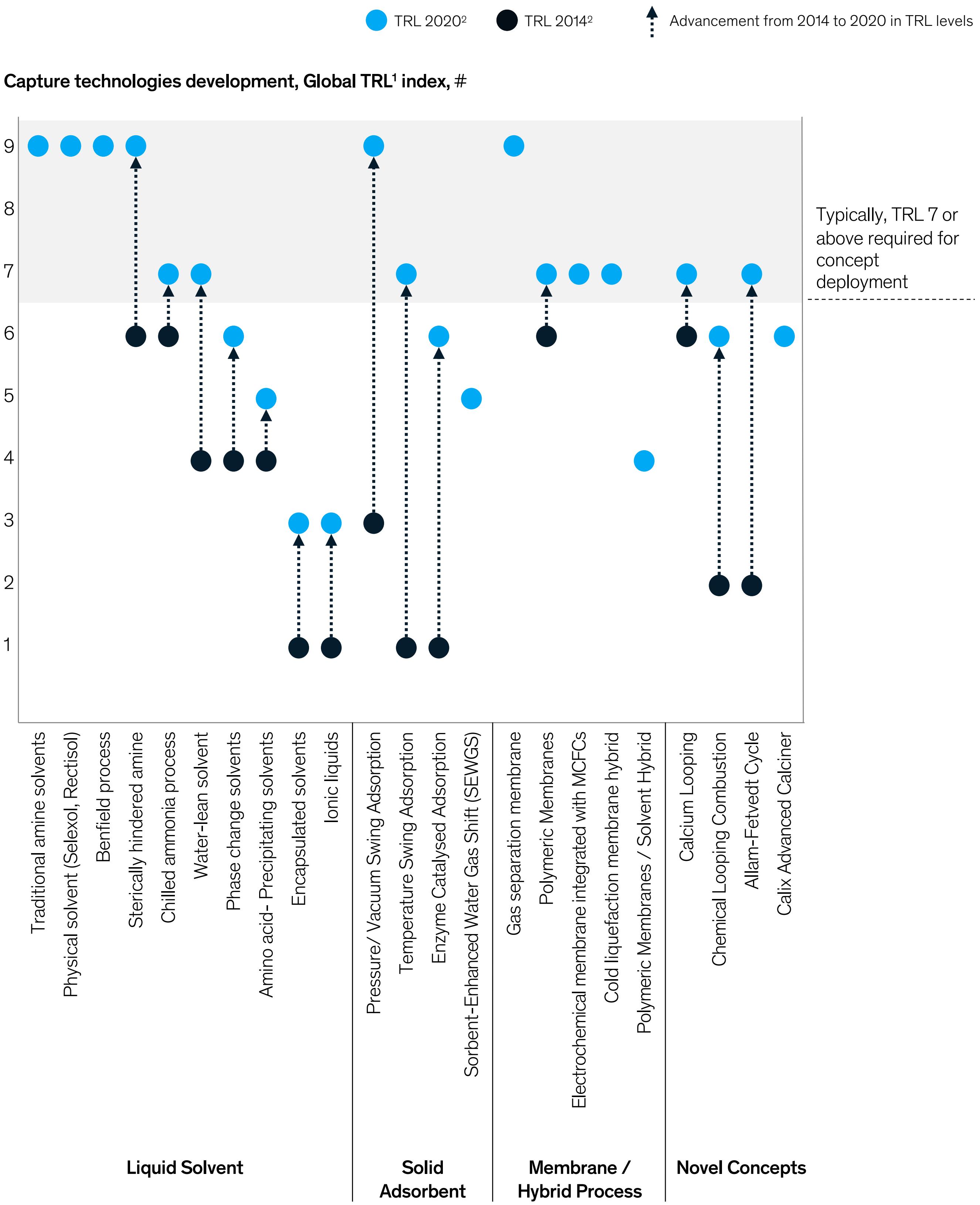
## Cost of capture is inversely proportional to concentration of $CO_2$ source.



Source: EU DPO Emission Baseline Database, EU ETS Data; Global CCS institute; NPC

Exhibit 115

## Momentum in technology advancement could make CCUS a cost-effective decarbonisation option.



**Capture technologies development, Global TRL[1] index, #**

1. TRL: Technology readiness level.
2. Global CCS Institute.

**Transportation.** Transporting captured carbon to storage or utilisation sites can be done via rail, trucks, ships and pipelines, with pipelines being the most cost-effective and scalable. The compression of captured carbon is an essential precursor to all modes of transportation, and with longer pipeline distances, additional compression stages may be needed.

**Storage potential**. India has a storage potential of 3 $GtCO_2e$ in existing oil fields, which could address the country's carbon-storage demand until 2045. To tackle the cumulative demand till 2070 of 11–11.5 $GtCO_2e$, further storage would need to be identified across the country. It is estimated that there is 60 $GtCO_2e$ storage potential in saline aquifers in India, which will require further exploration and assessment.[194]

For India, a CCUS hub model could be the most cost-effective way to capture and transport carbon from multiple point sources to storage sites. Five hubs close to storage sites and the right pipeline network could accommodate 25–30 percent of India's point-source emissions within 300 km and 65–70 percent within 500 km. The hubs would need to be in Gujarat, Maharashtra, Rajasthan, Andhra Pradesh and Odisha, optimally positioned near oil fields, the coastline or potential storage sites in saline aquifers (Exhibit 116).

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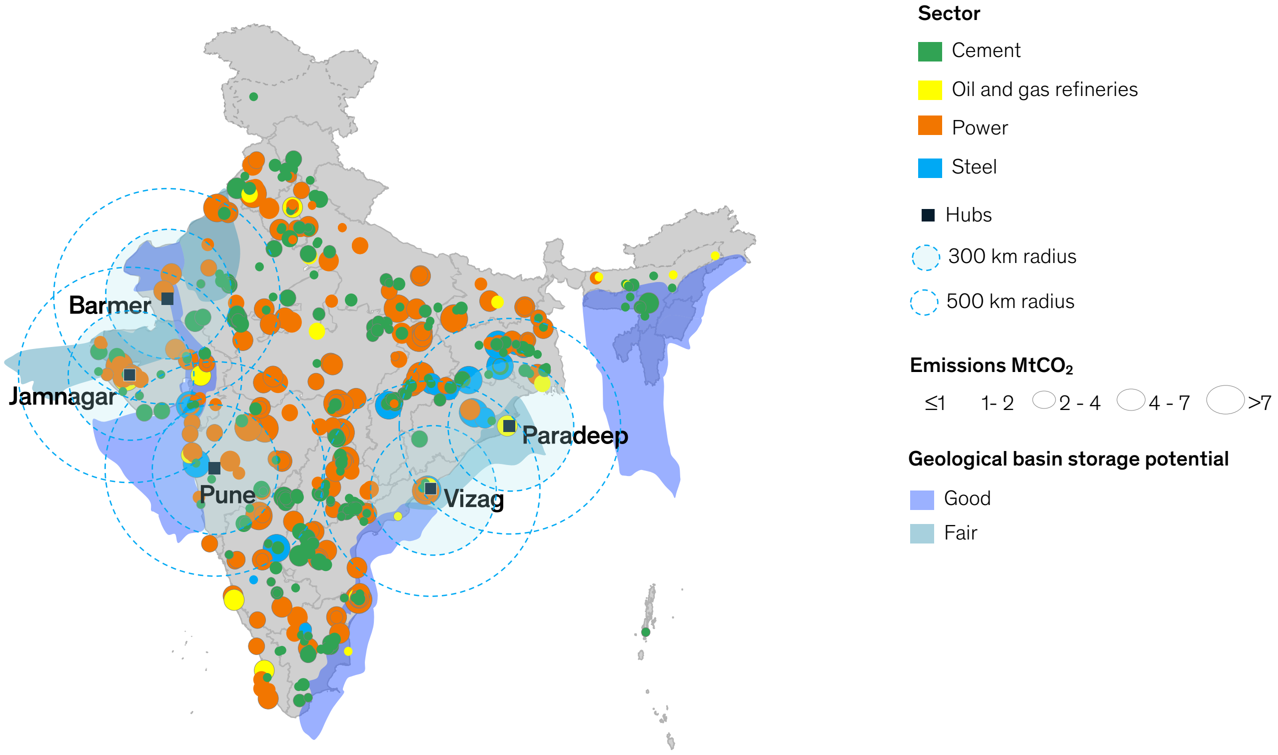
[194] British Geological Survey; European Commission; Global CCS Institute 2021; $CO_2$ Storage Resource Catalogue; Wood Mackenzie O&G site database.

Exhibit 116

## Around 25–30 percent of point source emissions could be captured within 300 km and 65–70 percent within 500 km of five hubs.

**Possible CCUS hubs in India**



Source: Global Greenhouse Gas Emissions, EDGAR; Joint Research Centre, European Commission; Netherlands Environmental Assessment Agency

**Utilisation.** Captured carbon can be used in multiple ways (Exhibit 117). However, the current uses such as fuel (including synfuel), EOR, biochar and greenhouse fertilisation have limited current potential while newer uses like construction materials (artificial limestone and carbon-cured cement), chemicals (plastics) are still in the early stages of development (Exhibit 118).

Exhibit 117

## Captured carbon can be used in multiple ways.

**Current end uses for captured carbon**

Maturity ● High ○ Low

| Demand category | Use case | Advantages | Disadvantages | Tech. status | Implementation requirements |
|---|---|---|---|---|---|
| **Enhanced oil recovery (EOR)** | Conv. $CO_2$ EOR | Commercially used for decades | Storage volume might be limited | ◕ | Long-term storage capabilities to be proven |
| | ROZ $CO_2$ EOR | Additional storage | Implemented only a few years ago | ◑ | Economics and know-how |
| | Unconv. $CO_2$ EOR | High oil extraction in untapped reservoirs | Still under development | ◔ | More testing and higher oil price |
| **Construction materials** | Cement/ concrete | Circular economy within one company | Storage and/or transport is costly | ◕ | Up-scaling, penetration |
| | Aggregates | Circular economy within one company | Storage and/or transport is costly | ◔ | Research and testing |
| **Fuel** | Synfuel | High potential | High energy need; high cost of H2 | ◔ | Pilot plant and cheap, green H2 |
| | Macro- and micro-algae | Large-scale investment | Algal fuel not cost-competitive | ◑ | Optimising strains and costs |
| **Plastics/ chemicals** | PE, PP, MeOH-based | Plastic value chain well established | Still in R&D stage | ◔ | Proof of large-scale technology and economics |
| | PC, PU | Plastic value chain well established | Still in R&D stage | ○ | Proof of concept |
| **Other uses** | Biochar | Known and feasible technology | Starts with biomass and not $CO_2$ | ◕ | Consensus to use biomass for biochar |
| | Carbon Fiber | Carbon fiber value chain well established | High energy requirements | ◑ | Proof of large-scale technology |
| | Food and beverage | Established outlet for $CO_2$ | Limited additional potential | ● | Implemented |
| | Greenhouses | Can increase plant production | Low demand/ no scale | ◑ | High-tech greenhouses; economics |
| **Storage** | Conv. $CO_2$ EOR | More storage than production | Additional cost to manufacturers | ◕ | Not seen as a long term solution |

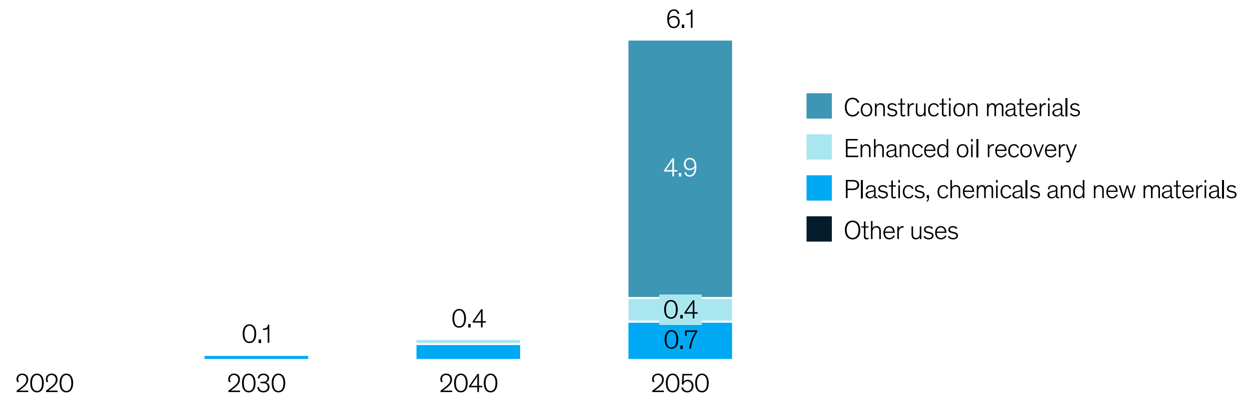
Source: McKinsey Energy Insights Global Energy Perspective 2022

Exhibit 118

## Most of India's CCUS utilisation potential could be driven by construction materials in 2050.

Accelerated scenario

**Estimated CCUS uptake in India, $MtCO_2e$ p.a.**



Source: McKinsey Energy Insights Global Energy Perspective 2022

## Investment implications

Capture makes up the majority of CCUS costs. Capex across capture, transportation and storage adds up to $1130 billion by 2070 for a 300 km network and $1320 billion for a 500 km network (Exhibit 119). Utilisation costs have not been estimated in the analysis.

## Proposed enablers to drive CCUS in India

While it is an expensive alternative for reducing emissions, CCUS is an important decarbonisation lever, particularly for hard-to-abate sectors like cement and steel. Possible unlocks include policies, technology development and storage assessment.

— **Technological advancements in carbon capture and utilisation** could also significantly reduce costs, e.g., a significant DAC cost reduction could help capture fugitive emissions and enable India to decarbonise by 2050.

— **Policy interventions** could help increase CCUS investment and adoption in India and potentially reduce costs. For example, a carbon price (likely more than $75–$100/$tCO_2$) could spur hard-to-abate industries to decarbonise. A negative emissions market (including voluntary offsets) may incentivise producers to capture biogenic carbon (as is done in trading schemes in China and Korea).[195] Regulatory de-risking could support large-scale $CO_2$ storage throughout the asset life of 50–100 years.

— **Storage potential exploration** and assessment of saline aquifers would likely be needed to meet the storage demand.[196]

— **Innovative business models** such as CCUS-as-a-service, cluster integrator (for distributed point source emissions in a hub) and transportation and compression pure play could be potential business models for CCUS in India. Further, carbon removal technologies such as bio-energy CCS (BECCS) and DAC could also get incremental support for advancement through advance market commitment mechanisms such as Frontier Climate.

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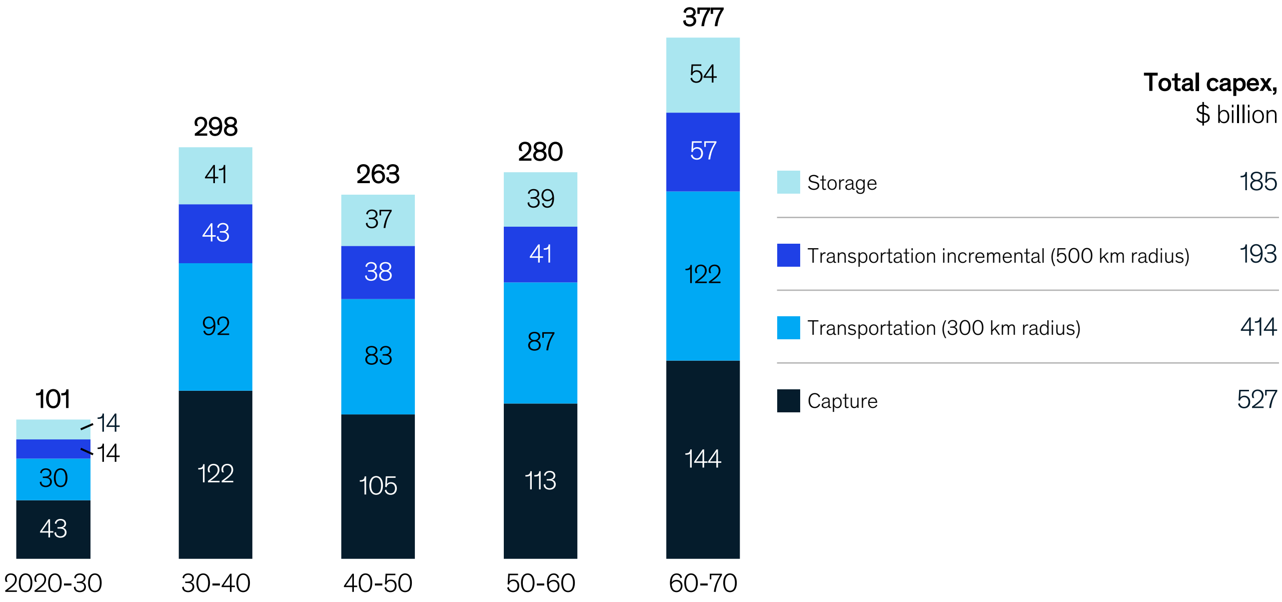
[195] IEA - China ETS market.

[196] British Geological survey; Global CCS Institute; assessment of $CO_2$ storage potential in Indian subcontinent.

Exhibit 119

## Most of the Capex investment would be needed in carbon capture and transportation.

**Capex investment for carbon capture[1], transportation and storage[2],** $ billion



1. Capture cost for all point source emissions, existing oil field storage can cater to 300 km hub storage requirement till 2070 and 500 km hub requirement till 2050-2055.
2. Storage capex for existing oil fields (cumulative 3 GtCO2e), Transportation includes compression and transportation costs.

Source: EU DPO Emission Baseline Database; EU ETS Data; Global CCS institute; NPC; Perez et al., “Technico-Economical Evaluation of $CO_2$ Transport in an Adsorbed Phase, Low Carbon Economy,” 2012; McKinsey CCS cost model, Westney Capital Analytics, Energy Insights

Assumptions : Taking pipeline as primary transport mode. Assuming 25 year lifespan, On-shore oil-fields storage costs assumed as per Global CCS Institute, McKinsey CCS cost model

# 4. Implications of India's decarbonisation pathways on emissions, energy systems, land use, people and benefits

## Key takeaways

**India's GHG emissions would likely increase to 11.8 $GtCO_2e$ per annum by 2070** even assuming continued emission intensity reduction at the current rate. The LoS scenario would likely reduce the absolute emissions to 1.9 $GtCO_2e$ per annum by 2070 leading to an estimated cumulative carbon saving of 207 $GtCO_2e$ by 2070. The Accelerated scenario would likely create a further carbon saving of 80 $GtCO_2e$ cumulatively by 2070.[197] Seven levers that could contribute to 83 percent of the emission reduction are: renewable energy, electrification of mobility, use of hydrogen, sustainable agriculture practices, material circularity, natural climate solutions and CCUS.

**Implications for energy systems.** In the LoS scenario, coal would likely decline from the 45 percent of the energy mix today to 26 percent and oil would likely reduce from 26 percent to 21 percent by 2050. In the Accelerated scenario, the decline would be much steeper as coal's and oil's share in the energy mix would likely reduce to three percent and ten percent, respectively, by 2050. In the Accelerated scenario, 182 Mt per annum of refining capacity would need to be repurposed or stranded by 2040. By 2050, coal consumption would likely be reduced to a tenth of current consumption and all current coal-based power capacity would need to be decommissioned. Scarce feedstock would need to be directed to the right use, for instance, the biomass currently being used for the power sector and the agri-based fuels for the transport sector might need to get directed to the hard-to-abate sectors like steel and aviation, respectively.

**Land use implications.** Currently, 23 percent of available land is forest area, 59 percent is agricultural and the remaining 18 percent is used for non-agricultural purposes, grazing pastures and barren land.[198] Accelerated decarbonisation will likely require additional land for carbon sinks and renewable power. This is in addition to the land needed for continued urbanisation and industrial growth. Our estimates indicate a shortfall of 45 million ha of land by 2070 (15 percent of total available land). India would need to implement efficient land use practices such as alternative land uses for barren land, vertical farming, urban carbon sinks, offshore wind and rooftop solar expansion.

**Implications for people.** A critical consideration is the impact the Accelerated scenario could have on the average Indian household's spending requirement. We estimate that there will not be a major impact on overall spending since food spending sees no major impact, spending requirements for energy and transport see a reduction, only housing becomes slightly more expensive. Further, in the Accelerated scenario more than 30 million jobs could be transformed (24 million new jobs could be created while 6 million existing jobs could be lost) by 2050.[199] However, this number is small in the context of the macro trends affecting India's workforce (e.g., 60 million people will join the workforce and 30 million people will shift from farm jobs to non-farm jobs by 2030).[200]

**Other benefits from Accelerated decarbonisation.** While the primary benefit of decarbonisation would be the ability to arrest climate change, the transition offers other benefits, too. It would result in localisation of India's energy requirement with the shift from coking coal, oil, gas to renewable energy, green hydrogen and biomass, all of which would strengthen energy security. This could result in Forex savings of $2.4–3.0 trillion. Further, India could also establish a global manufacturing hub for green H2, solar panels, etc. and become a global leader and exporter of green technologies.

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[197] UNFCCC, climate action tracker, India's biennial update report 3.

[198] Land use statistics at a glance, Government of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture & Farmers Welfare, Directorate of Economics & Statistics, November 2021.

[199] McKinsey Global Institute: The net-zero transition - what it would cost, what it would bring.

[200] McKinsey Global Institute: India's turning point.

**Situation today**

India has reduced its emissions intensity of GDP by 1.3 percent per annum over the last decade. However, this pace is insufficient to reduce India's absolute emissions given the fast-paced growth of GDP. India's GHG emissions would likely increase to 11.8 $GtCO_2e$ per annum by 2070 assuming the current rate of emissions intensity. In the LoS scenario, absolute emissions could continue to rise and then decrease to 1.9 $GtCO_2e$ per annum by 2070; a 90 percent reduction in the GDP emissions intensity versus 2019. The Accelerated scenario could further close the gap to net zero, reducing absolute emissions to 0.4 $GtCO_2e$; a 98 percent reduction in emissions intensity by 2070 versus 2019. The LoS scenario could create a cumulative carbon space of 207 $GtCO_2e$ by 2070 over the improving intensity line, while the Accelerated scenario could create a further carbon space of 80 $GtCO_2e$ cumulatively by 2070 (Exhibits 120, 121).[201] These emissions have been estimated with largely currently feasible technologies. It is expected that India could get to its net-zero-by-2070 commitment on the back of its upcoming technology developments over the next decades (e.g., direct air capture).

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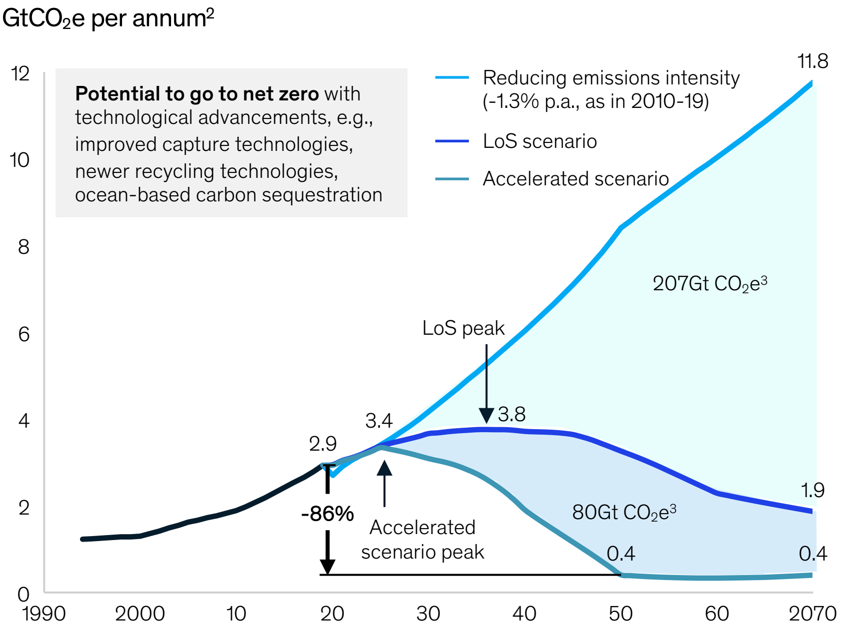
[201] UNFCCC, climate action tracker, India's biennial update report 3.

Exhibit 120

## Possible pathways for India to decarbonise.

**India's GHG emissions**[1]



**LoS scenario**

- **Implementation** of India's NDC, existing and currently announced policies
- Technology advancement as per current trajectory
- Shift in demand to sustainable alternatives in selected areas, e.g., EV

**Accelerated scenario**

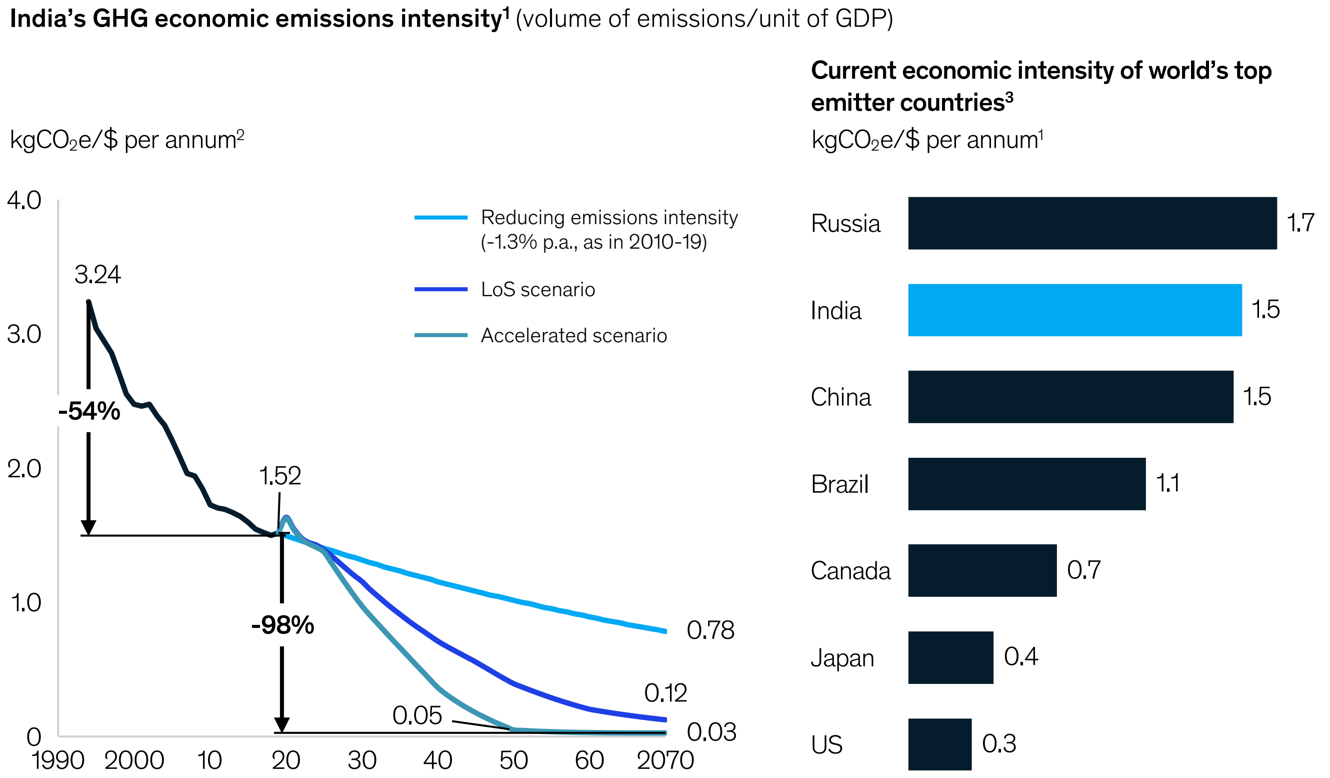
- Adoption of **new policies** such as carbon pricing
- **Technology breakthroughs,** e.g., CCUS and faster implementation of existing levers
- **Accelerated shift** to sustainable consumption, e.g., EV, alternative materials, coarse cereals, green steel

1. These emissions have been estimated with largely currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture).
2. Including LULUCF emissions and offset.
3. Global carbon budget for 1.5 degree pathway as per IPCC AR5 is 580 $GtCO_2e$.

Source: UNFCCC, climate action tracker, McKinsey India DSE, India's biennial update report 3

Exhibit 121

## Economic emissions intensity reduction for India.



1. These emissions have been estimated with largely currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture).
2. Including LULUCF emissions and offset.
3. Economic emission intensity from annexed and non-annexed countries in UNFCCC.

Source: UNFCCC, climate action tracker, McKinsey India DSE, EIU , India's biennial update report 3

## The challenge of rapid decarbonisation

The LoS reductions are challenging; the Accelerated scenario's is even more so. India has moved in several sectors at an enviable pace – renewables, energy efficiency, EVs, hydrogen. Results are there to see in the continued reduction in carbon intensity of GDP, and with several sectors poised for scale up. There are still major challenges to be overcome, but it is doable if early action to prepare for the transition is taken within this decade, given that a very large proposition of decarbonisation levers are in the money (Exhibit 123).

For example, in the Accelerated scenario, **renewables** (wind and solar) capacity addition will likely need to increase from 10–12 GW per year today to 50 GW per year in 2030 and 90 GW per year in 2040. Ten times as much land as is used today would need to be found. Panels and corresponding raw material manufacturing would need to scale, given 80–90 percent of solar panels are imported currently.

**In automotive,** 100 percent of two wheelers, three wheelers and light truck sales would need to be electric early in the next decade, all car sales will likely have to be electric by 2035 and trucks by 2050. For this, battery costs will likely decline by 40 percent in 2030 relative to today. Charging stations would need to increase 13 times by 2030 and 40 times by 2040 relative to today. Consumer financing, given higher up front electric vehicle costs, and raw materials for batteries would need to be found.

**Green hydrogen,** which is not economical until 2030 versus alternatives, will likely need a subsidy of $60–80/KW for electrolyser manufacturing and carbon prices (within this decade) to support uptake for its largest use case of green steel making. 29 GW of electrolysers would need to be installed by 2030 (relative to current deployment of about 1.4 GW, globally)[202] and almost 400 GW by 2040.

**Steel** will likely see growth in hydrogen

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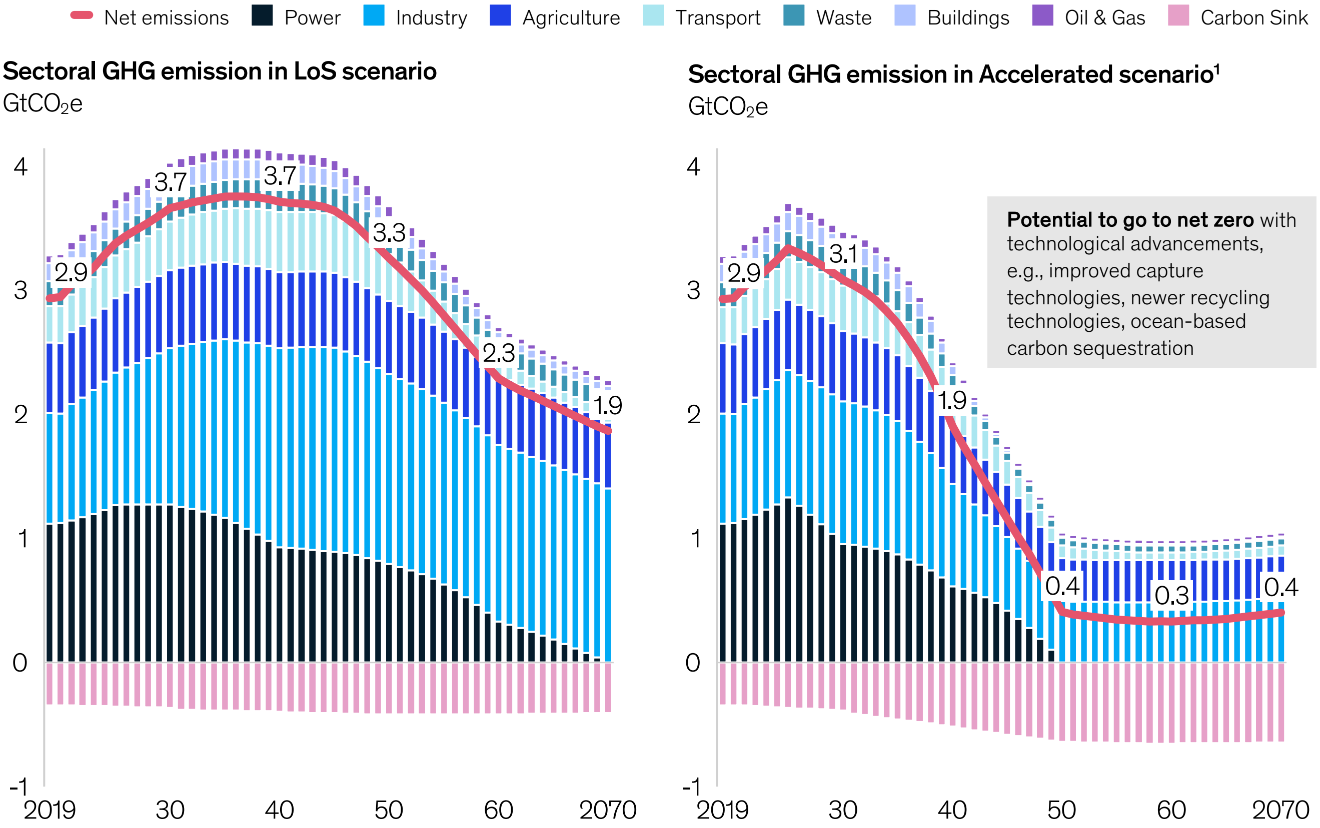
[202] https://www.iea.org/reports/electrolysers.

Exhibit 122

## Emission curves for LoS and Accelerated scenarios.



1. These emissions have been estimated with largely currently feasible technologies. It is to be expected that India could get to its net-zero-by-2070 commitment through the upcoming technology developments over the next decades (e.g., direct air capture).

green steel capacity from 0 today to 152 Mt by 2040 while seeing an initial increase to 119 Mt by 2040 from 55 Mt in its BF-BOF capacity. It would also need to decrease its BF-BOF capacity to 85 Mt by 2040.

**The power** sector will likely see a transition from the current coal power generation of 211 GW today to 120 GW by 2040 and 0 by 2050. This would need to be replaced by renewable power (solar + wind onshore) capacity of 480 GW and 1370 GW by 2030 and 2040, respectively, versus 94 GW today.

**Refining capacities** will likely decrease from 213 Mt per annum today to 114 Mt per annum by 2040 and 105 Mt per annum by 2050.

**Additional land** would likely be needed to meet India's land requirements. This will be needed for agriculture (12 million ha by 2040), solar plants (5 million ha by 2040), forest densification (4 million ha by 2040), etc. However, land is not readily available so India will have to implement efficient land use practices to free up the necessary land.

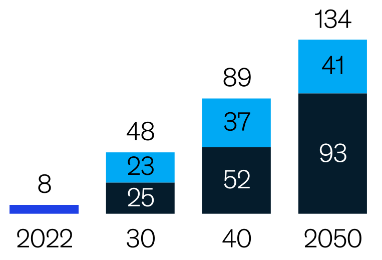
Exhibit 123

## Challenges for India's decarbonisation.

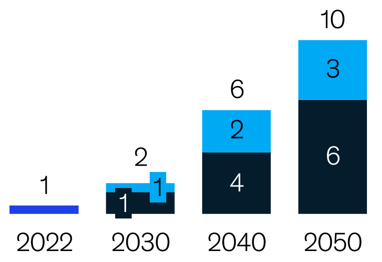
■ LoS scenario
■ Accelerated scenario
■ Current situation

### Power

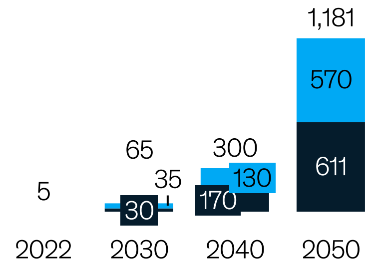
**Average annual solar + wind onshore capacity addition,** GW



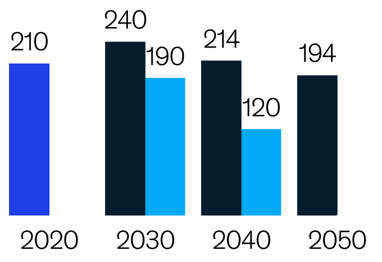
**Land requirement for solar + wind onshore,** Mha



**Storage capacity,** GW

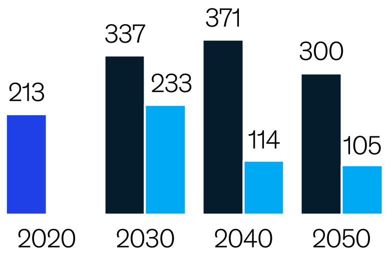


**Coal power generation capacity,** GW

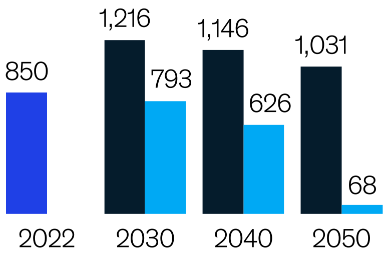


### Energy & hydrogen

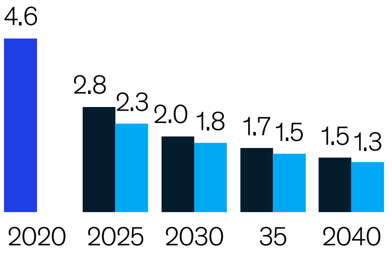
**Refining capacity,** MMTPA



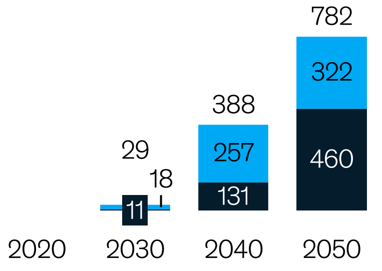
**Coal consumption,** MMTPA



**Cost of green hydrogen,** $/tonne



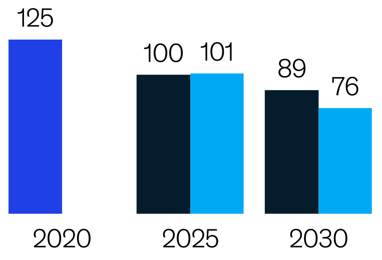
**Electrolyser capacity,** GW



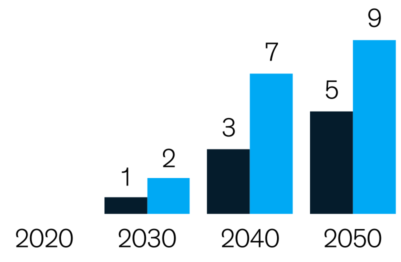
- Subsidy of $60-$80/KW for electrolyser manufacturing

### Automotive

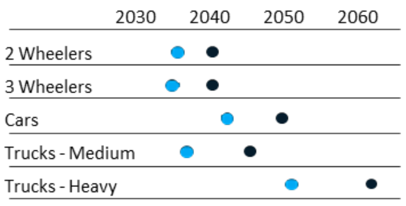
**Battery costs,** $/KWh



**No. of chargers,** millions



**Switchover to 100% EV sales**



- Fame subsidies extended till 2030
- Retail fuel prices maintained
- 2022 battery spot prices hovering around $180/KWh to $195/KWh due to geopolitical issues and Covid impact

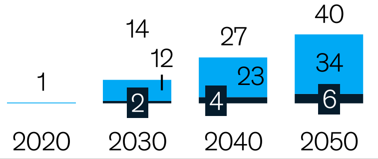
Exhibit 123 (Continued)

## Challenges for India's decarbonisation.

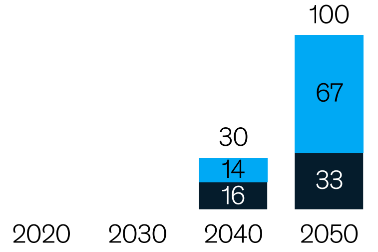
■ LoS scenario
■ Accelerated scenario
■ Current situation

### Agriculture & NCS

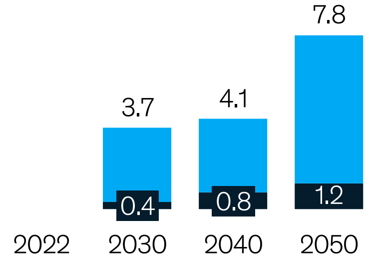
**Improved rice straw management,** %



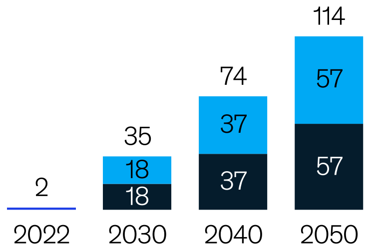
**Electrification of on-farm equipment,** %



**Incremental land required for trees,** Mha

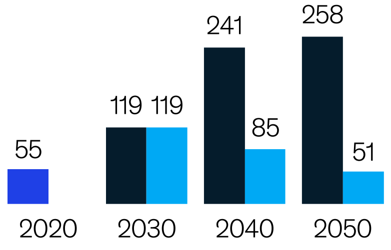


**Incremental land required for regenerative agriculture,** Mha

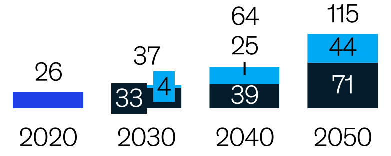


### Steel and cement

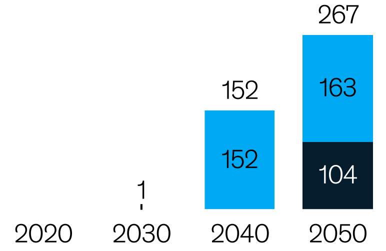
**Steel - BF-BOF capacity,** Mt



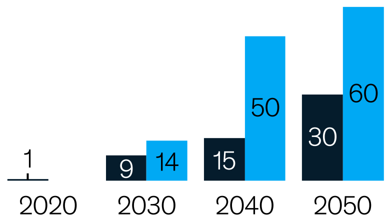
**Steel - scrap based EAF-IF capacity,** Mt



**Steel - hydrogen green steel capacity,** Mt



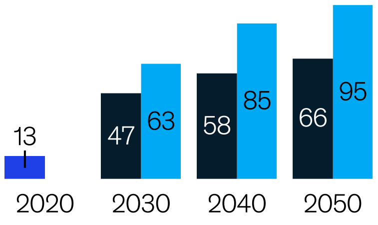
**Cement - heat demand met by green fuels,** %



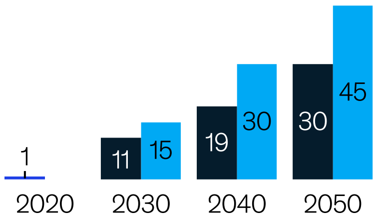
- Carbon price of $50 by 2030
- Clinker to cement ratio reduces to 60% by 2050 in Accelerated scenario (vs 65% for LoS)
- CCUS needed to capture 65% of remaining emissions from cement

### Circularity & financing

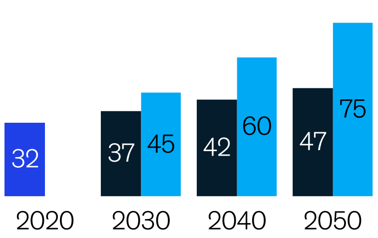
**Recycling rates, plastics,** %



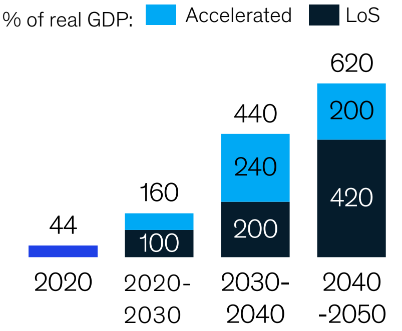
**Recycling rates, construction & demolition,** %



**Recycling rates, municipal solid waste,** %



**Average annual investment,** $ bn



| | | | |
|---|---|---|---|
| 1.6% | 2.6% | 3.1% | 4.1% |
| 1.6% | 4.1% | 6.8% | 6.0% |

**Seven key levers that could help accelerate decarbonisation**
Our analysis shows that seven levers could help abate 83 percent of the emissions (Exhibit 124).

**1. Expand renewable energy capacity:** 100 percent decarbonisation by 2050 in the Accelerated scenario as opposed to by 2070 in the LoS scenario could result in abating 16 $GtCO_2e$ by 2070. With wind- and solar-generation technologies already available at scale, power could be the quickest sector to decarbonise, potentially reaching net-zero emissions by the mid-2050s.

India's solar and wind capacity could increase from its current 95 GW[203] to 2700 GW by 2050, representing a 95 percent share of generation. This would likely need an acceleration in the annual build to 40–50 GW from the current 10 GW a year. Ex-bus bar solar tariffs are currently in the range of INR 2.0–2.5/kWh; lower than the marginal generation cost for 60–70 percent of coal power plants.[204] This gap is likely to widen further. Transition to renewable sources of electricity could also decrease power generation costs from the current INR 3.9/kWh to INR 2.9/kWh by 2050, with lower cost renewables and grid-stabilising storage. To accelerate renewable energy production, India would likely have to quadruple the rate of capacity addition, resolve supply side bottlenecks (land, grid, etc.), accelerate market reforms and storage buildout (1200 GW by 2050) to integrate renewables and grid reliability, foster innovation and localise manufacturing. A quarter to two-fifths of the energy supply could be from infirm sources by 2030 in the LoS and Accelerated scenarios, respectively. The capacity in both scenarios could double in the decade of the 2030s and double again in the 2040s. The basics, including capacity-inducing and investment-reducing market reform, could be put in place now.

**2. Increase penetration of EVs across vehicle types.** Electrification of mobility is estimated to deliver 7 $GtCO_2e$ of cumulative abatement from now till 2070 between the LoS and Accelerated scenarios. This is underway due to advances in battery technology (storage capacity up two times, cost reduction of 17 percent every year over the last ten years). The sector benefits from government

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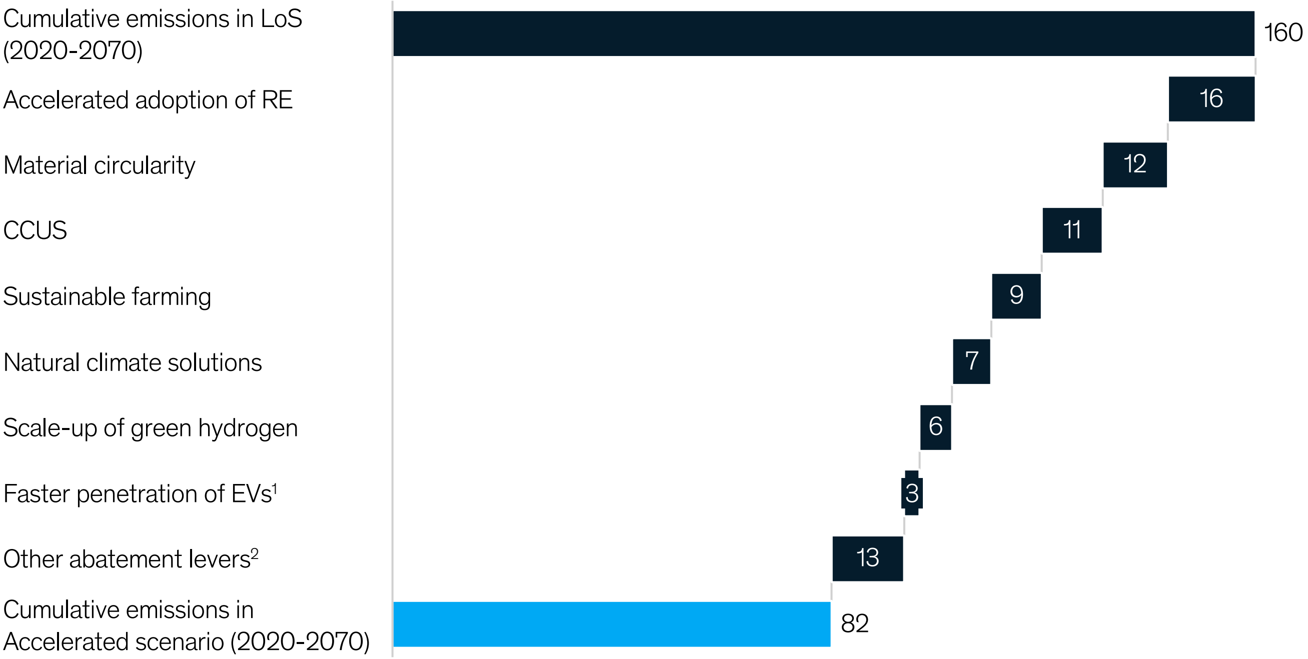
[203] As of April, 2022.
[204] Ex-bus bar tariff excludes the cost of transmission and distribution. Analysis based on the unit-level coal plant variable cost; Data from RE navigator and ministry of power annual reports.

Exhibit 124

## More than 80% of abatement can be achieved through 7 key levers.

**Cumulative emissions reduction between LoS and Accelerated scenarios,** 2020-70, $GtCO_2e$



1. In the LoS scenario, EV penetration reaches 100% only by 2070.
2. Includes other miscellaneous abatement levers such as 100% electrification of cooking, complete treatment of wastewater, improved energy efficiency in industry, and so on.

support (GST benefit of five percent for EVs versus 28–51 percent for ICE vehicles; schemes such as FAME and PLI to provide support).[205] Perhaps the most important factor is an implicit carbon tax on transportation fuels of \$140 to 240/$tCO_2e$.

In the Accelerated scenario, all new vehicle sales are assumed to shift to EVs fully around 2030 for two wheelers, around 2040 for cars and 2040–2050 for CVs. These assumptions are based on TCO parity which, in turn, needs to be balanced out by market maturity considerations. Typical maturity bottlenecks, which need to be solved for, include adequate availability of EV models, charging and swapping infrastructure maturity as well as incentive/dis-incentive schemes as proposed by the government. The infrastructure bottlenecks would need decadal Capex investments to the tune of \$3 trillion for which green financing would need to be solved for. This transition would likely be enabled by: a) further reducing battery costs and fuel cells through at-scale localisation; b) providing continued government support through GST and FAME benefits and fossil fuel taxation; c) achieving the target modal mix of 45 percent for rail freight by 2040; and d) focusing targeted affirmative action on select transitions, e.g., commercial fleets, especially HCVs.

**3. Ramp up green hydrogen as fuel or feedstock:** Hydrogen is a versatile energy source and chemical reductant. Adoption of green hydrogen could enable an annual abatement of 900 $MtCO_2e$ for India by 2050. This is subject to green hydrogen becoming cost competitive with alternative energy sources, which can be accelerated by faster R&D, adopting technology and ensuring early demand drives down costs. Green hydrogen demand would first emerge as a replacement for grey hydrogen in use cases such as refining, urea, methanol as it becomes more competitive versus grey hydrogen by 2030. In our LoS scenario, hard-to-abate sectors such as steel, automotive and power would drive demand only in the decade of the 2040s. These sectors have the potential to drive disproportionate demand for green hydrogen in the decade of the 2030s and 2040s with blending mandates and a carbon price of \$50 per tonne.

Accelerating hydrogen adoption in steel-making will likely help India build the right assets. The steel industry could make an investment of about \$265 billion over the next 30 years in the new BF-BOF capacity installation, which could risk getting stranded in case of climate shock, or early closure, even with India's 2070 net-zero NDC. Indian steel makers could avoid this risk by investing early in green hydrogen-based steel-making instead of the conventional blast furnace route to the tune of 200 Mt starting from 2030. This will likely need to be enabled by the right policies including a carbon price of \$50/t, plans for which would have to be in place within two or three years for steelmakers to plan their investments. This could create additional carbon space of 3.1 $GtCO_2e$, and result in cumulative Forex savings of \$420 billion in oil/gas imports and \$280 billion in coking coal imports by 2050.

**4. Reform agriculture and dietary systems:** Decarbonisation in the agriculture sector can lead to an annual carbon abatement of 292 $MtCO_2e$ by 2050, or nearly half of all expected annual emissions from agriculture. This would mainly be driven by sustainably cultivating rice (20 percent of abatement), reducing nitrate fertilisers (16 percent) and shifting towards sustainable consumer alternatives such as plant-based protein (15 percent) and millets (seven percent).

Paddy farming and livestock account for 70 percent of agricultural emissions.[206] Reducing paddy farming emissions by practicing rice-straw upcycling, dry seeding and SRI in half of India's rice cultivated area and reducing livestock emissions by adopting efficient feeding and manure management practices for half the livestock population would be critical for decarbonising agriculture.

**5. Drive material circularity:** India currently generates 750–800 million tonnes of waste across waste streams with recycling rates of 13 percent for non-agricultural waste streams.[207] Improving recycling rates to 80 percent could provide significant recycled raw material and help abate up to 34 $GtCO_2e$ by 2070 in the Accelerated scenario (12 $GtCO_2e$ more than the LoS scenario which takes into consideration recycling rates increasing to 55 percent). Recycled raw materials could help save 50–95 percent emissions in material production across steel (scrap-based EAF steel production), cement (recycled concrete, biomass fuels), plastic (recycled feedstock, recycled plastics), aluminium and other materials.[208] While most technologies for recycling various waste streams already exist, driving material circularity would require investment in recycling infrastructure as well as enforcement of waste management and extended producer responsibility regulations. Demand signals would need to be created through recycled material use mandates.

**6. Sequestrate using NCS:** NCS can help remove or sequester emissions through the conservation and restoration of nature. In the Accelerated scenario, India's natural resources can sequester 640 $MtCO_2e$ annually by 2050, nearly 300 $MtCO_2e$ higher than 2019 levels and 230 $MtCO_2e$ more than the LoS scenario. This translates to additional sequestration

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[205] McKinsey battery insights; FAME, Ministry of heavy industries.

[206] FAOSTAT.

[207] World Consumer research report; UNDP plastic waste management program; CPCB solid waste management reports, Indian textile journal; Indian council for agricultural research; ministry of steel; Building material promotion council; FAO; Ministry of Steel – Steel Scrap recycling policy; National Policy on Crop Residue Management by Ministry of Agriculture.

[208] Material Economics - The Circular Economy report.

of 3 $GtCO_2e$ between 2020–2050, and 7 $GtCO_2e$ by 2070 compared to the LoS scenario. Nearly 85 percent of sequestration would come from forests (avoiding deforestation, reforestation), agroforestry (trees in cropland, regenerative agriculture) and urban tree plantation. This would likely involve restoring an additional eight million hectares of forest (over ten percent of current forest cover) and practicing regenerative agriculture (such as low-till farming) in at least half of India's croplands, as opposed to 20–25 percent adoption in an LoS scenario.

**7. Scale CCUS across industries:** Adoption of new carbon-capture technologies could help reduce industrial emissions further, particularly for hard-to-abate sectors like cement, oil and gas and chemicals. CCUS could help capture 11.4 $GtCO_2e$ across these sectors cumulatively by 2070 for utilisation or storage. A hub model set-up for CCUS could be a cost-effective approach and five hubs in India located close to storage could address 70 percent of point source emissions with a transportation radius of up to 500 kilometres. There could also be potential for utilising the captured carbon in applications like chemicals production, artificial limestone and construction blocks. CCUS is expensive and would lrequire significant investment and R&D to scale and become cost-effective.

## Implications for energy systems

India depends on fossil fuels to meet approximately 75 percent of its current energy demand.[209] This declines rapidly in both scenarios (Exhibit 125). For example, decarbonisation in the transportation sector would require shifting from petroleum-fueled cars to electric vehicles with electricity being increasingly supplied by renewable sources. The industry sector would shift from reliance on fossil fuels to a mix of electricity, hydrogen and biomass for manufacturing processes.

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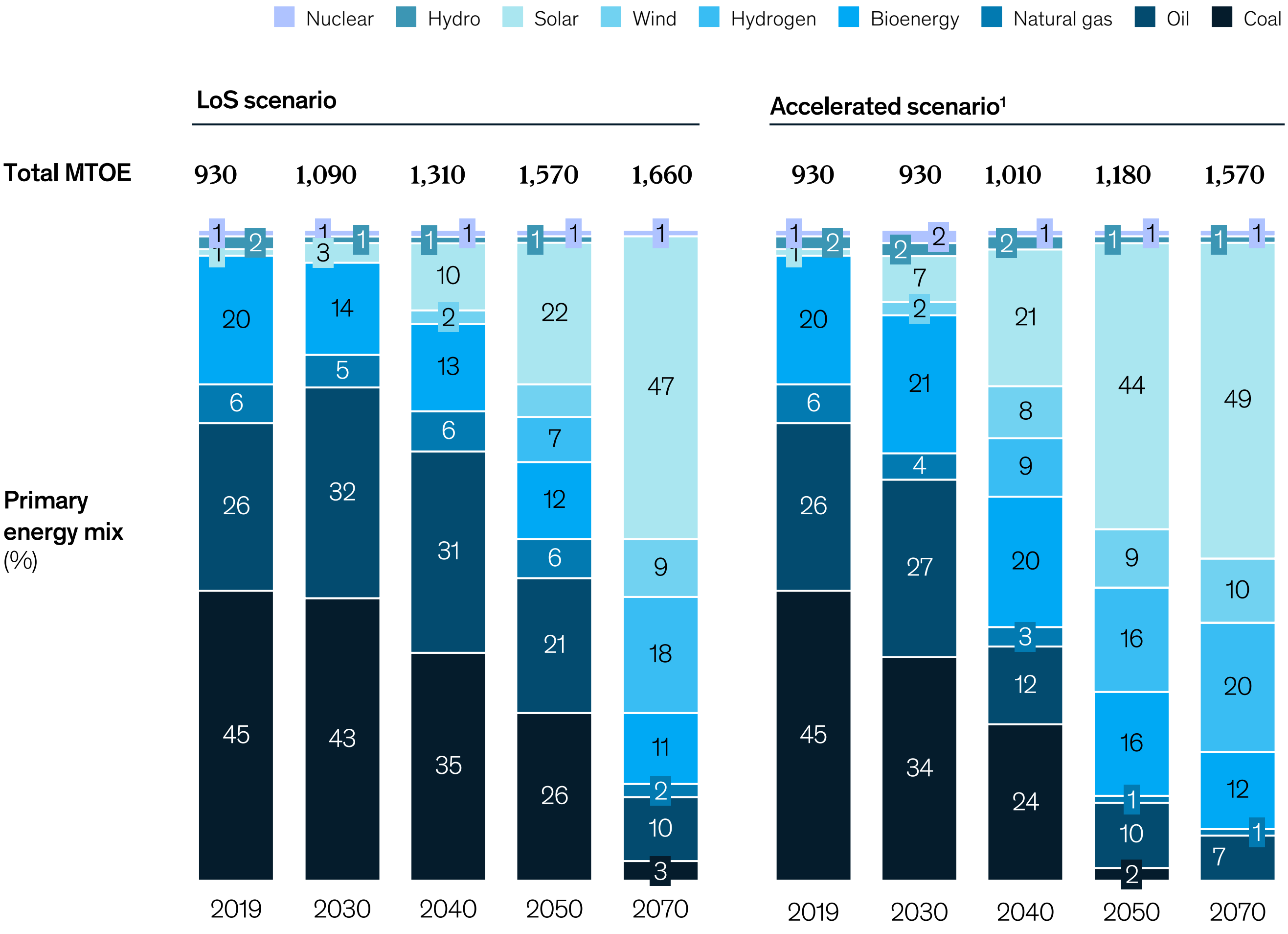
[209] IEA World Energy Balances.

Exhibit 125

### The primary energy mix would likely shift to renewable sources of energy.



1. Total primary energy supply is lower in Accelerated scenario than in LoS scenario because of how renewables are accounted for

In agriculture, farm equipment would become electric. And, as India moves away from coal-based power generation to renewables such as solar and wind, the thermal coal demand would reduce drastically. The overall energy demand in the Accelerated scenario would likely be lower by 18 to 24 percent between 2030 and 2050 on account of higher energy efficiency, circularity and shifts in material use. This energy mix shift implies shifts in capacity including some which might strand some assets (stranded refining capacity, coal-based power plants and coal mining) and hence require support.

### a. Refining capacity

The oil and gas industry's operations account for only five percent of total industrial emissions (about a percent and a half of India's overall emissions), but it produces fuels which contribute to 18 percent of India's total scope 3 emissions. Given that over 80 percent of India's crude consumption is imported, decarbonisation will have limited impact on the upstream sector (crude oil and gas production).

In the LoS scenario, all new two-wheelers and cars would likely be fully electric by 2040 and 2050, respectively. Additionally, by 2055–2060, all new CVs would be electric too, resulting in a parc which would likely be 95 percent electric by 2070. This could reduce demand for refining since half of all oil products are consumed for mobility (Exhibit 126).

The expansion of refining capacity and increase in motor spirit (MS) and high-speed diesel (HSD) demand would continue until 2040. However, MS and HSD demand could peak in 2030 and 2040, respectively, after which they may decline due to the electrification of vehicles. Liquified petroleum gas (LPG) demand could decline after 2030 due to the electrification of cooking and be phased out by 2070 with complete electrification. Meanwhile, the demand for aviation fuel would likely grow at a CAGR of three and a half percent but could be gradually substituted by SAF to achieve 50 percent blending by 2070. Naphtha demand could grow at a CAGR of four and a half percent from 2030–2050, and 2.3 percent from 2050–2070, due to the increasing demand for petrochemicals in the LoS scenario.[210] However, the effective demand would be lower due to the increase in recycling activity.

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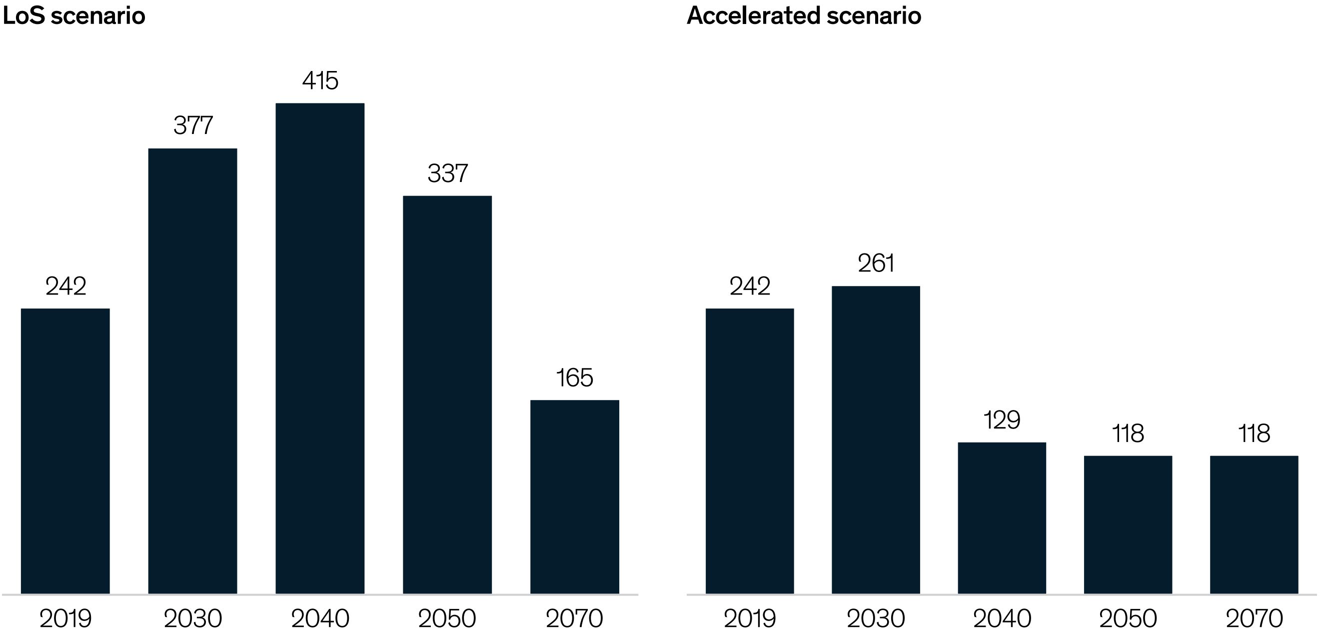
[210] McKinsey chemical insights HSM – Forecast for India.

Exhibit 126

## Oil consumption would likely grow till 2030 and then halve by 2050 in the Accelerated scenario.

**India's oil consumption**
MTOE



Source: IEA- India energy outlook 2021

The demand for petrochemicals can play a crucial role in determining the required refining capacity to produce petrochemical feedstock. Hence, despite the phaseout of petrol and diesel, 147 Mt per annum of refining capacity would likely be required to meet naphtha demand till 2070. Overall, 150 Mt per annum of refining capacity could be repurposed or stranded by 2060 (Exhibit 127) in the LoS scenario.

In the Accelerated scenario, all new two-wheelers and cars would likely be fully electric by 2035 and 2045, respectively. Additionally, by 2045, all new CVs could be electric, resulting in a parc which would likely be more than 95 percent electric by 2050. As a result, demand could see decline and 182 Mt per annum of refining capacity would need to be repurposed or stranded by 2040 (Exhibit 127).

However, both central and state governments could fill up revenues from liquid fuel taxes and dividends from state-owned enterprises(SOEs) in the petroleum sector, which accounted for approximately INR 5.6 lakh crore (total contribution to central and state exchequer) in FY 2019–20.[211]

Some of the largest companies in India are refiners. They would need to take action to protect their value as this transition takes place. Petrol and diesel—which typically account for around half of refinery production—would give way to naphtha (for chemicals), aviation turbine fuel (ATF) and biofuels production as the primary sources of revenue.

— **Gradually shift from crude processing to petrochemicals production.** The demand for fossil fuels may decline but the demand for petrochemicals could increase with GDP growth (Exhibit 128). Hence, this is an opportunity for refiners to forward integrate into petrochemical complexes and chemicals manufacturing. For example, fluidised catalytic convertor modification and hydrocracker optimisation could deliver a 40 percent share of chemicals in existing refineries.[212] Greenfield refineries could be set up to produce 80 percent of the chemicals (such as the crude-to-chemicals complex of a north American refinery player). Refiners could increase their gross refining margins from $6–8 per barrel to $20 per barrel by maximising their conversion to chemicals.

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[211] Petroleum planning and analysis cell: https://www.ppac.gov.in/content/149_1_PricesPetroleum.aspx

[212] Reliance.

Exhibit 127

## 182 Mt per annum refinery capacity would need to be decommissioned/repurposed in the Accelerated decarbonisation scenario by 2040.

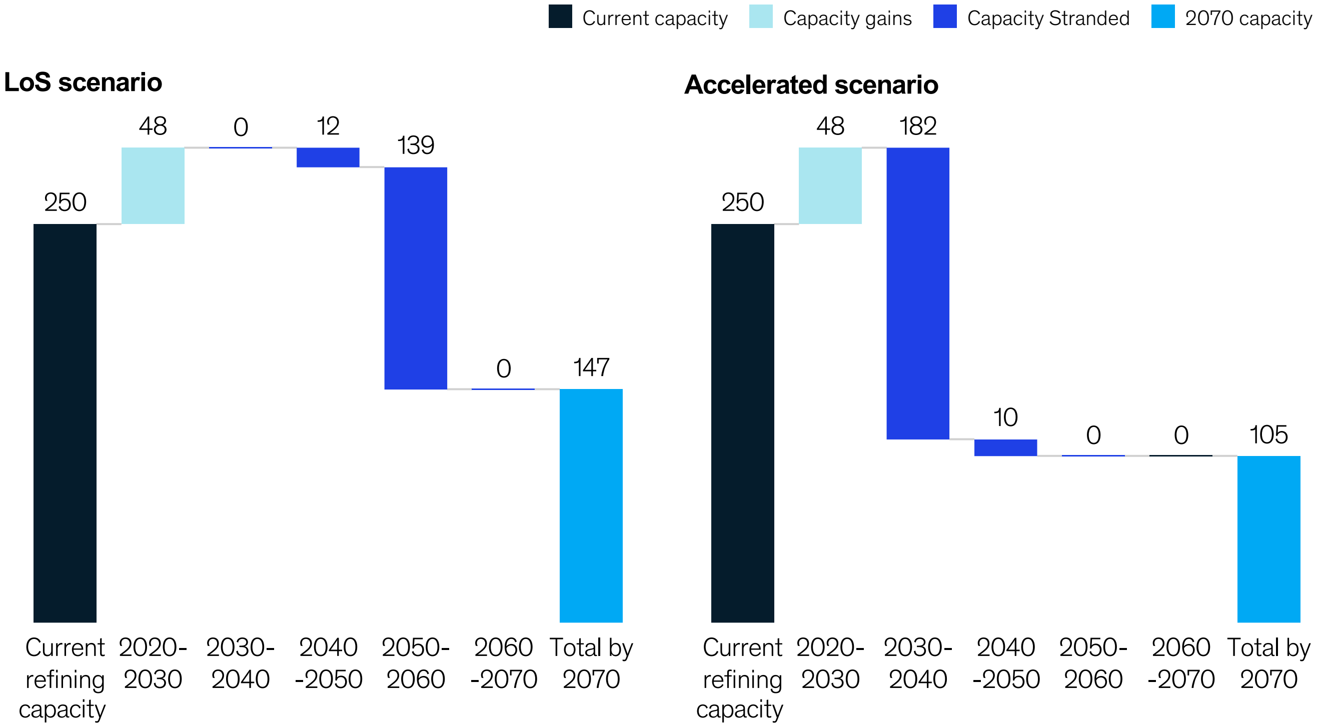
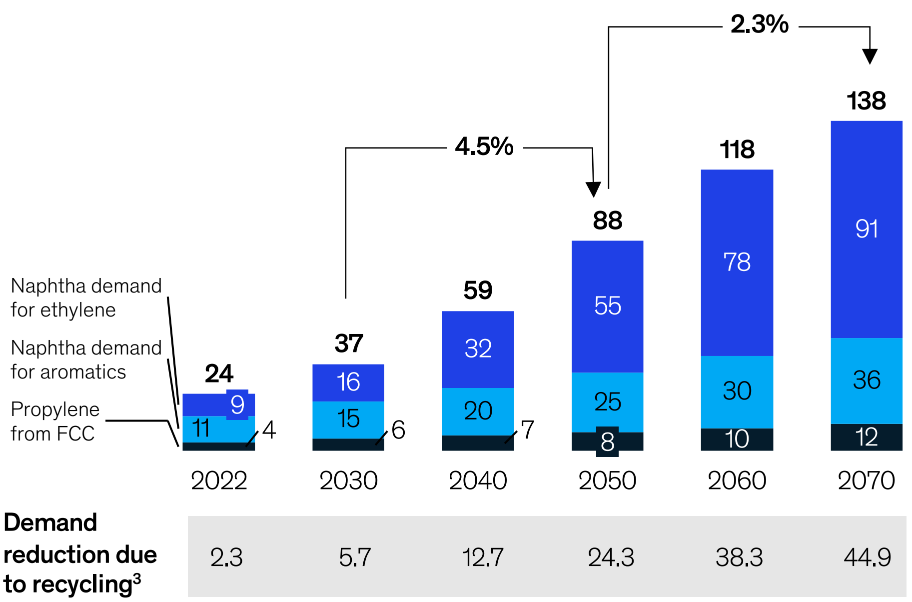


Exhibit 128

## Demand for petrochemicals could drive growth in Naphtha demand.

**Chemicals demand growth converted into refinery products,[1]** Mt per annum



**Refiners can adjust production modes to capture increasing chemicals demand**

- **Increase ethylene:** Convert less reformate (used to produce gasoline) and use as ethylene feedstock; produce more straight-run light naphtha
- **Increase propylene:** Add HS-FCC capacity to convert more propylene at the expense of lower gasoline
- **Increase aromatics:** Use reformate to feed aromatics unit instead of gasoline blending

1. Assumes conversion factor of 0.86 for reformate and 0.3 for ethylene from Naphtha.
2. Assumes 50-60% conversion from crude to Naphtha basis high chemical conversion of refineries (40-50%).
3. In Mt per annum; includes potential for both mechanical and chemical recycling.

Source: McKinsey Chemical Insights; IHSM

— **Repurpose existing refinery assets to produce green hydrogen, ammonia, synthetic fuels, SAF and other biofuels.** Refineries have existing set ups for utilities, storage infrastructure and distribution that could be leveraged to become key players in the green hydrogen and ammonia supply chain.The fuel mix of bunkering is expected to shift to 25 percent ammonia[213] and 11 percent hydrogen by 2050[214] and coastal refineries with storage infrastructure could potentially become bunkering hubs for supplying green fuel to the shipping industry. Green hydrogen can also be used to produce synthetic fuels using captured carbon from the refinery. Demand for SAF could rise as blending mandates are enforced to decarbonise the aviation sector. India has the potential to produce 14 Mt per annum of SAF across multiple pathways (such as Gas-FT and alcohol-to-jet fuel) by 2050 and could become a global supply hub with an SAF-production surplus of 5 Mt per annum by 2040 in the Accelerated scenario.

### b. Coal mining and coal-based power plants

Coal accounts for 45 percent of the country's needs.[215] The sector has played a significant role in job creation and local development, particularly in the coal-producing and mining states of Jharkhand, Odisha, Chhattisgarh, West Bengal, Madhya Pradesh and Telangana. Almost 80 percent of domestic coal is consumed by the power sector, seven percent by steel, five percent by cement and the remainder is used as fuel for industrial applications.[216]

In the LoS scenario, coal's share in the primary energy mix is expected to decline from its current 45 percent to 26 percent by 2050; in the Accelerated scenario, it could drop to two percent by 2050 (Exhibit 125). Most of this decline is driven by the power sector's shift to renewable energy sources. The remaining coal used to make steel and generate heat in cement production would likely be phased out over time, as the consumption of green fuels such as electricity, hydrogen and bioenergy increases. (Exhibit 129)

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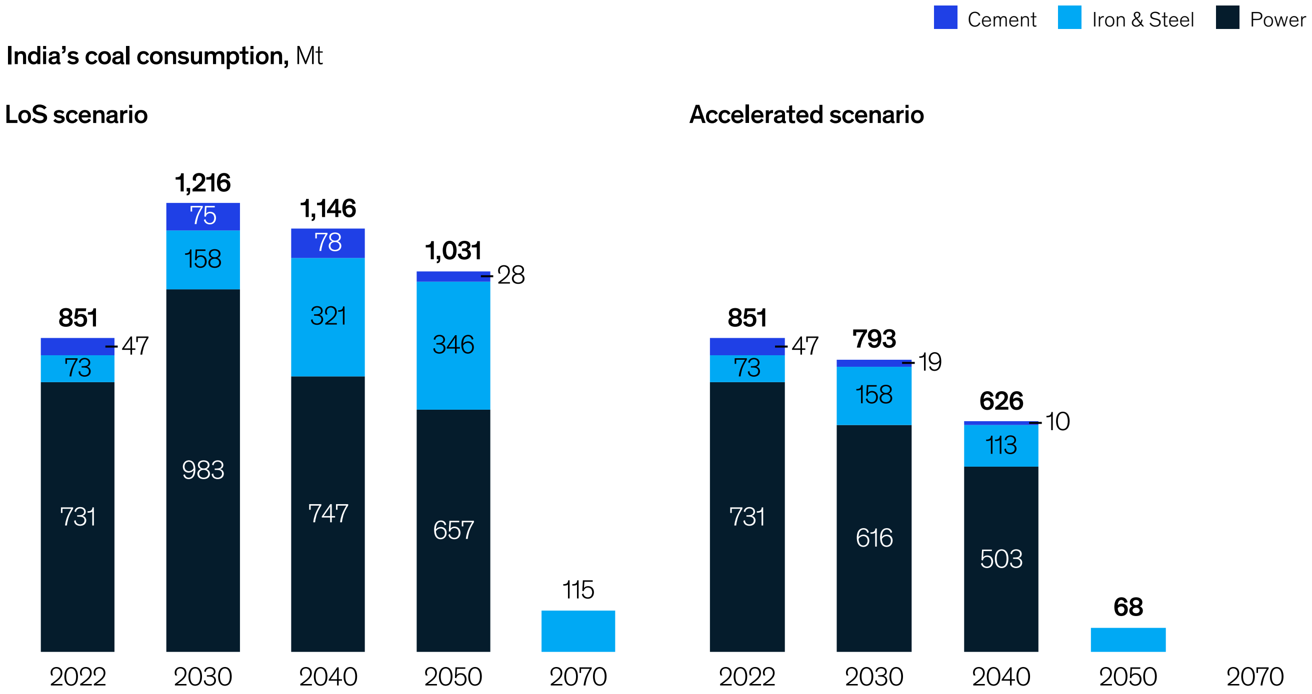
[213] Global Energy Perspective on Maritime powered by Maersk Mc-Kinney Moller Center for Zero Carbon Shipping NavigaTE model (November 2021).
[214] Ammonia energy.
[215] Ammonia energy.
[216] IEA.

Exhibit 129

## Coal consumption could decline to 8% of current consumption by 2050 in the Accelerated scenario.



1. 4102 Kcal/kg gross calorific value assumed for converting coal projections to Mt per annum.

Source: McKinsey bottom-up model for power, steel and cement sector

Coal capacity in power generation currently stands at 211 GW. 80 percent of this capacity has been set up between 2010 and 2020, with about 30 GW of additional capacity being planned by 2030. Since India's coal fleet is relatively young, it is expected to remain operational until 2050. About 46 GW of capacity in the LoS scenario and all the current 211 GW in the Accelerated scenario could be at risk for closure and require decommissioning by 2050 (Exhibit 130).

The transition would also impact coal demand in other sectors. Steel production, for example, uses around 73 Mt of coal annually in blast furnaces. That could be completely phased out by 2070 as a result of accelerated decarbonisation. Likewise, the cement sector currently uses 47 Mt of coal that could be entirely substituted by green fuels by 2050.[217]

In India, petrochemical imports stood at $40 billion (FY2019) and were expected to reach $75 billion by FY2025.[218] The sector is heavily dependent on imports of crude/petrochemicals and coal gasification can enable India's transition to a chemical manufacturing hub while developing alternative uses for domestic coal. Coal gasification is technically and commercially proven but the overall profitability of the coal to chemicals project would depend on both the price of crude oil and coal in future. China has been using it to produce large quantities of chemicals, fertilisers, etc.[219] GHG emissions are higher for coal-based chemicals, which can be mitigated by mandating new capacity to include carbon capture and storage (adds five percent to capital costs) and the remaining emissions may be mitigated by carbon offsets.[220] India has made initial progress by setting up pilot plants in Talcher (coal to fertiliser) and Dankuni (coal to methanol).[221] It has also announced a vision of 100 Mt Coal Gasification by 2030 (National Coal Gasification Mission by the ministry of coal) to find an alternative use for coal and utilise the natural resources available in the country.[222] Our LoS and Accelerated scenarios have not considered this alternative use of coal.

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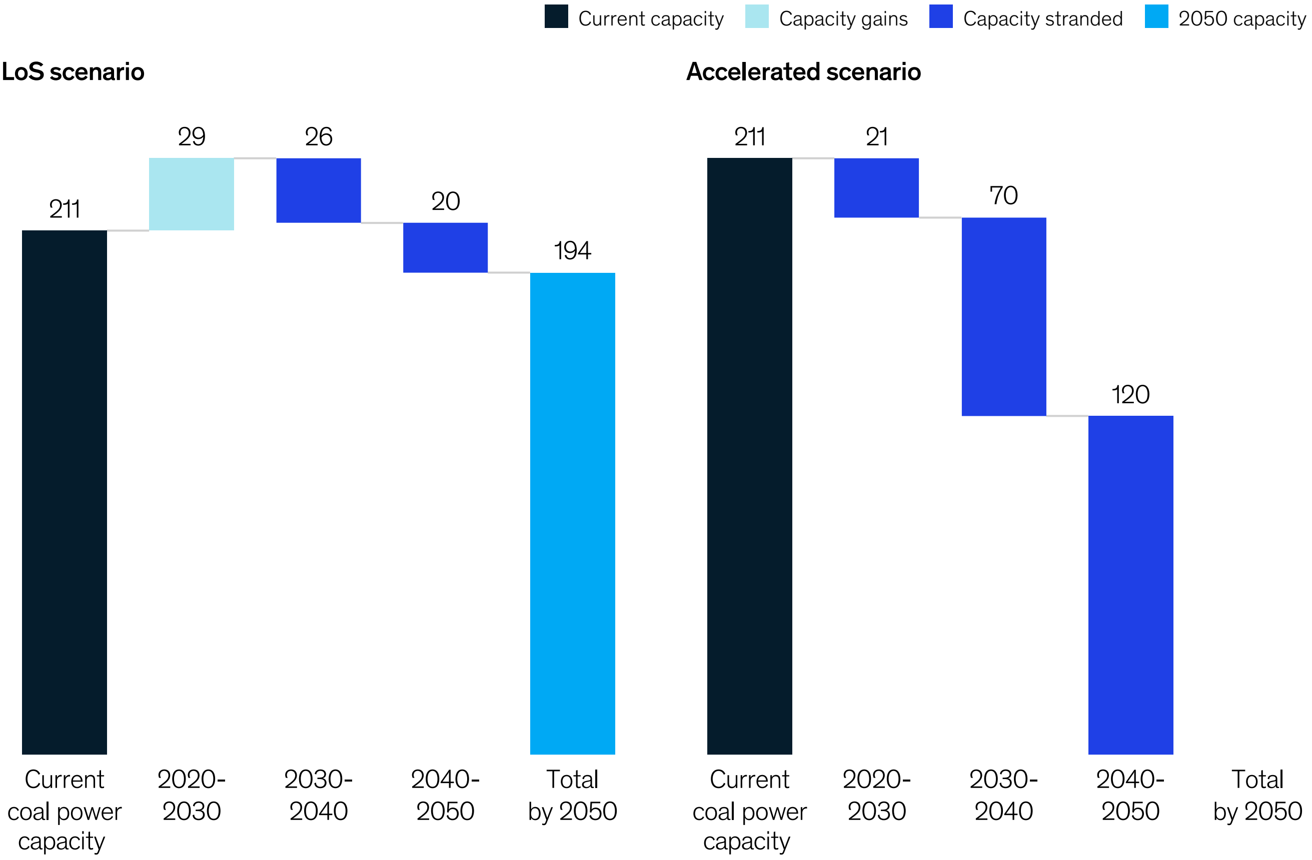
[217] McKinsey analysis based on bottom up modelling on steel and cement sectors.
[218] Adani – coal to chemicals.
[219] Adani – coal to chemicals; HSBC global research.
[220] Ibid.
[221] Ministry of coal – action plan for 2022–23.
[222] Press information bureau.

Exhibit 130

## 91 GW of coal power generation capacity could be decommissioned in the Accelerated scenario by 2040.



### c. Use of biomass and agri-based fuels

Increasing the use of carbon-neutral biomass (agricultural crop residue) is critical for decarbonising India, especially in the hard-to-abate sectors. India currently produces close to 500 Mt of crop residue out of which 110 Mt can be made available for biofuel production (bioethanol),[223] biomass-based power generation and fuel for the industrial sectors such as steel and cement. 250 Mt of the crop residue is used as cattle feed and the remaining 140 Mt is not managed actively/mismanaged.[224] The biofuels usage envisaged for the future is a fundamental transformation of how agricultural residue would be used in the future versus how it is directly burned today.

The National Policy on Biofuels (2018) has mentioned targets of blending 20 percent of bioethanol into petrol and five percent of biodiesel into diesel by 2030 which could incentivise the utilisation of biomass for liquid fuel production. Bioethanol as a petrol substitute is a credible alternative for the short term. In the medium-term, liquid low-carbon fuels (from bagasse) could be used. And, in the long term, electrification could drive the decarbonisation of transport (except for heavy trucking). Carbon-neutral biomass could be prioritised for the cement, steel and aviation sectors through regulatory support like RDF usage in cement kilns.

In the Accelerated scenario, 600 Mt of crop residue is expected to be generated in India in 2050 of which 315 Mt would be utilised as cattle feedstock. 120 Mt would be needed for soil-based carbon sequestration using bio-decomposers. Of the remaining 165 Mt, 45 Mt could be prioritised for cement/steel and 60 Mt for biomass-based power generation. This would leave only 60 Mt of carbon-neutral biomass available for SAF. SAF would likely require 130 Mt of feedstock and to meet the balance 70 Mt, organic MSW would need to be utilised.

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[223] Bio-ethanol generated from sugarcane waste / bagasse.
[224] Ministry of agriculture.

## Implications for land use

India has a total land area of 329 million ha, out of which 21 million ha is inland water, leaving a total available land mass of 308 million ha. Today, 23 percent of this available land is forest area, 59 percent is agricultural and the remaining 18 percent is used for non-agricultural purposes, grazing pastures and barren land.[225] As India grows in a sustainable fashion in the Accelerated scenario, it will likely need land not only for urbanisation and an increase in industrial and agricultural output but also for renewable power capacity installation, carbon sinks, biomass, etc.

Based on current land usage practices, we estimate that the total increased land area requirement would be 45 million ha in 2050 versus today (Exhibit 131). However, this land is not readily available and India may have to implement efficient land use practices to ensure necessary land is made available. These measures would need to be innovative and could possibly include alternative land uses for barren land, vertical farming, urban carbon sinks, offshore wind and rooftop solar expansion.

The following solutions could be considered to unlock India's land efficiency:

— **Increased agricultural productivity:** Adopting sustainable and higher-yield farming practices like converting long-term fallows to current fallows and bringing them under cultivation could provide 15 million hectares of land.

— **Barren land use:** Barren land can be utilised for different purposes like installing solar and wind power plants or new industrial plants and could cater to 11 million hectares of incremental requirement.

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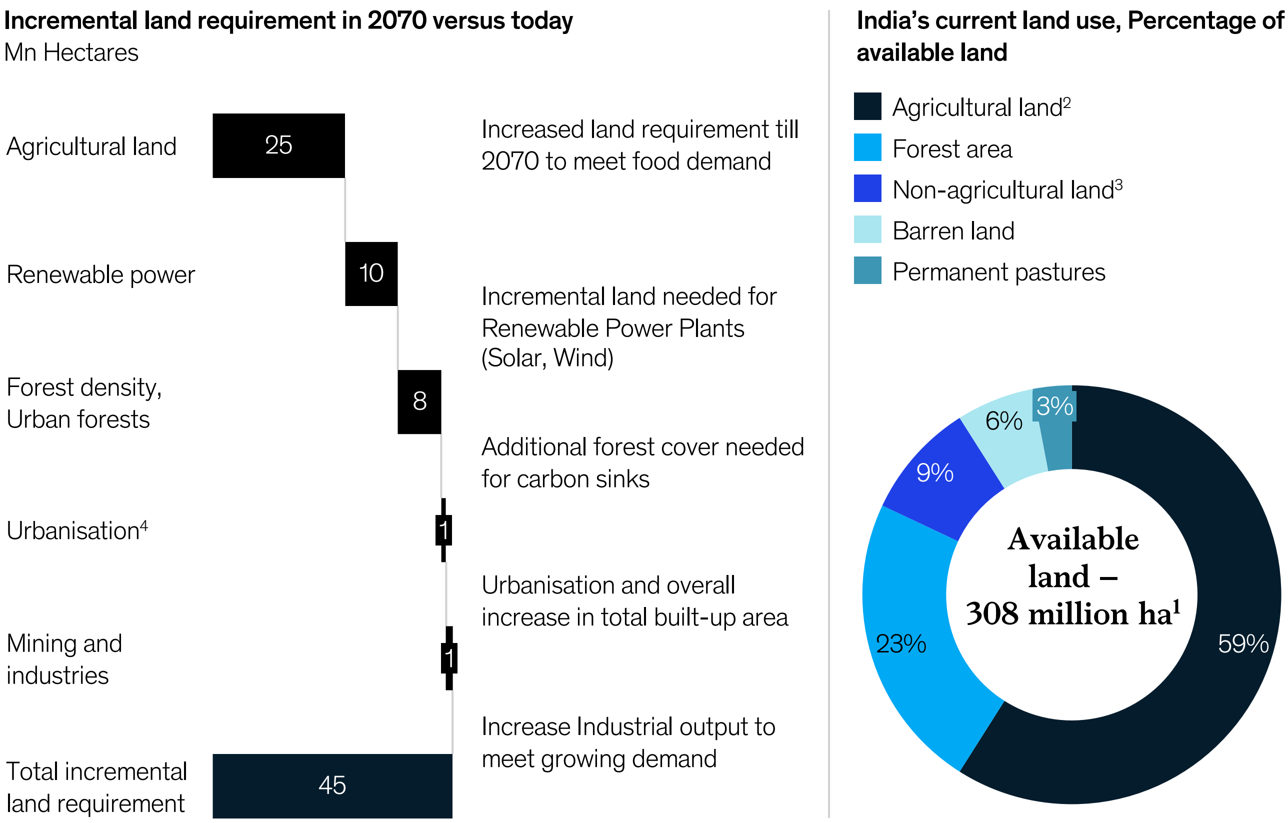
[225] Land use statistics at a glance, Government of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture & Farmers Welfare, Directorate of Economics & Statistics, November 2021

Exhibit 131

### 45 million ha incremental land would likely be required in the Accelerated scenario by 2070.



**Incremental land requirement in 2070 versus today**
Mn Hectares

**India's current land use, Percentage of available land**

1. Total land 329 million ha less Inland waters of 21 million ha.
2. Agricultural land includes croplands, culturable wastelands, land under miscellaneous tree crops and fallow lands.
3. Non-agricultural land includes built up urban and rural areas, mining land and land used for other industrial purposes like railways, irrigation, etc.
4. Urbanisation requirement includes a need to increase built up urban area by 3.7 million ha, which is offset by a decrease in rural built-up area by 2.8 million ha.

Source: McKinsey analysis

- **Denser forests and urban forests to meet carbon-sink goals:** Denser forests, increased agroforestry and urban tree cover could meet carbon-sink targets, as there is not sufficient forest area available to meet the Paris commitment of 33 percent land under forest cover; denser forests could provide land efficiency of 5.6 million hectares.
- **Vertical urbanisation:** Urbanising existing built-up areas, creating higher population densities in towns and cities, instead of increasing overall built-up area could provide 2 million hectares of land.

These measures could help acquire 34 million ha of additional land but a further 11 million ha would still be needed. To acquire this remaining land, expensive routes like artificial islands and land reclamation could be considered.

India can consider establishing a nodal authority to define a national land use plan, lay out clear land-use guidelines and mandates for optimised use across urbanisation, industrial needs, carbon sinks, agriculture and renewables. The nodal body can make trade-offs and enable efficient land use in consultation with states ('land' being a state subject). It would be essential to have a long-term outlook to balance the growing need for land across sectors. Finally, policies would be needed to ensure efficient land use across sectors.

## Implications for people

- **Household spending:** A critical consideration is the impact accelerated decarbonisation will have on the average Indian household's spending requirements. To estimate this impact, we have used the Empowerment Line[226] that assesses what constitutes a meaningful, economically-empowered standard of living.

  Spending on food, which represents over 40 percent of the total spending requirement, is likely to have no major impact as the incremental Capex expenditure in agriculture could be offset by cost savings from sustainable practices and improved productivity. Energy spending could be reduced as the faster expansion of renewable energy can help lower power generation costs (current INR 3.9/kWh to INR 2.9/kWh by 2040). Housing spending could increase with the rise in steel and cement prices but the overall impact on construction costs would be limited to two or three percent by 2040. Other spend categories such as transport could also be reduced as the shift to EVs from the current ICE vehicles would lead to operational savings. Having said that, financing would be needed for the higher upfront cost of EVs. Moreover, faster EV adoption in light commercial vehicles could help reduce the logistics cost for goods and services consumed by households. In conclusion, our analysis suggests that there will not be a major impact in overall spending requirements[227] as a result of accelerated decarbonisation by 2040 (Exhibit 13).
- **Jobs:** The Accelerated scenario is expected to impact jobs and skills requirements across sectors as they decarbonise. India's coal mines are estimated to employ around 0.35 million workers currently. Additionally, more than 1.7 million people are indirectly dependent on the coal sector.[228] The phasing out of coal as India decarbonises would need to be supported by new businesses that support the transition for this workforce. Further, all current coal-based power plant capacity (211 GW) could be closed by 2050 in this scenario. However, the power sector would likely see an uptick in employment with jobs moving from non-renewable energy plants to jobs in solar and wind projects. Overall, there could be a shift of jobs from coal rich eastern India to high renewable potential southern and western India.

  The Indian public sector companies in the Oil and Gas sector employ 0.1 million workers currently with more than half of these jobs in refining and marketing.[229] As two-thirds of the 2030 refining capacity could be stranded by 2050 in the Accelerated scenario, the workforce in this sector could have trouble transitioning, even with the potential repurposing of the stranded refining capacity. The automobile industry would also see a shift from ICE to EV manufacturing roles. Similarly, steel and cement would also see restructuring from BF-BOF to hydrogen-based green steel and the adoption of new raw materials for clinker development, respectively.

  Overall, the accelerated decarbonisation of India is expected to transform more than 30 million jobs[230] (24 million new jobs could be created while six million existing jobs could be lost) by 2050.[231] However, this number is small in the context of the macro trends affecting India's workforce as outlined in Exhibit 133.

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[226] https://www.mckinsey.com/featured-insights/asia-pacific/indias-path-from-poverty-to-empowerment.

[227] Consumer spending requirement, particularly for low-income groups, would likely need continued support in form of government subsidies which have not been considered in this analysis.

[228] TERI.

[229] Indian petroleum and natural gas statistics, Ministry of petroleum and natural gas.

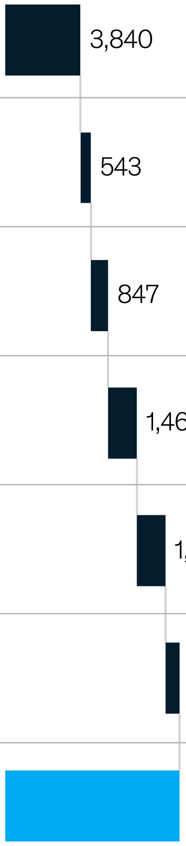
[230] The net-zero transition, what it would cost what it would bring, McKinsey.

[231] McKinsey Global Institute: The net-zero transition - what it would cost, what it would bring.

Exhibit 132

## Decarbonisation-driven household spending impact for households on the Empowerment Line[1] (in 2040).

↔ No major impact ↓ Decrease in spending ↑ Increase in spending



| **Normative spend for household FY20** (INR/month) | | **Impact in Accelerated scenario in 2040** | **Factors not considered** |
|---|---|---|---|
| Food | 3,840 | ↔ Incremental agri capex offset by savings from sustainable practices, improved productivity, and income from crop residue and agroforestry (carbon credits) | Climate impact on agriculture yields and hence food prices |
| Housing | 543 | ↑ Increase in cost of cement (impact of 1-1.5%) and steel (impact of 0.5–1%) increases housing costs | Land price increases caused by land demand for decarbonisation |
| Energy | 847 | ↔ Decrease in average supply cost from 6.15 kWh to 5.4 kWh. Increase in T&D costs offset by decrease in generation costs due to shift to RE and reduction in AT&C losses | Land driven increases, increase in raw material prices |
| Transport and others[2] | 1,463 | ↓ ICE to EV shift leads to reduced costs | Financing assumed to be available for higher upfront cost of EVs; fuel related tax losses not compensated for through auto and power taxes |
| Health and social security[3] | 1,450 | ↔ Increased cost of building infrastructure, lower spends on transportation and power costs, not impacting the overall spend | Adaptation costs |
| Education[4] | 702 | ↔ No major impact | |
| **Total** | **8,845** | ↔ | |

[1] MGI 2014 Report: From poverty to empowerment. Data adjusted for inflation and household of four people assumed.
[2] Includes clothing, footwear, entertainment, communication and domestic appliances.
[3] Adjustment for value of subsidies in sanitation and drinking water is included under health.
[4] Includes elementary and secondary education.

Source: McKinsey Global Institute analysis

Exhibit 133

## Multiple macro level trends affecting India's workforce.

**40+ million**
jobs in India estimated to be affected due to digital adoption between 2019-2025

**60 million**
workers will enter the workforce from 2020-2030 based on demographics changes

**30 million**
workers will move from farm work to non-farm work from 2020-2030

**30+ million**
jobs to be transformed between 2020-2050 due to 'green transition'

## Resultant benefits accrued from decarbonisation

While the primary benefit of decarbonisation is the ability to arrest climate change and reduce global warming, this transition offers a series of other benefits to the country that it is important to recognise. In our analysis, we have identified the following additional benefits:

— **Energy import reduction and energy security.** Decarbonisation would result in the localisation of India's energy requirements with the shift from coal, oil and gas to renewable energy, green hydrogen and biomass. This would likely imply a huge reduction in coal (184 Mt) and oil imports (145 tons) by 2050 with a corresponding increase in lithium-ion batteries and modules, cells, turbines for renewable energy.

— **Substantial Forex savings.** The import reduction could bring substantial Forex savings for the government, i.e., $1.5–1.8 trillion from reduction in oil imports, $0.4–0.6 trillion from reduction in natural gas imports and $0.8–1.0 trillion from reduction in coking coal imports. However, there could also be an increase of $0.3 trillion in battery imports and $0.3 trillion in solar panels. This could be reduced by intensively focusing on indigenous manufacturing with the help of initiatives such as PLIs, etc.

— **Leadership opportunities.** There would be the opportunity to use India's huge demand to catalyse the development of globally competitive cleantech industries and give India the opportunity to lead the world. India could establish a global manufacturing hub for green H2, solar panels, etc. and become a global leader and exporter of green technologies such as green H2, green steel, green pig-iron, SAF (5.5 Mt of annual SAF export, worth $5.5 billion) and storage technologies not based on lithium or carbon.

## Pathway uncertainties

Both the LoS and Accelerated scenarios depend heavily on green technologies being adopted, cost curves evolving and necessary policy frameworks being implemented. The LoS scenario relies upon the adoption of existing and upcoming technologies for decarbonisation based on today's cost projects and current and announced policies to drive decarbonisation (FAME, Green Hydrogen policy, etc.). While in the Accelerated scenario, a faster adoption of the lower-cost technologies is assumed with a correspondingly faster decline in the cost of new technologies and implementation of stricter policies such as carbon price, blending mandates, etc. A few factors could evolve differently in the future which would have a major impact on how the path evolves:

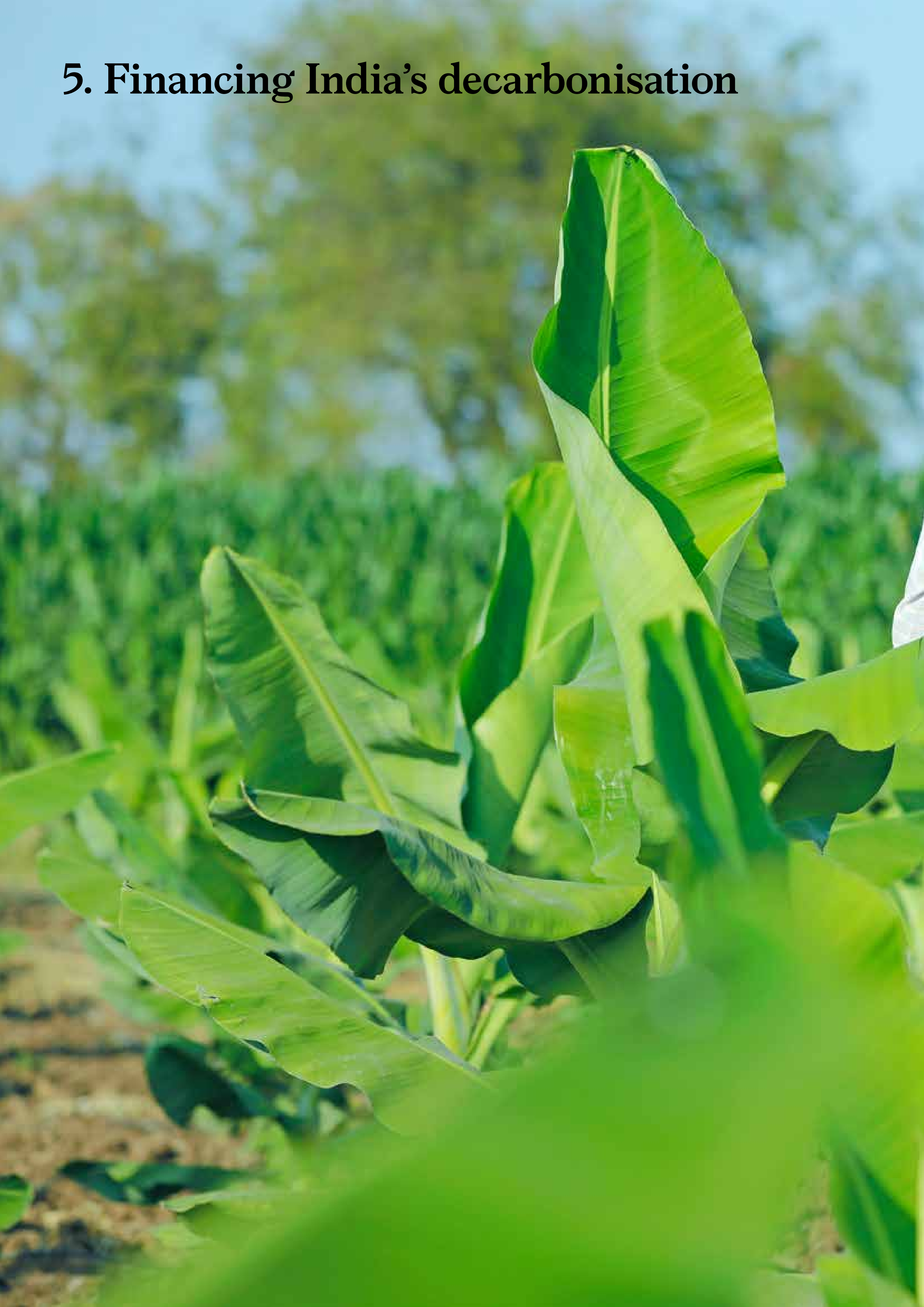
— **Evolution path of existing technologies:** Both the LoS and Accelerated scenarios have projections regarding timelines and cost curve evolution of existing technologies such as green hydrogen, battery, offshore wind, etc. Depending on technology developments in the next ten years, current projections might change.

— **Development of new technologies:** The Accelerated scenario relies heavily on certain technology breakthroughs such as direct air capture and utilisation, low-cost storage for carbon capture, non-lithium long duration storage, blue-carbon capture, etc. The pathways outlined in the report depend on innovation and R&D in these areas.

— **Policy implementation:** Methodical implementation of current policies would be critical if the LoS scenario is to hold. Similarly, the pace of the new policy launch as well as the timing and rate of implementation could impact the Accelerated scenario.

— **Others:** Certain other factors such as availability of green finance, the careful implementation of a just transition, competitive dynamics from the changing energy mix, etc. could have an impact on scenario evolution.

# 5. Financing India's decarbonisation



## Key takeaways

**Financing decarbonisation will be an acute challenge for India.** India will need an estimated $7.2 trillion[232] in green investments until 2050 to decarbonise in the LoS scenario and an additional $4.9 trillion for the Accelerated scenario (about 3.5 percent[233] and 2.4 percent of India's GDP through this period, respectively).

**The investments required are front-loaded;** India would have a runway till 2040 to orchestrate half of the total $12.1 trillion required by 2050. The balance half of the investments would be required in the decade of the 2040s. However, decarbonisation could decrease operating costs by $2.1 trillion by 2050, mostly in the decade of the 2040s, thus easing cash needs.

**50 percent of the abatement required for decarbonisation is 'in the money',** with a majority related to renewable energy, automotive and agriculture. However, current annual financing for decarbonisation meets only 10–12 percent ($44 billion[234] in FY2019–20) of the investment demand in the Accelerated scenario.

**Despite the positive return profile for most cases, financing is constrained** due to real and perceived risks (e.g., technology risks, payment risks, project execution, policy stability) and structural constraints (e.g., investor expectation mismatch, limited participation from the Indian banking sector).

**India needs an aligned, cross-sectoral, top-down plan for its decarbonisation, cascaded into the right industrial policies.** One of these could be to accelerate the nationwide compliance carbon market to fast-track green investment and increase the flow of capital toward hard-to-abate use cases. This could also help the move to greener technology at a time when India will likely add a lot of capacity, thus preventing a lock into fossil fuel-based technologies (e.g., for steel).

**Banks, a major funding source, could define glide paths for their financed emissions and set ambitious targets for financing new green businesses.** Institutional measures like shaping banking regulations towards transition financing and setting up a green transition bank to orchestrate capital are greatly required to fast-track decarbonisation.

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[232] Capex calculations are based on bottom-up investment analysis for only green/low emission levers.

[233] GDP data forecast from The Economist Intelligence Unit; Real Gross domestic product in $ at 2010 prices.

[234] Climate policy initiative report on "Landscape of Green Finance in India."

## Proposed investment needed for India’s decarbonisation

This transition will likely require $7.2 trillion to be invested[235] in green technologies till 2050 for the LoS scenario and an additional $4.9 trillion for the Accelerated scenario (3.5 percent and 2.4 percent, respectively, of cumulative GDP for the period) (Exhibit 134).

Investment for the power sector includes green Capex on low carbon emission power generation such as solar and its supporting infrastructure. Similarly, investment for industry considers additional green capacity via technologies such as hydrogen-based steel production. Mobility investment includes Capex for EVs (including incremental Capex for the vehicle), SAF production units and supporting infrastructure. Agriculture investment includes Capex in electric tractors and installation of equipment for the green transition in agriculture. Other investments include Capex in green hydrogen (electrolyser manufacturing, pipeline and storage infrastructure), CCUS (setting up capture, transportation and storage infrastructure for $CO_2$) and material circularity (infrastructure for waste management and segregation).

In both scenarios, about 70 percent of the capital investment would be required for decarbonising the power and automotive sectors, with agriculture and industry making up a quarter of the overall estimated investments (Exhibit 135).

Accelerated decarbonisation will likely create operational cost savings[236], such as lower costs of power generation due to increased solar penetration. As a result, some portion of the additional investment could be recuperated through operating cost savings. From now until 2050, operating costs could lead to overall savings of $2.1 trillion, offsetting about 45 percent of the capital investments over this period (Exhibit 136).

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[235] Calculations for sectors across the LoS and Accelerated scenarios is based on bottom-up investment analysis for green/low emission levers and supporting infrastructure. Non-green / high-emission ongoing capex has not been considered in the capex numbers above.

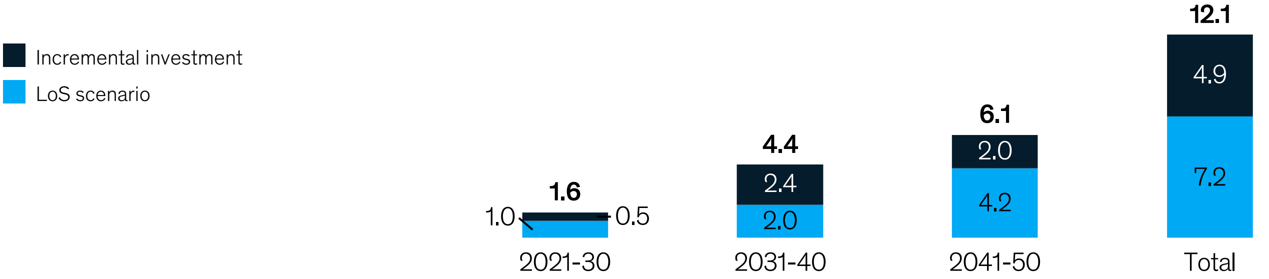
[236] Opex calculations for each sector and cross-cutting theme have been done irrespective of green or non-green technologies to demonstrate overall incremental savings due to accelerated decarbonisation.

Exhibit 134

### Investment is required for India's decarbonisation in the LoS scenario; and to accelerate the transition.

**Decade-wise investment**[2]
($ trillion)

| | | | | Cumulative |
|---|---|---|---|---|
| **Total investments as % age of real GDP (LoS)** | 2.6% | 3.1% | 4.1% | 3.5% |
| **Total investments as % age of real GDP (Acc.)** | 4.1% | 6.8% | 6.0% | 5.9% |



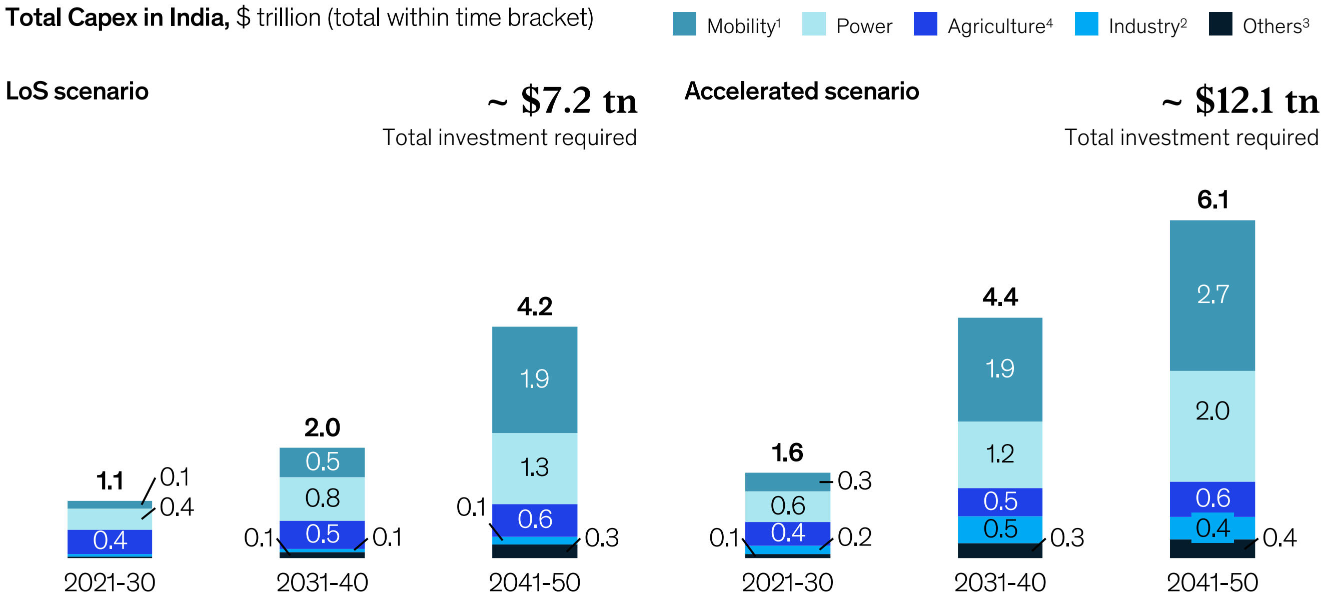
| | | | | |
|---|---|---|---|---|
| **Average annual investment** | LoS, $ trillion | 0.10 | 0.20 | 0.42 |
| | Accelerated, $ trillion | 0.16 | 0.44 | 0.61 |

1. EUI data used for GDP forecast.
2. The investment numbers are based on bottom-up investment analysis for abatement and supporting infrastructure, built granular, sector by sector. High-emission ongoing capex has not been considered; Capex calculations derived from bottom-up models for power, steel, cement, other industries, transport, agriculture, NBS, CCUS, hydrogen and material circularity.
3. Estimated cumulative GDP: 2021-30: $38.7 tn; 2031-40: $64.6 tn; 2041-50: $101.6 tn.

Exhibit 135

### 70% of total investment would likely be required to decarbonise the power and mobility sectors.

**Total Capex in India,** $ trillion (total within time bracket)



1. Automotive and aviation sectors combined under mobility header.
2. Industry includes steel ($113 bn), cement ($81 bn), aluminium, ammonia and waste management in LoS, includes CCUS in Accelerated scenario ($325 bn).
3. Others includes cross-cutting themes, i.e., hydrogen ($189 bn) and circular economy ($185 bn) in LoS.
4. Total production capex involved in agriculture, including factor costs and green levers.

Source: Bottom-up models for sectors

However, the cost savings are not balanced across sectors (Exhibit 137). Power invests an incremental $1.3 trillion over this time frame for the Accelerated over the LoS scenario, while saving $0.5 trillion in operating costs; transportation invests an incremental $2.3 trillion, while saving $1.9 trillion; agriculture invests an incremental $0.05 trillion, while saving $0.3 trillion. On the other hand, industries like steel and cement invest $0.9 trillion, with a simultaneous increase in costs ($0.2 trillion); other levers such as NCS and material circularity would require investments of $0.1 trillion while saving $0.3 trillion (Exhibit 137).

Between the Accelerated and LoS scenarios, two-thirds of the emissions could be abated at negative or low cost (<$10/$tCO_2$e) and 50 percent of the emissions could be abated through in-the-money levers (Exhibit 138 – MACC[237] curve). This is because the cost of decarbonisation is expected to decline as technologies mature. Solar energy, wind power and EVs, that comprise the first quintile of the abatement potential, present a very positive investment case.

The levers in the last quintile are the high-cost ones, comprising some advanced agriculture practices, offshore wind, CCUS, which could cost more than $60 per $tCO_2$e and would likely need demand signals to be set up. Hydrogen-based steel could cost $47/$tCO_2$e till 2040. From 2040–2070, it could cost $9.6/$tCO_2$e. An estimated carbon price of $40–50/$tCO_2$e could potentially drive domestic carbon credits generation by making all sequestration levers cost competitive (100 percent sequestration levers are cost competitive at $35 per $tCO_2$e).

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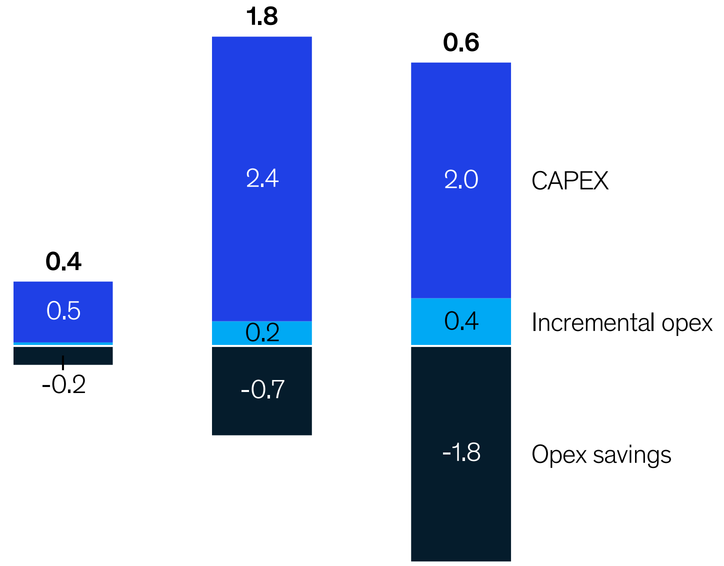
[237] Marginal abatement cost curve.

Exhibit 136

## In the Accelerated scenario, decarbonisation could offset 45% of incremental capital investments.

**Incremental[1] decade wise spend[2] for accelerating decarbonisation,** $ trillion

**$50 tn**
**(25% of GDP)**
total spending on physical assets over 30 years in Accelerated



**$4.9 trillion**
incremental spending on green physical assets over 30 years

**$2.1[4] trillion**
incremental operating cost savings over 30 years

| | 2021-2030 | 2031-2040 | 2041-2050 | Cumulative[3] |
|---|---|---|---|---|
| Net incremental spend5, percent of cumulative GDP in period | 1.02% | 2.90% | 0.55% | 1.37% |

1. Spending on physical assets in Accelerated scenario, minus those in the LoS scenario for capex and vice versa for opex; excluding opex reduction in refining sector (which is mainly due to reduction of the refining activity).
2. Estimation of capex includes spending on physical assets in power, mobility, steel, cement, agriculture, CCUS, hydrogen, circular economy and other industries. Estimation of opex includes spend for physical assets across various forms of energy supply (e.g., power systems, hydrogen, and fuel supply), energy demand (e.g., for vehicles, alternate methods of steel and cement production), and various forms of land use (e.g., GHG-efficient farming practices).
3. Calculated as spending on physical assets net of operating costs in that period, divided by GDP in the period. GDP is for the cumulative GDP from 2021-2050 is taken directly from IHS-Markit.
4. Savings from one sector may not directly compensate for capex requirement of other sectors and numbers shown present a macro-economic view for the nation.
5. Potential revenue from levers has not been captured.

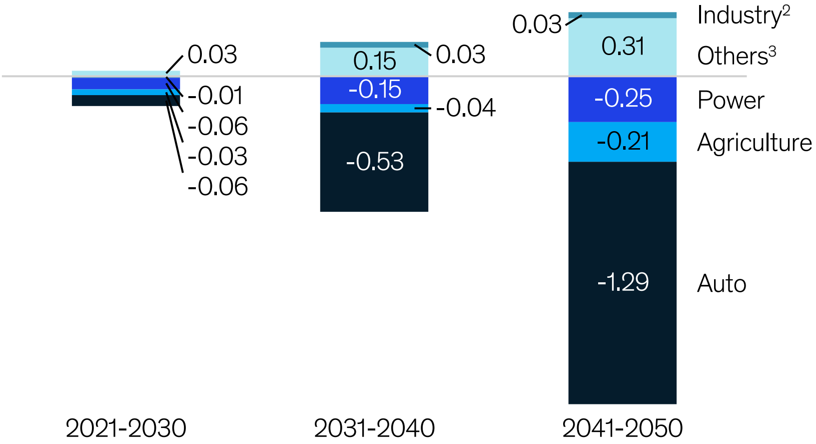
The cost of decarbonisation is expected to decline as technologies mature – even in a high growth economy, as innovation and economies of scale lower technology costs over time. A portion of emission abatement levers considered in the Accelerated scenario (e.g., marine fuels, some advanced agriculture practices and electrification of high-temperature industrial heat) could remain high cost – and will likely require additional support to make happen.

More importantly, a large number of levers are not in the money in the initial decades of the 2020s and 2030s (Exhibit 138). This could be an indication of the policy load in the early years to get the abatement engine primed up, through blending mandates, carbon prices and other, sector-specific policies. Additionally, external demand drivers could include supplying to regions like Europe, Japan and Korea, which are likely to have high carbon prices and border adjustment mechanisms, and would welcome green imports.

Exhibit 137

## Mobility alone could contribute to more than half of total savings in operating cost.[1]

**Operating cost savings by sector,** Accelerated vs. LoS scenario, $ trillion



1. Potential revenue from levers has not been captured.
2. Industry includes opex from steel, cement and CCUS.
3. Other operational expenditure included costs for NCS and material circularity.

Source: McKinsey bottom-up sector models and DSE

## Challenges in financing this transition – incentivise capital providers across corporates, banks and investors

The current annual green financing market in India is estimated to be around $44[238] billion across both debt and equity investments. This could increase to an annual spend of $160 billion per annum (4.1 percent of GDP) in the current decade, $440 billion in the 2030s (6.8 percent of GDP) and $610 billion in the 2040s (six percent of GDP) in our Accelerated scenario (Exhibit 134). Two-thirds of this spending will likely be needed even in the LoS scenario. This funding could be mobilised largely from the retained earnings of corporations, banks, public markets and the government. Private equity and sovereign wealth funds could have a smaller, but important, role to play. Challenges to raising this funding comprise:

— **Delayed benefits, even for NPV positive levers:** About 50 percent of the abatement levers (e.g., EV, RE), even between the LoS and Accelerated scnearios, are NPV positive. Yet, even for these positive levers, Opex savings kick in substantively only in the 2040s, while the investment is made in the prior decade, creating a cash flow mismatch for the economy.

— **Uneconomic business cases responsible for a quarter of the abatement,** such as CCUS, hydrogen-based green steel (till 2045) and green hydrogen as a grey hydrogen replacement (till 2030).

— **Capital formation challenges for positive investment cases,** due to both financial and structural constraints. These include payment-related risks (e.g., PPA[239] renegotiations as technology costs decline, payment delays by power distribution companies), project risks (e.g., land acquisition challenges, delays in grid connection) and currency risks for import dependent projects.

— **Capital flows constrained by investors' expectation mismatch:** Most investor groups have a short-term investment horizon, while green projects have long-term funding requirements (e.g., most solar/wind projects need financing for over 20 years while most bank borrowings are five years in tenure).

— **Limited participation from the Indian banking sector:** There are very few banking regulations and incentives to drive sustainable finance in a scalable manner. As per the RBI ESG Survey 2022, 45 percent of the boards of Indian banks have not discussed the need to increase green finance in the last two years.[240]

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[238] Climate policy initiative report on "Landscape of Green Finance in India."

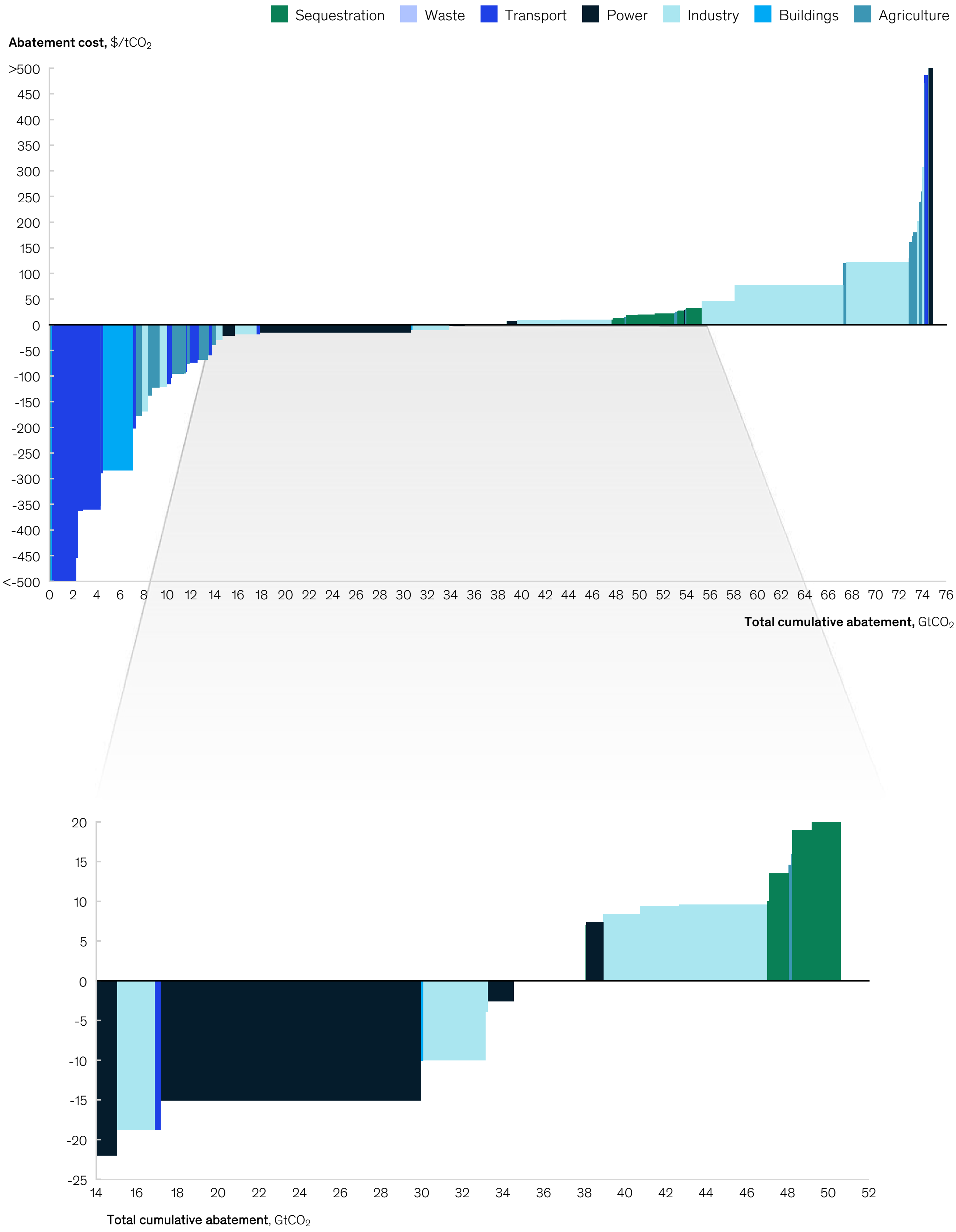
[239] Power purchase agreements is a legally enforceable contract signed between a buyer and seller of electricity.

[240] RBI ESG survey.

Exhibit 138

## Two-thirds of the emissions can be abated at low or negative cost (<10 $/tCO$_2$).

### Cost curve displays the cumulative abated emissions wrt LoS scenario



## Proposed interventions could be considered to accelerate financing to support the green transition

Five important interventions could accelerate the availability of domestic and international funding. These include a national plan cascaded into a decarbonisation policy, carbon markets to get ideas into the money faster, glide paths for all banks, regulatory enablers for banks and a green bank.

1. **A national plan to provide stability and direction for the investments to come**

   An overarching Indiawide plan could be considered with an appropriate governance system to ensure coordination across ministries and external stakeholders in delivering net zero. Such a plan, with multiple horizons (five-, 15-, 25-year), could form the basis for developing industrial policies which would enable the large industrial investments needed for India's decarbonisation. In the absence of such a plan, the capacities could get built on legacy technologies (e.g., fossil fuel-based steel), or possibly capacities would not come, leading to shortages and higher prices.

2. **Carbon markets to get ideas into the money faster**

   In order to accelerate the process of decarbonisation, India could explore three types of carbon-pricing mechanisms that have been implemented globally—carbon tax, emissions trading systems (ETS) and voluntary carbon markets (VCMs). The first two are mandatory and enforced using regulatory measures, whereas VCMs are based on internal targets and buyers can buy carbon credits based on voluntary commitments.

Carbon tax is comparatively easy to implement but it has limitations—for example, it has a higher impact on low-income households and no market-based adjustments—and many developing countries are now shifting to an exchange-based carbon-pricing mechanism.

In the ETS, the regulator sets a cap of $CO_2$ to be emitted (overall or for a sector). Firms emitting lower emissions can sell their surplus quota in a regulated market to firms that need more allowances than originally received, leading to the formation of a price. This has proven to be the most effective way to reduce GHG emissions as can be seen in the example of European ETS (Box 2). By restricting the supply of allowances, higher carbon prices can prevail, providing critical economic signals for decarbonisation.

India has already announced that it will transition its successful PAT scheme into a compliance carbon market.[241] This is also being legislated as a part of the Energy Conservation bill, currently in Parliament. Carbon markets will likely need to be accelerated in India to build India right. For example, in the case of steel, without visibility into carbon pricing in the next two or three years, India will likely build and lock itself into long-lasting high carbon steel-making assets in the decade of the 2030s.

**2 a. VCMs for the short-term**

In the short term, India could consider launching a VCM to build awareness, signal future policy intent and build the necessary capabilities and administrative muscle needed for launching and operating ETS. Carbon trading by tapping global VCM markets has already started gaining momentum in India – $300 million or about 60 $MtCO_2e$ worth of carbon credits were exported from India across different VCMs in 2021.[242] Multiple local initiatives are already running to generate value by selling carbon credits (e.g., the Indian Agricultural Research Institute is building a carbon credit market for Indian farmers in Punjab and Haryana).[243]

For setting up the VCM, India could consider:

- **Creating demand for VCMs in India:** Increasing global carbon credit demand opens up an attractive opportunity. India's own large medium-term demand for carbon credits would need support to materialise through advocacy and awareness.
- **Building a robust supply pipeline:** India has robust supply, but project types need to shift from avoidance to removal. Most credits generated in India are from renewable energy projects, which are no longer accepted by many global standards. Robust demand signals would likely be needed to stimulate nature-based and emerging technology projects.
- **Designing a VCM open to international participation,** which may better support India's NDCs since it could provide stronger returns to developers of carbon projects. The Paris Agreement's Corresponding Adjustments (CAs) provision helps avoid double-counting and allows voluntary cooperation in the implementation of countries' NDCs to allow for higher ambition and promote sustainable development and environmental integrity. Companies buying international carbon credits on VCMs are unlikely to require CAs as the purchases are made to meet voluntary commitments and not their respective host countries' NDCs. Allowing international trade of carbon credits could enable proponents of climate mitigation projects to receive robust prices and improve the financial prospects of such projects.

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[241] BEE publication; effort to be initiated in 2023.

[242] S&P global commodity insights.

[243] TERI.

### 2b. Compliance carbon markets (CCMs) for the longer-term

To build itself right, India needs to learn from the world and accelerate its compliance carbon markets through the proposed five steps:

- **Define an ambitious purpose:** A blueprint which incentivises a systematic switch of investments into green assets such as hydrogen-based green steel-making, rather than only incremental activities such as energy efficiency, would likely ensure that India builds the right industrial configuration. India could consider an ambitious plan which:
  - Covers at least 50 percent of emissions from high-emitting sectors by 2030.
  - Ramps up to a carbon price of $50 per ton by 2030 to enable investments into green technologies and prevent locking in further into long-lasting, carbon-intensive technologies.
  - Comes into effect quickly – India could target implementing ETS in 36 months. The EU's ETS was the first large-scale compliance market, and it took time to rollout and achieve the desired results. However, based on its learnings, other markets have been able to ramp up faster. ETS in China was announced in the December of 2017 and the trading was initiated in July 2021. Similarly, Mexico started ETS design work in 2017 and began the ETS pilot which involved about 300 companies in 2020.[244]
- **Outline clear guidelines, roles and responsibilities in the government to set up the market:** Given that multiple stakeholders will be working in concert for the success of a CCM, the blueprint could clearly lay down the roles, responsibilities and expectations from ministries, nodal agencies such as Bureau of Energy Efficiency, from emitters and industry players such as exchanges, registries and verification bodies. Appointing a ministry or coordinating body that could design the ETS and ensure compliance (e.g., Directorate-General for Climate Action in the EU or The Secretariat of Environment and Natural Resources in Mexico) could constitute the first step. This body could then make clear what the timelines for implementation are, what methodologies would need to be followed for obtaining and distributing allowances (Box 3), benchmarking and reporting, and what private sector capabilities would be needed (e.g., measurement, reporting and verification). It might also tender certain roles to the private sector (e.g., auctioning platform and exchange for trading allowances like the European Energy Exchange in the EU). This could ensure that the private sector and financiers would have the long-term visibility needed and begin to rise to the occasion.
- **Draw up a competitiveness impact assessment and mitigation plan:** India could conduct a comprehensive sector-level assessment of the impact such instruments may have on the competitiveness of Indian manufacturers and the potential for carbon leakage. Surfacing these issues in a fact-based manner and addressing them head on with mechanisms like carbon border adjustments could help obtain the buy-in of all stakeholders. Risk mitigation plans including levers such as free allowances for some sectors could also be put in place.
- **Build a private ecosystem including the measurement, reporting and verification (MRV) of carbon credits:** Strong systems for reporting, verification and accounting of emissions are key to the success of a CCM. The private sector could efficiently provide MRV and other services such as advisory for a successful transition to a CCM.
- **Use CCM proceeds to ensure a just transition and for capacity building:** There could be reskilling required for new green jobs which can be funded through the carbon revenues. This may also ensure that the policy is 'self-funding' and won't require to be reallocated from elsewhere. For instance, in the EU – the Social Climate Fund has been proposed as part of the new Transport & Buildings ETS.[245] The revenue from auctioning of allowances would go to this fund, which would be used to finance temporary direct support to vulnerable households and make infrastructure investments that reduce emissions in these sectors. In California, ETS revenues go to the Greenhouse Gas Reduction Fund to design and implement programmes that facilitate greenhouse gas emission reductions and benefit disadvantaged communities and low-income households.[246] Overall, India's national carbon plan could be balanced to include capability-building for industries, service providers, bankers and stakeholders to build an understanding about carbon markets. Learning how to decarbonise and trade will likely boost participation.

Once India establishes its own market, it might also have an opportunity to take the expertise to other analogous countries (e.g., other high growth, emerging markets).

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[244] IISD – SDG knowledge hub; press search.

[245] European Union climate action.

[246] Centre for climate and energy solutions.

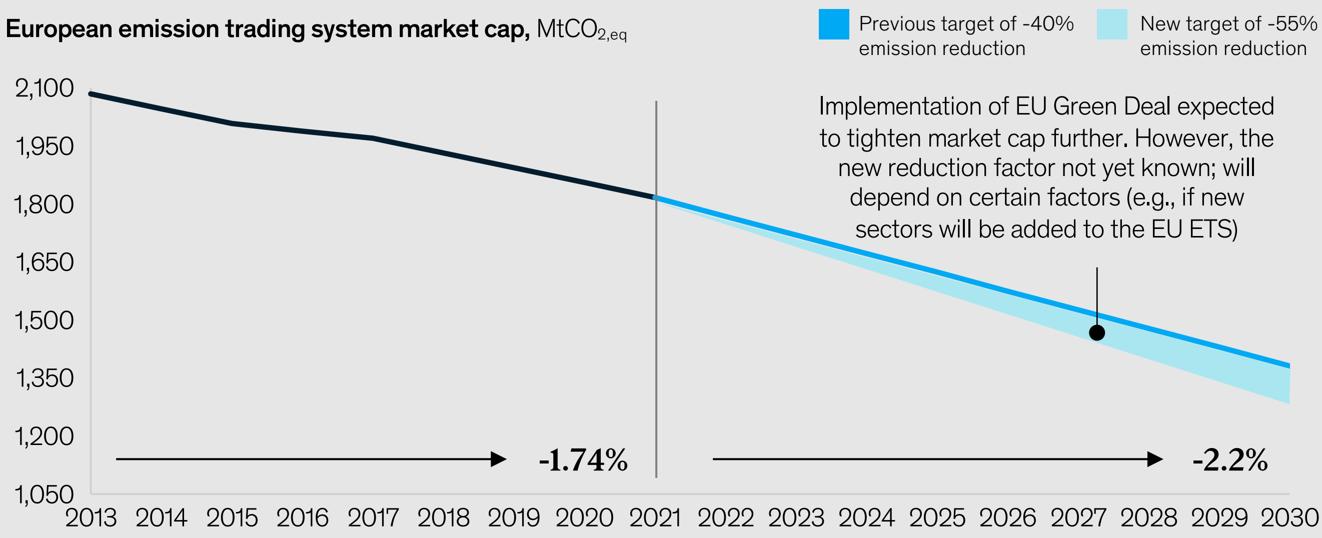
## Box 2

## Case study on EU ETS

The EU ETS was the first large-scale compliance market, and it delivered a positive result for the EU's decarbonisation efforts. After implementing ETS, the EU has been able to achieve a reduction of 40 percent in total emissions from 2005 to 2020 and has set a new target of 55 percent emissions reduction by 2030.

The European ETS was launched in phases to ensure step by step implementation and to avoid the kind of pitfalls large-scale rollouts can be prone to. It took almost 15 years to enter the final phase.

### Reduction of overall GHG emissions after implementation of ETS.



Source: European Commission

### The EU ETS regulatory framework entered Phase IV in 2020.

| | 2005<br>**Phase I** | 2008<br>**Phase II** | 2013<br>**Phase III** | 2020<br>**Phase IV** |
|---|---|---|---|---|
| **Target** | Trial period | Compliance with Kyoto: -8% against 1990 levels | Post-Kyoto framework: 2.04 billion allowances, 38 Mt or 1.74% yearly reduction | 2.2% yearly reduction |
| **Cap** | Bottom-up<br>Country level | Kyoto commitment<br>Country level | By 2020 21% below 2005 levels<br>Single EU cap | By 2030 43% below 2005 levels<br>Single EU cap |
| **Coverage** | Power/heat, refineries, cement, iron, steel, glass and P&P<br>40% of EU emissions<br>EU 25 | As phase I<br>EU 27 + Norway, Iceland and Liechtenstein | + petro-chemicals, aluminium, ammonia, inclusion of nitrous oxide and perfluorocarbons<br>EU 27 + Norway, Iceland and Liechtenstein | + Inclusion of nitrous oxide and perfluorocarbons<br>EU 27 + Norway, Iceland and Liechtenstein |
| **Penalty** | 40€/t | 100€/t | 100€/t | 100€/t |

1. Emission cap set based on historical emission level of the installation corrected for a certain improvement factor.
2. Emission cap set via benchmarking.

Source: EU Commission

## Box 3

## Methods for obtaining and distributing allowances under ETS

ETS participants could obtain $CO_2$ allowances in three ways:

**Auction:** MoEF can declare the total number of allowances available for participants and organise tenders to distribute allowances from market prices set by tender bids,

**Market trade:** Participants can trade their allowances on an exchange platform run by the newly-created carbon exchange. Prices can be determined based on supply-demand principles.

**Free allowance:** MoEF can distribute free allowances to the industries exposed to carbon leakage risk to prevent them from losing their competitiveness in international markets.

Additionally, the methodology for allowance distribution could be based on:

**Grandparenting:** Free allowances are given to each facility based on historical emissions (e.g., an iron & steel plant may take 1 $mCO_2$ of allowance for free since it has emitted 1 $mCO_2$ in 2019).

**Benchmarking:** For each sector, the $CO_2$ emission factor unit is set (e.g., clinker factor-$tCO_2$/t clinker-for-cement). Benchmark value is assigned to these factors and each facility takes free allowances based on its production level. Free allowances can be adjusted if production levels deviate from the historical activity substantially.

3. **Active and visible support lent by Indian financial institutions to the nation's decarbonisation, consistent with the national plan**

   Globally, climate change impacts banks through various forces, with risk emerging from portfolio allocation, intensifying regulations, increasing investor activism and rising public expectations. The UN-convened Net-Zero Banking Alliance has brought together banks from around the world—representing about 40 percent of global banking assets—that have committed to aligning their lending and investing portfolios with the 2050 net-zero emissions target.[247]

   Indian banks could play a pivotal role in shaping India's decarbonisation pathway, too. They would need to define net-zero ambition on their loan books and show commitment toward financed emissions and for facilitating the necessary transitions, defining sector-specific glidepaths and building a comprehensive net-zero roadmap (Exhibit 139).

   Furthermore, a holistic sustainable finance strategy can help banks create long-term value by offsetting transition-related risks (such as potential market share loss or increased risk with newer technologies) and tapping into new opportunities for value creation (Exhibit 140).

4. **Proposed regulatory actions that could be considered to enable banks**

   A well-coordinated set of interventions could be implemented by different regulatory bodies and government agencies across sectors to increase the availability of finance (Exhibit 141):

   - **Resilience-building:** Strengthening the sector's resilience to sustainability-related risks; this could be done through institutionalising scenario analysis and climate stress-testing within risk management; defining the governance frameworks for climate finance (e.g., risk appetite framework, board oversight, etc.).
   - **Market solutions and development:** Incentivising and facilitating the growth of sustainable investments, such as grants and direct investment, into sustainable projects.
   - **Infrastructure enablers:** Enabling efficiency and ensuring the integrity of the financial ecosystem—for instance, setting industry-wide green taxonomy and product-development frameworks.
   - **Capability-building:** Developing a knowledge and talent base in sustainable finance and risk assessment through educational programmes.

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[247] UN environment programme finance initiative.

Exhibit 139

## 4 key ingredients could be considered to help banks define a sustainable finance agenda.

**Sustainable finance agenda**

**Set the overall ambition and emission strategy**

Define net zero glidepath on financed emissions, set targets for green financing; define and execute plans to achieve it

**Build and capture business opportunities**

Define BU specific targets for climate finance opportunities and a clear actionable roadmap to realise it

**Strengthen resilience and climate risk management**

Strengthen the bank's climate risk management, including appetite statements, frameworks / policies, and tools / processes

Conduct climate scenario analysis and stress testing to inform climate risk management and identify opportunities

**Ensure capabilities for execution**

Target state and execution plan for capability, culture and initiatives

Define, develop and continuously improve climate governance model

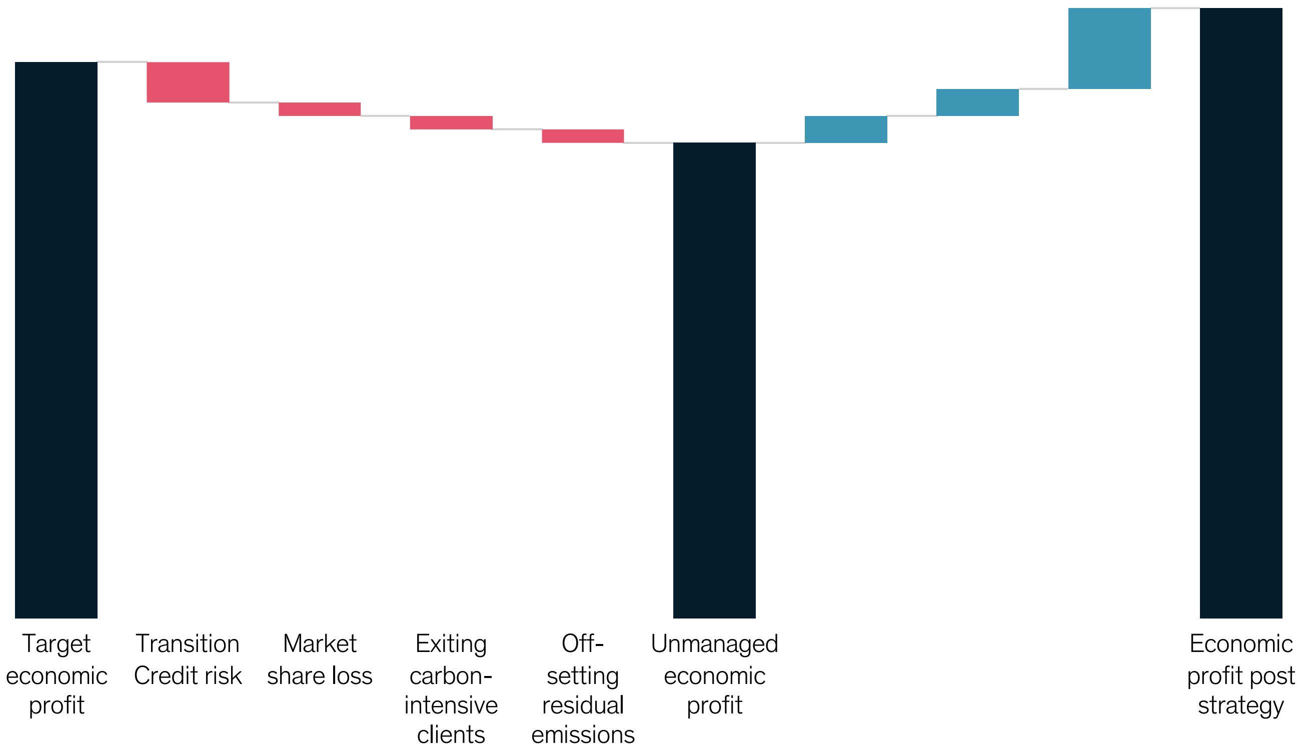
Data, reporting: Track impact of climate related opportunities and commitments (ensure commercial considerations)

Deliver the bank's climate communications strategy

Exhibit 140

## Opportunity to create long term value via a comprehensive sustainable finance strategy could be considered to offset risk from climate change.

Illustrative



- **Disclosure guidelines:** Standardising disclosure guidelines to build transparency and a network of verification agencies to enable investors to evaluate opportunities. By mandating disclosure requirements, particularly in high-emitting sectors, companies could be awarded 'ESG' ratings, which in turn could inform investors about where to channel funds and would act as a guardrail for financing.

5. **Green banks[248] could accelerate and enable financing of 'hard-to-abate' use cases**

   Significant barriers exist to obtaining green project funds such as insufficient capacity in debt capital markets and perceived risks in policy frameworks or new technologies. Small projects also struggle to attract funding as the short-term expectations of investors often don't meet long-term financing requirements. This is where a green transition bank could come into play:

   - As an innovative transition structure to mobilise low-carbon investment and support local community development.

   - To orchestrate government funds and support financing for early-stage projects before they become viable for other investors.

   - As a market maker to channel global green capital into local projects and as a catalyst for securitising green loans (rated and classified into tranches), which could create additional avenues for green-focused investors with different risk profiles.

A green transition bank could help India unlock finance in its goal toward net-zero, as in other parts of the world—Australia, Japan and the United Kingdom have all created nationalised banks to leverage private investments in sustainable technologies. The UK Green Investment Bank, for example, was established in 2012 and, to date, has mobilised over £25 billion for 36 GW of renewable energy projects.[249]

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[248] A green transition bank is typically a public financial institution that uses innovative financing methods and market development tools with the private sector to accelerate decarbonisation.

[249] Green investment group.

Exhibit 141

## Case example: ECB leads the way in climate risk related initiatives.

| | |
|---|---|
| **Resilience building** | • Issued “Guide for Climate-Related and Environmental Risks” providing supervisory expectations on risk management and disclosures<br>• Developing climate stress-testing methodology and conducting stress test of the Euro System balance sheet and individual banks<br>• Requires banks to have transition plans to have a view on how they are aligned with the broader EU policy goals<br>• Public risk reporting on physical and transition risk exposure and mitigation plans in place |
| **Market solutions & development** | • Acceptance of sustainability-linked bonds as collateral for Eurosystem credit operations<br>• Adapting the framework for Corporate Sector Purchase Programme of the Eurosystem to include climate change considerations<br>• Initiated a plan to introduce requirements targeted to climate change risk into the Eurosystem Credit Assessment Framework (ECAF) for credit rating agencies |
| **Sustainability infrastructure enablers** | • EU Taxonomy for classifying sustainable economic activities<br>• EU Sustainable Finance Disclosure Regulations (SFDR, Regulation (EU) 2019/2088) for compulsory sustainability disclosure for Fis in force since Mar 2021 along with “Regulatory Technical Standards” (RTS) for content and presentation (issued by the European Supervisory Authorities)<br>• Initiated development of “European Green Bond Standard” (EGBS) providing standards for taxonomy, transparency, review and supervision for green bonds, to scale up green investments (under development)<br>• Introduced disclosure requirements for private sector assets as a new eligibility criterion for collateral and asset purchases |
| **Sustainability knowledge & capability building** | • Established High-Level Expert Group (HLEG) on Sustainable Finance to steer capital to green investments and mitigate environmental risk to financial system<br>• Founding member of the International Platform for Sustainable Finance (IPSF) to scale up the mobilisation of private capital towards sustainable investments<br>• Development of statistical indicators covering green financial instruments and carbon footprint and climate risk exposure for Fis<br>• Best practice identification and sharing of sustainability and risk management practices amongst banks<br>• Standardised parameters for stress testing initiatives for banks to use through ECB’s own stress testing measures |

Source: European Central Bank, McKinsey analysis

Exhibit 142

## Green Transition Banks could enable governments to support infrastructure finance whilst at the same time stimulating other policy goals.

**Significant barriers still exist today in obtaining funds for green projects…**

- Insufficient capacity in debt capital markets
- Perceived risk on policy frameworks and on new technology
- Difficulty in financing large number of small projects
- Relatively long-term financing requirements and short-term expectations of investors

**…requiring governments to play a crucial role in accelerating the green transition through strategic interventions to…**

- Mobilise private sector capital
- Lower risk for investors
- Reduce cost of capital for green projects

to enable sustainable financing without dependence on government funds

**…One such innovative transition structure is an "ESG Transition bank"**

- Unlocking project finance through equity co-investment, debt & insurance products for low carbon tech & infra
- Creating green bonds to access the large pools of capital held by institutional investors
- Act as a market maker / orchestrator for channelising global ESG capital
- Institutionalise market innovations (e.g. securitisation) to scale up ESG financing

**A Green Transition bank is an innovative transition structure which can help mobilise low-carbon investment, get on a path towards ambitious emission targets and support local community development.**

# 6. Ten bold actions

**Ten urgent actions could be considered to accelerate India's decarbonisation and ensure it is orderly.**
From our analysis, it appears that benefits to India could outweigh the downsides of a well-planned, orderly, accelerated transition given India's growth outlook. However, India must take action within this decade to set things up. If it does so, India must use its growth momentum and build India right in the decades thereafter.

It is vital for all stakeholders – government, corporates, consumers, civil society – to come together and act now and in concert to accelerate India's decarbonisation and ensure it is orderly. The government could provide policy and regulatory support to make projects across sectors economically viable. These include but are not limited to incentivising usage of EVs and FCEVs by balancing taxation schemes, simplifying regulations for authorising and installing new power and grid installations, creating demand signals for higher-cost green materials like steel and generating support for localising electrolyser manufacturing. Support may also be required to ensure a just transition that minimises impact on low-income households. These actions could work together and happen in the right sequence in order to avoid shortages, price rise and the risk of a disorderly transition.

Achieving the necessary technological breakthroughs to reduce emissions in hard-to-abate sectors and accelerating their progress to market would likely require consistent public and private investment. It would also require greater willingness among business leaders and policy makers to adopt new technologies. These could include longer duration storage technologies to capture the seasonality of renewable sources, advancement in fuel cell technology and improvement in recycling technologies.

In this backdrop, the ten actions to be considered today to accelerate India's decarbonisation comprise:

1. **Laying out a detailed medium-term (5 - 15 - 25-year) decarbonisation plan** with sector-specific priorities and policy frameworks that provide the demand signals and a steady hand to allow corporates to invest. This would likely need an overarching governance mechanism through an accountable nodal agency to ensure coordination across ministries and external stakeholders in delivering net zero. It could include compensating mechanisms to address socioeconomic impact. Delays in doing this or quality gaps (e.g., inconsistent policies across sectors, too many changes) could lead to the wrong investment decisions worth several hundreds of billions of dollars, or reduced investment. The EU, for instance, has set up the post of the European Commissioner for Climate Action, which has been separated from the Environment Portfolio. The European Commission has put in place a series of proposals on how to achieve EU's net zero targets by 2050[250] so as to align business, government and civil society, set them on the same pathway, and provide policy stability for investments.
2. **Accelerating the implementation of a compliance carbon market (within three years)** could also create demand signals to accelerate decarbonisation, especially in the hard-to-abate sectors and incentivise investments in newer technologies like CCUS. Policy makers could take a strategic (as opposed to a compliance-oriented) view of this, and work across ministries. Getting this right fast could enable both domestic and foreign investment. For instance, growing steel demand means rapid and continued capacity addition between 2030 and 2050. With a $50/t carbon price, India could avoid being locked into 200 Mt per annum of BF-BOF steel by 2050 (high carbon asset) and replace it with hydrogen-based green steel which would create a carbon space of 20 $MtCO_2e$. While the European ETS took 15 years to set up, other countries have accelerated this and India could potentially do it in as few as three years.[251]
3. **Enabling banks to support the transition catalysed by a green transition bank.** Banks could be asked to come up with their own investment glide paths within a year or two and build the necessary capability for assessing risks in these new spaces. The regulator could assist with the necessary taxonomy, disclosure guidelines, actions to reduce risks. A green transition bank with a clearly-defined set of green financing norms could act as the catalyst for change.

All stakeholders would need to come together to launch institutional measures to accelerate financing in line with the national plan for net zero. Banks could define their net-zero ambition on their loan books, show commitment toward financed emissions, facilitate the necessary transitions, define sector-specific glidepaths and build a comprehensive net-zero roadmap. Institutional measures like shaping banking regulations toward transition financing and setting up a green transition bank to orchestrate capital could be considered to fast-track decarbonisation.

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[250] European Commission climate action.
[251] Ibid.

4. **Accelerating renewable adoption in the power sector** to scale up capacity addition four times, and to deepen market reforms with a 30-year outlook in a manner that ensures a stable grid fed predominantly by in firm power. Such reforms could include deepening power markets with the introduction of derivatives and futures for risk mitigation, launching ancillary services and capacity markets, leveraging demand-side flexibility by speeding the adoption of consumer time-of-day tariffs and EV charging. It could also include creating supply-side flexibility by enabling existing coal and hydro plants to blend RE into existing PPAs and incentivising underutilised plants to participate in the capacity market. These market reforms could reduce the investment requirement by \$150–200 billion by 2050.
5. **Empowering a nodal authority to define a national land use plan,** laying clear land-use guidelines and mandates for optimised use across urbanisation, industrial needs, carbon sinks, agriculture and renewables. It could make trade-offs and enable efficient land use in consultation with states ('land' being a state subject). It would be essential to have a long-term outlook to balance the growing need for land across sectors. Finally, policies could ensure efficient land use across sectors (e.g., vertical urbanisation).
6. **Creating a resilient indigenous manufacturing capability and increasing investment in cleantech R&D.** Effort would likely be needed to develop local raw material resources (e.g., rare earths), secure materials from elsewhere in the world and produce equipment (e.g., PV modules, battery) locally through mechanisms like the PLI. This could be supported by a green innovation mission in collaboration with private sector, academia, startups, etc. to accelerate investments, at-scale adoption and localisation of clean technologies. This can leverage India's large technical and digital talent base to lead innovation and R&D in achieving low levelised costs of carbon capture in CCUS applications, high efficiency solar modules, low costs of green hydrogen, next generation energy storage, green metals, carbon credits tracking, etc.
7. **Evaluating five CCS hubs in Gujarat (Jamnagar), Odisha (Paradeep), Rajasthan (Barmer), Maharashtra (Pune) and Andhra Pradesh (Vizag)** could be considered for public-private partnership for utilisation and storage of captured carbon. These hub locations are within 500 km of 70 percent of India's point-source emissions. The captured carbon can be transported through pipelines to existing oil fields for storage. Uptake would likely require funding support (e.g., grants) for exploration of carbon storage hubs and technology for capture, utilisation of carbon and development of pipeline infrastructure from point source of emissions to capture hubs. Various policy interventions like regulation-imposed carbon prices (over \$100/ $tCO_2e$) could push businesses to decarbonise.
8. **Consider creating a national circularity mission** with recycling hubs in the top 20 Indian cities (contributing 35 percent of MSW), mandating targets on recycling rates, recycled raw material use (e.g., blending norms) and landfill levies. For this to work, it would likely need the enforcement of existing and upcoming EPR regulations along with demand signals for recycled products (e.g., through carbon pricing on emission-heavy, virgin raw-material). India can take inspiration from the circularity plans of the EU, Australia, China and the US.[252] Links would be needed between sectors that can upcycle agricultural and crop waste (e.g., for use as packaging material, carbon-neutral biomass in industry) to reduce straw burning and crop-residue mismanagement. Strong supply networks could be set up to ensure easy collection, transportation and usage of residues.
9. **Enhancing the National Hydrogen Mission.** The low cost of renewable energy in India can help it become a leading exporter of green hydrogen embedded products in the short term, leveraging carbon regulations in energy-short markets. The government could play a key role in accelerating demand through blending mandates, boosting cost competitiveness via capital subsidies and R&D investments and enabling export opportunities via international trade agreements. It can create blending mandates across the fertiliser, refinery and steel sectors, which could kick-start the adoption of green hydrogen (and derivatives) as a replacement for grey hydrogen. Additionally, introducing carbon pricing through compliance carbon markets, in a calibrated but accelerated manner, could provide steel makers with the policy certainty to be able to invest. This could be accompanied with appropriate carbon border adjustment mechanisms to ensure the global competitiveness of India's steel and manufacturing industry. Further, the introduction of PLIs to induce local manufacturing for electrolysers and balance of plants would be needed to reduce dependence on imports.

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[252] EU Circular economy action plan; Waste Levy under Environmental Protection Act, Australia; China Scrappage Program; US Car Allowance Rebate System.

10. **Aiming to play on the front foot, companies** could evaluate investment opportunities that this green trend would unlock, aligned with India's national plans or the opportunities opened up by decarbonisation of other countries (e.g., green hydrogen derivative exports). To thrive further, companies could focus on creating strategic alignment, reallocating capital and people and engage with the government. As leaders prepare to discuss green transformation with their boards, it may help to quantify the potential. For companies that are not aligned with science-based carbon budgets and slow to reallocate capital for the green transition, the gap between management expectations and market valuation could grow. They would need to shift focus from prolonging the lead in traditional technologies to building competitive positions in zero emission technologies.

Government policies could create the demand signals for decarbonised products and services. The global financial sector and international customers (e.g., European customers impacted by ETS and carbon border adjustment mechanisms) could also demand decarbonisation roadmaps and committed action. Companies would need to respond. The government and corporate India may need to provide policy support and capability building for MSMEs to decarbonise faster (e.g., scoping three targets taken up by large firms could incentivise supplier ecosystems to decarbonise).

These actions could be supported by consumers wholeheartedly such that we see a shift in consumer behaviour. The government has announced the Lifestyle for Environment (LiFE) mission at CoP26. This would be a crucial component of India's transition.

To conclude, India could consider thoughtful action now, for setting itself up for an accelerated and orderly transition. Looking beyond the short-term and laying the foundation for this transformation within this next decade would be the overarching imperative for the country as it sets forth on its decarbonising journey.

# Technical appendix

## Modelling methodology

To shape our decarbonisation pathways, we used the Decarbonisation Scenario Explorer (DSE), McKinsey's proprietary tool that helps to model scenarios built on underlying activity levels (e.g. vehicle PARC, tons of cement, steel, etc.) that drive the country's emissions throughout the projected time horizon. The tool contains over 300 technologies and abatement levers across all sectors of the economy that allow us to build our tailored abatement scenarios. Five sectors – Power, Transport, Agriculture, Steel and Cement— were modelled bottom-up with granular offline teardowns of activity levels (by segment and technology), demand projections, emission factors and costs. Other sectors in the DSE, such as Buildings and Waste and Industrial sectors such as aluminium, ammonia, were modelled at a high-level using McKinsey's existing Decarbonisation Lever Library (DLL).

The modelled abatement pathways were not optimised for costs or co-optimised for GDP. However, each scenario assumes demand in line with projected sectoral growth rates as well as GDP. For example, while demand increases rapidly in industrial sectors, mechanisation and improved productivity drive slower growth in primary sectors such as agriculture.

The DSE also defines various technologies and fuel types for each segment – differing uptake levers in line with sectoral growths are input in the DSE for the lever library technologies and fuel types for each sector and segment. These range from conventional technologies, such as ICE long-haul trucks and coal blast furnaces for industrial heating, to technologies still under development, such as hydrogen trucks and electric furnaces. For new technologies, uptake rates were estimated based on products reaching the market and reasonable ramp-ups based on their technology development pace. The resulting pathway provides a lever-by-lever outlook of how India could decarbonise

Cross-cutting themes such as CCUS, material circularity, NCS and Green hydrogen were modelled bottom-up based on inputs from the sector-wise models and integrated into the DSE. India's NCS potential was estimated using McKinsey Nature Analytics' proprietary geospatial modelling effort. India's CCUS hubs were determined using point source emissions geospatial mapping while material circularity potential was calculated based on various waste streams' utilisation potential across sectors.

To express volumes of different greenhouse gases using a common metric, we used metric of tons of $CO_2$ equivalent ($CO_2e$). Different greenhouse gases have different impacts on global warming. $CO_2$ can remain in the atmosphere for decades, while methane has a much stronger warming effect but a half-life of only 12 years. It is not obvious how much methane abatement is equal to abating a gram of $CO_2$, since the average global warming potential of methane is much higher over a 20-year period than over a 100-year period. To translate methane and other GHG emissions to $CO_2$, therefore, requires setting a common timescale. We adopted the 100-year global warming potential for all greenhouse gases to aid comparability.

## Financing analysis methodology

The financing model looks at the full system Capex required for production as well as the Capex and Opex incurred in adopting decarbonisation levers. We defined cost outlooks for various commodities and technologies through the DSE based on inputs from the offline sector deep-dives as well as the DLL. For fossil fuels, we assumed prices would decline with falling oil demand. Power and hydrogen prices were dynamically modelled in the McKinsey Power Model and used as input for the demand sectors in the DSE. The capital cost reductions for some critical technologies such as batteries and electrolysers are based on the learning rate; the faster electrolysers are rolled out at scale, the faster they can decline in cost. Our cost outlooks for such technologies assumed that the rest of the world scales up their decarbonisation efforts, helping drive adoption and the associated downward pressure on costs.

The Marginal Abatement Cost Curve presented in this report is a cumulative abatement cost curve. To build this, we compared the total cost of ownership and level of abatement for each of the 300 technology levers between our two main scenarios: the LoS and the Accelerated scenarios. To account for the varying levels of costs and abatement, we employed a weighted average across all years and to arrive at the total cumulative abatement, we added the total difference in abatement between the two scenarios.

# Acronym glossary

| | |
|---|---|
| BEV | Battery electric vehicle |
| BF | Blast furnace |
| BOF | Basic oxygen furnace |
| CAPEX | Capital expenditure |
| C&D | Construction and demolition |
| CNG | Compressed natural gas |
| CCUS | Carbon capture storage and utilisation |
| CNG | Compressed natural gas |
| CV | Commercial vehicle |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide equivalent |
| DAC | Direct air capture |
| DISCOM | Distribution company |
| DRI-EAF | Direct reduced iron in the electric arc furnace |
| DSE | Decarbonisation scenario explorer |
| EC | European Commission |
| ESG | Environmental, social and corporate governance |
| ETS | missions trading scheme |
| EU | European Union |
| EV | Electric vehicle |
| FAME | Faster adoption and manufacturing of hybrid and electric vehicles |
| FCEV | Fuel cell electric vehicle |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| GT | Gigatonnes |
| $GTCO_2e$ | Gigatonnes of carbon dioxide equivalent |
| GW | Gigawatt |
| GWh | Gigawatt-hour |
| H2 | Hydrogen |
| HCV | Heavy commercial vehicle |
| ICE | Internal combustion engine |
| kW | Kilowatt |
| kWh | Kilowatt-hour |
| Li-ion | Lithium-ion |
| LCV | Light commercial vehicle |
| LoS | Line of sight |
| LPG | Liquified petroleum gas |
| LULUCF | Land use, land-use change and forestry |
| Mha | Million hectares |
| MGI | McKinsey Global Institute |
| MMTPA | Million metric tonnes per annum |
| MPM | McKinsey power model |
| MSW | Municipal solid waste |
| Mt | Million tonnes |
| $MtCO_2e$ | Million tonnes of carbon dioxide equivalent |
| MW | Megawatts |
| NDC | Nationally determined contribution |
| NMC | Nickel manganese cobalt |
| OEM | Original equipment manufacturer |
| OPEX | Operating expenditure |
| PLI | Production linked incentive |
| PV | Photovoltaic |
| RE | Renewable energy |
| SAF | Sustainable aviation fuel |
| SMR | Steam methane reformer |
| SRI | System of rice intensification |
| T | Tonnes |
| $tCO_2e$ | Tonnes of carbon dioxide equivalent |
| TCO | Total cost of ownership |
| TJ | Terajoules |
| TW | Terawatt |
| TWh | Terawatt-hour |

October 2022
This report has been updated to provide additional context and new data (March 2023)

Designed by INO-VG & Design Team

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