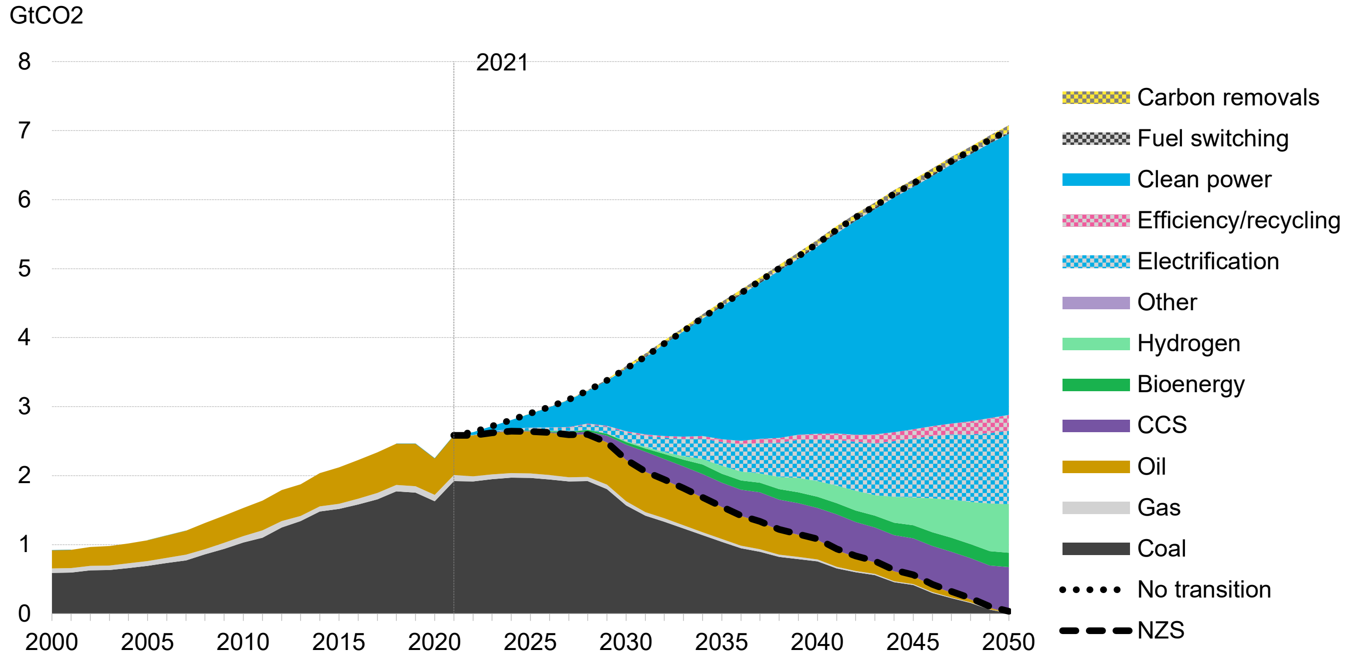
Net Zero Scenario

Getting to net zero by mid-century requires a complete phase-out of unabated fossil fuel use in India's energy sector.

Figure 17: India's carbon emissions reductions from fuel combustion, Net Zero Scenario versus no transition scenario



Source: BloombergNEF. Note: The 'no transition' scenario is a hypothetical counterfactual that represents a world in which no further actions are taken in the power and road transport sector to reduce carbon emissions, keeping the current fuel mix constant at 2021 levels and growing proportionally under the same ETS demand forecast. In industries, most sectors continue to use the same fuel mix through 2050 in the no transition scenario. NZS – Net Zero Scenario, CCS – Carbon capture and storage.

Similar to the ETS, switching power generation from fossil fuels to wind and solar is the single biggest contributor to India's emissions reduction in the NZS, accounting for 62% of all emissions abated over 2022-50. Electrification in direct energy use is again the second-biggest contributor, accounting for 14% of total emissions abated over the period. Bioenergy use outside the power sector and hydrogen together contribute a sizable 10% of emissions abatement.

CCS to gain importance in NZS, accounting for 10% of total emissions abated between 2022 and 2050

CCS gains in importance from the 2030s as hard-to-abate sectors are being tackled and any remaining unabated fossil fuel plants are either replaced or retrofitted. CCS accounts for 10% of Indian emissions abated between 2022 and 2050 under the NZS. Carbon removals only account for 1% of emissions and are mainly needed to abate residual emissions from incomplete capture in CCS applications.

Our NZS is a pathway consistent **with a 1.77C global temperature rise by 2050** (with a 67% likelihood) with no overshoot or reliance on net-negative emissions technologies post-2050. This trajectory gives a 33% chance of staying within 1.5C, but a better than 67% chance of staying below 2C.

BloombergNEF

Emissions trajectory versus national plans

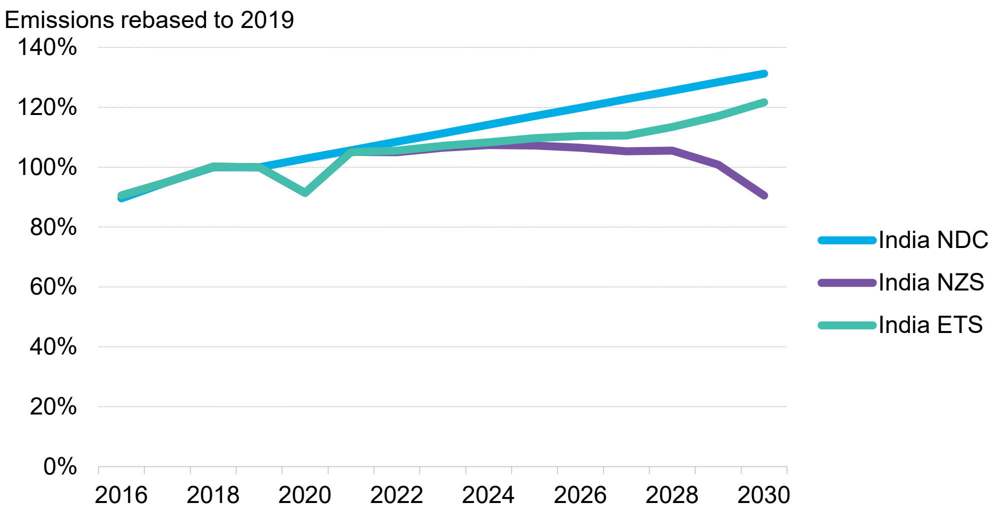
In August 2022, India's national government lodged an updated Nationally Determined Contribution (NDC) report with the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. The updated NDC committed India to reducing greenhouse gas emissions intensity of GDP by 45% below 2005 levels by 2030 – a 10-12 percentage point increase in ambition on the previous target.

Technology cost reductions enable India to meets its NDC

Our modeling suggests India is on path to achieve this target. Emissions in our base case rises by 22% between 2019 and 2030 which is less than the 31% increase that India has committed to in its revised NDC (Figure 18). India's extraordinary success, primarily in its transition to renewables has been largely supported by current policy directions taken by the government, such as conducting large-scale renewable auctions and also by declining costs of renewable energy technologies.

India will require even further concerted policy actions to accelerate the transition beyond policies that are in place today for it to decarbonize along the 1.77C pathway charted under the NZS. The power and transport sector offers the biggest near-term opportunities, with proven technologies already under commercial adoption. The net zero transition presents opportunities for investment, economic growth, local manufacturing and employment generation. It also presents a path to greater energy security and independence for the country. India's leadership, experience, policies and pathways can offer important lessons for other countries too.

Figure 18: India's emissions trajectory by scenario



Source: BloombergNEF. Greenhouse-gas data - World Resources Institute CAIT. NDCs - UNFCCC. GDP data - IMF. Note: Applies to India's economy-wide, unconditional, greenhouse-gas targets for 2030. For targets based on emissions or carbon intensity, IMF GDP projections are used to estimate emissions if NDC is met. NDC – Nationally Determined Contributions, NZS – Net Zero Scenario, ETS – Economic Transition Scenario.

Section 4. Energy trends

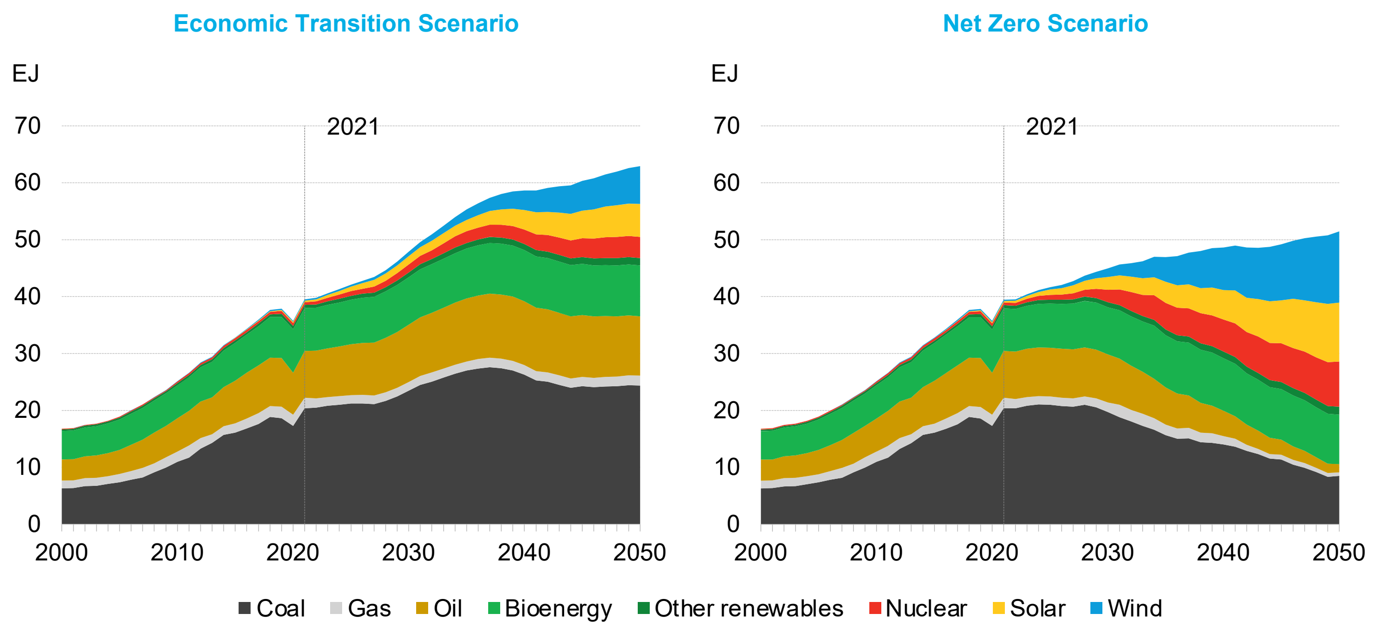
In both scenarios, coal is replaced by increasingly cheaper renewable energy. Electrification is the dominant route for industrial, transport and building sectors, but the rest of the energy mix differs by sector. Hydrogen makes some inroads in industrial and commercial transport sectors, while bioenergy also plays an important role in aviation and shipping.

4.1. Primary energy demand

Primary energy coal consumption in 2050 under NZS is a third of that in ETS

Domestic fossil fuel use in India is yet to peak. Under the NZS, India's primary energy consumption from coal in 2050 is 8,506PJ, nearly a third of that in the ETS. This is due to the important role that unabated coal power plays in the ETS, where alternative pathways such as use of CCS or hydrogen are economically unviable in the near term. India's gas consumption in the NZS is only a third (or 642PJ) of the consumption in the ETS in 2050. The drop in oil consumption is far more dramatic, with the NZS level at 1,429PJ, nearly a tenth of that under the ETS. The role of oil diminishes over time with the electrification of the transport sector and the displacement of fossil fuels by clean energy technologies.

Figure 19: India's primary energy consumption by fuel



Source: BloombergNEF. Note: 'Other renewables' includes hydro and geothermal.

4.2. Final energy demand

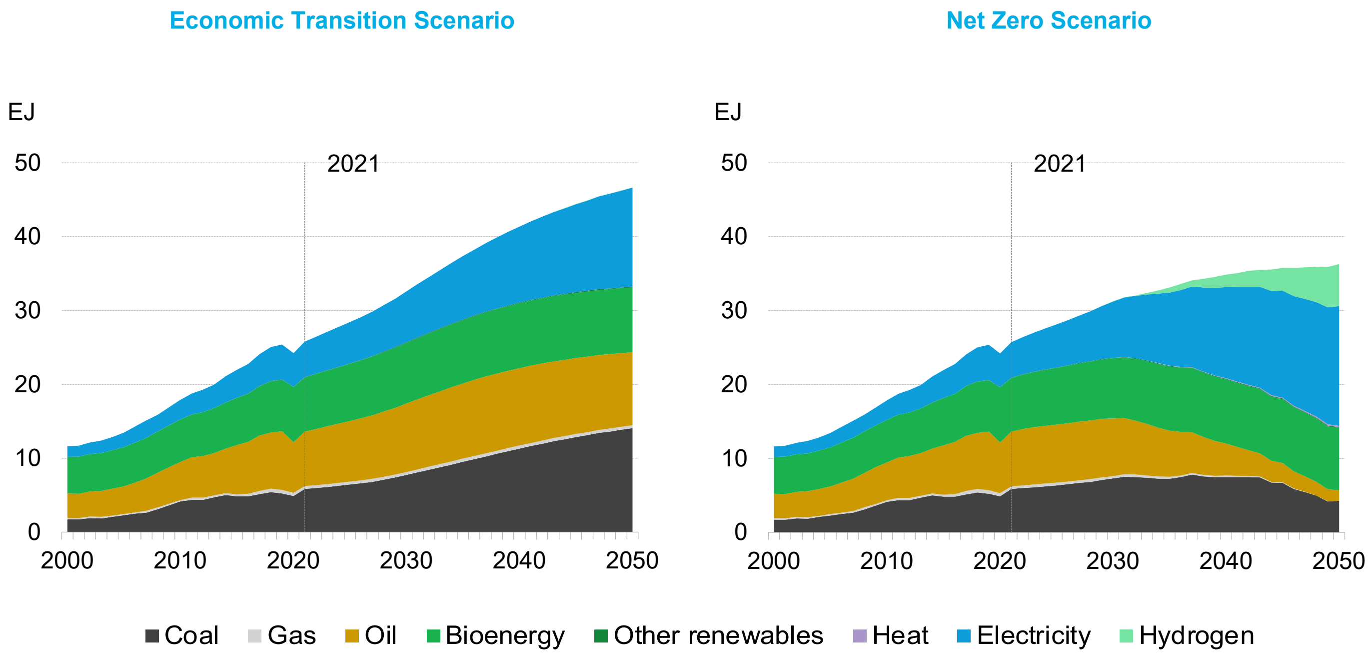
Final energy demand in 2050 grows by 41% from 2021 levels under NZS compared to 81% in ETS

India's total final energy demand reaches 46,655PJ in 2050 under the ETS, up 81% from 25,781PJ in 2021. In the NZS, final energy demand increases by 41% during the same period, reaching 36,300PJ in 2050.

Lower overall final energy demand under the NZS compared to the ETS is a result of greater electrification, which is more efficient than fossil fuel combustion. EVs, for example, use one-third of the energy that internal combustion engine vehicles use due to avoided losses from final to useful energy conversion.

Clean hydrogen development is still nascent and largely limited to feasibility studies and proposed pilot projects. Our modeling suggests that clean hydrogen can play a growing role in India's final energy demand toward 2030 in the NZS, particularly in hard-to-abate sectors of the economy, such as steel (see Section 6).

Figure 20: India's total final energy demand by fuel

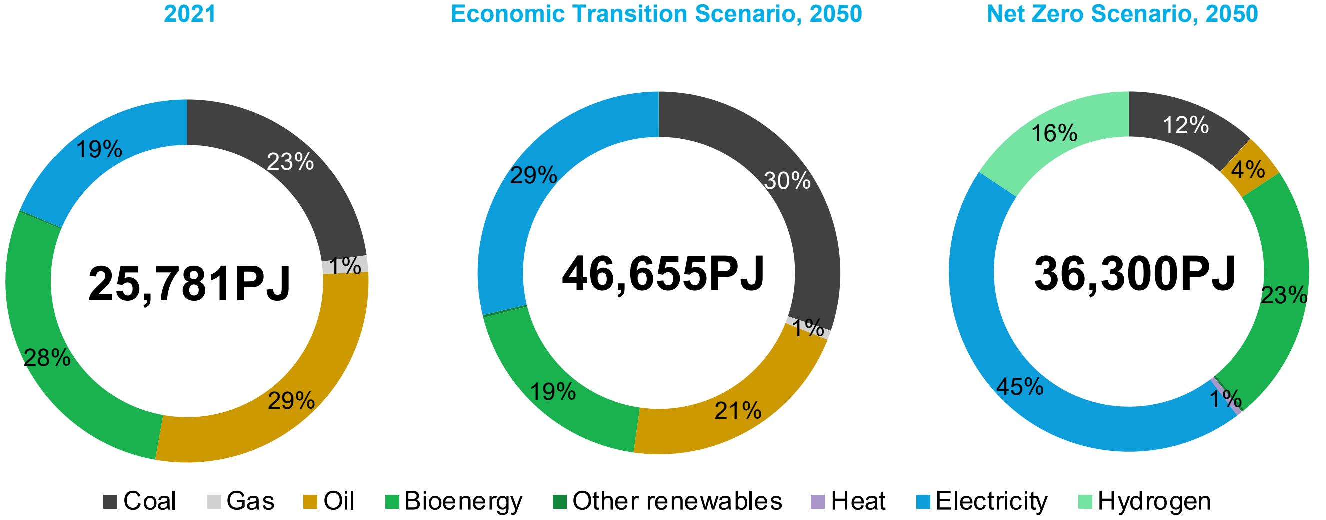


Source: BloombergNEF. Note: 'Other renewables' includes hydro and geothermal.

India's 2050 electricity use triples from 2021 levels under NZS

In the NZS, electricity use more than triples from 2021 levels to supply 45% (16,194PJ) of total final energy in 2050 compared to just 29% in the ETS, due to greater electrification. Decarbonizing India's power system and a drive for electrification where it is possible will therefore be critical for reaching the country's net-zero ambitions.

Figure 21: India's final energy consumption by fuel

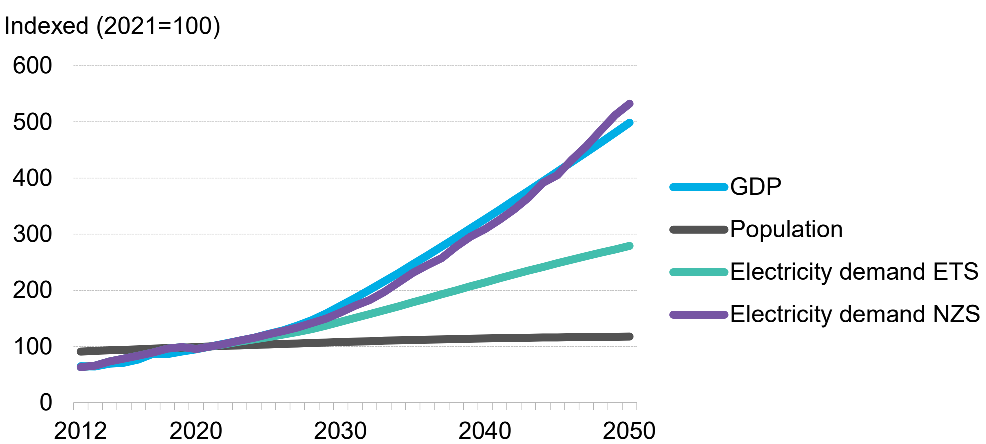


Source: BloombergNEF. Note: 'Other renewables' includes hydro and geothermal.

4.3. Electricity demand

The Covid-19 pandemic caused India's power demand to fall by 4% in 2020 compared to 2019. However, in the long-term, economic growth and an expanding population are expected to lead to a rise in gross electricity demand. Between 2021 and 2050, India's population is expected to grow by 18% and reach 1.6 billion, according to World Bank projections. The country's GDP reaches $17 trillion by 2050, nearly fivefold the $3.3 trillion in 2021 (Figure 22). In the ETS, there is a decoupling between electricity demand and the GDP in India, whereas in the NZS, the two follow each other closely.

Figure 22: Macroeconomics and electricity demand trends for India

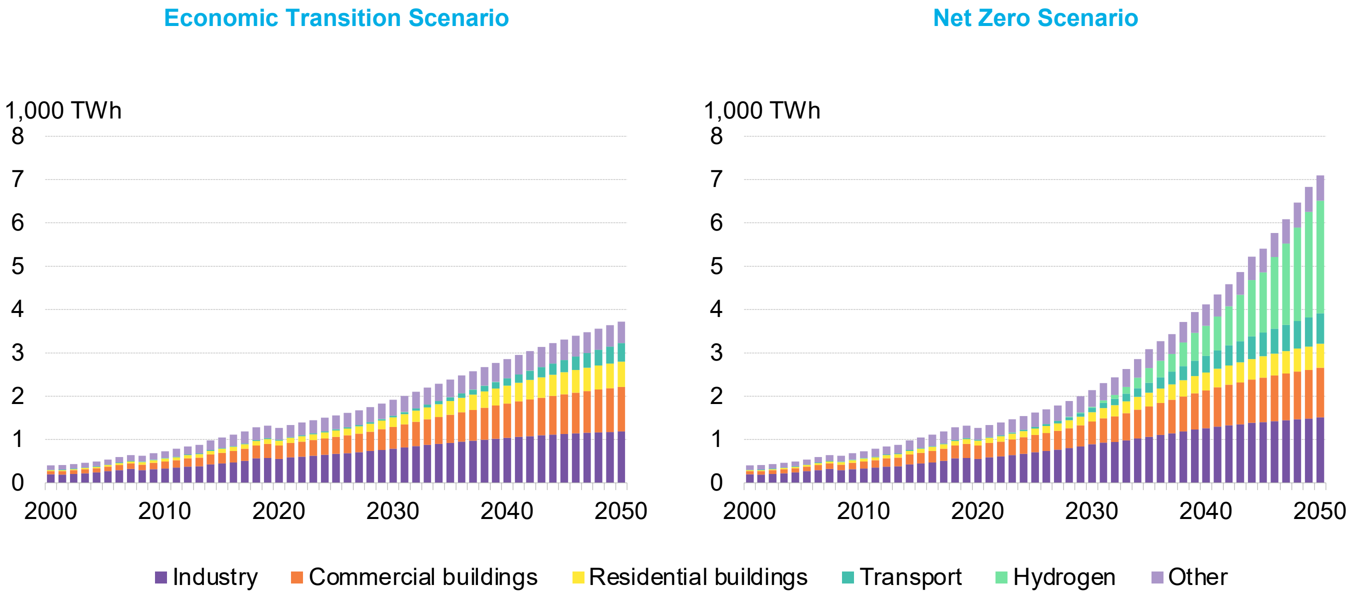


Source: BloombergNEF, WorldBank. Note: Electricity demand covers demand across all sectors including power, hydrogen, industry, buildings and transport. NZS – Net Zero Scenario, ETS – Economic Transition Scenario, GDP – Gross Domestic Product.

EVs and clean hydrogen are major electricity consumers under NZS

Reaching net-zero emissions by mid-century leads to a significant rise in India's electricity consumption. The ETS sees power consumption of 3,723TWh in India in 2050 – nearly three times of that in 2021. This rises to 7,100TWh in the NZS, more than fivefold of 2021's consumption. The increase is driven largely by electrification of road transport and demand from electrolyzers to produce low-carbon hydrogen, both of which see significantly higher power consumption compared to the ETS. Electricity consumption from transport in 2050 is 70% higher in the NZS compared to the ETS. Power demand from hydrogen, which is insignificant in the ETS, is close to 2,600TWh in the NZS by mid-century as we assume that nearly all of the hydrogen produced is via electrolysis.

Figure 23: Power consumption by sector in India



Source: BloombergNEF Note: Power consumption is lower than power generation due to system losses. Rail is included under transport.

Under the NZS, power demand from buildings is 1,699TWh in 2050 – around 5% higher compared to the ETS. The increasing use of electrical stoves and the deployment of heat pumps for heating in places that need them contribute to rising electricity demand in the NZS. But the rise in overall energy efficiency of appliances also helps offset some of that growth in electricity demand in this scenario.

Section 5. Power sector

The power sector contributes the most to India's carbon emissions today. In the NZS, unabated coal generation is replaced by cheaper wind and solar this decade. Together with other low-carbon technologies such as nuclear and CCS, they dominate investment in the sector to 2050. New wind and solar additions peak in the 2040s. Further, the electric power system also needs to ensure enough firm capacity to provide system adequacy, critical back-up and flexibility.

5.1. Installed capacity

Installed power capacity to grow sevenfold under NZS to 4,227GW by 2050

India's power capacity including batteries expands nearly fivefold to 2,982GW in 2050 under the ETS, up from 476GW[7] in 2021 – adding an average of 95GW gross capacity annually between 2022 and 2050. In comparison, the expansion under the NZS is nearly sevenfold to 4,227GW with an average annual gross addition of 148GW.

In the BNEF analysis, India, alongside Indonesia, China and Japan continues to build coal-fired plants on economic grounds (without CCS) in our base case ETS. In total, 175GW new build coal capacity is added by 2050 to the current 262GW. Due to the overall system growth the share of coal in installed capacity declines to 13% in 2050, from the current 55%. Some 30% of the new build is to replace existing coal plants by 2030. 52GW of new build coal capacity is to be added by 2030, of which about 26GW are already under-construction. The retirement of the existing fleet and the need to maintain a firm capacity margin in the grid leads to an additional new build of 64GW during 2031-40 and 59GW during 2041-50. In general, coal plants with low transportation costs can compete with renewables today on an economic basis[8]. Therefore, most new power plants in this scenario are built next to coal mines. For more analysis on the role of coal in the New Energy Outlook, see *New Energy Outlook: Coal* (web | terminal)

Share of non fossil-fuel sources in capacity mix to reach 89% by 2050 under NZS

Under the NZS, unabated[9] coal and gas capacities are largely retired, with only 5GW and 1GW remaining in the grid by 2050, respectively. Nuclear capacity reaches 97GW in the same period, whereas only 45GW is needed under ETS. The share of non fossil-fuel sources[10] in the capacity mix under NZS increases to 89% in 2050 – 10 percentage points higher than the ETS, compared to 35% in 2021.

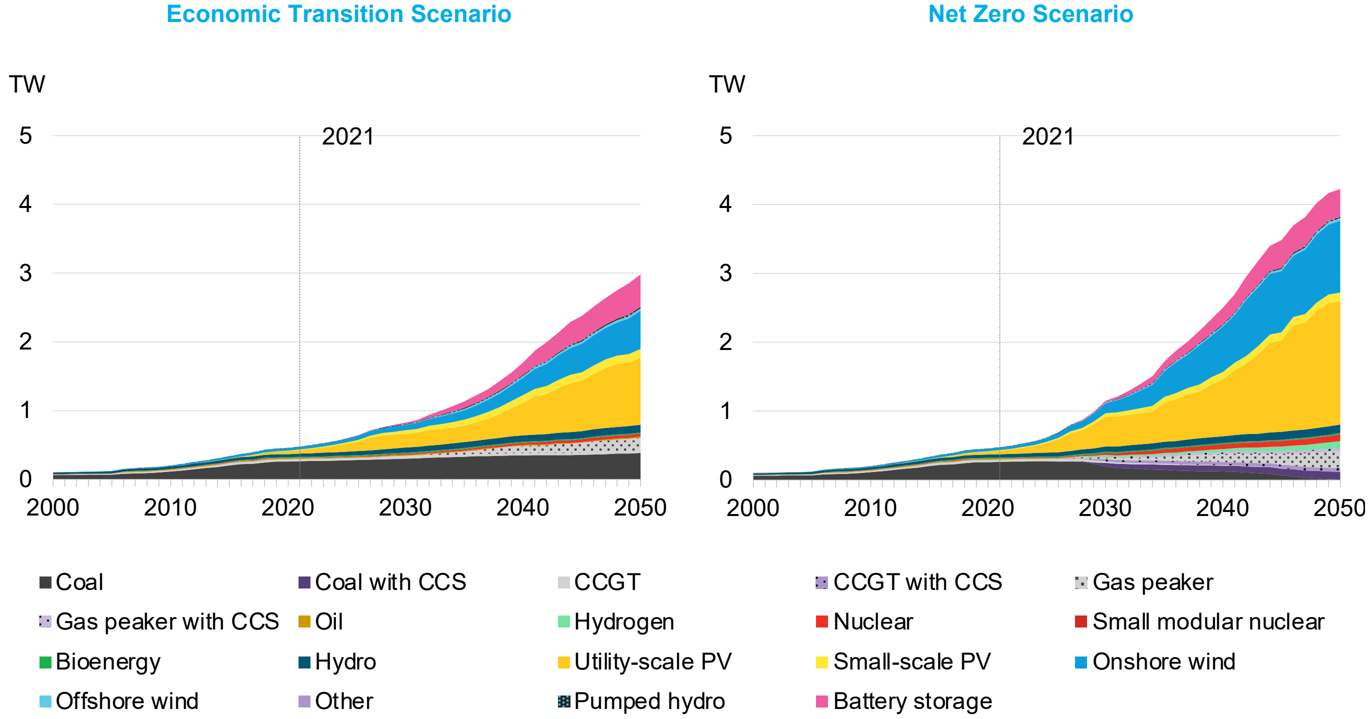
[7] Includes 73GW of captive thermal capacity

[8] Transport costs make up more than a third of the total landed fuel costs of an average existing non-pithead power plant in India. See *Indian Coal Prices Rise, Remain Half of Global Rates* (web | terminal)

[9] Unabated coal and gas capacities refers to power plants without carbon capture

[10] Includes batteries and pumped hydro

Figure 24: Installed generation capacity and batteries in India by technology/fuel



Source: BloombergNEF. Note: Includes electricity generation for hydrogen production. Note: CCS – carbon capture and storage, PV – Photovoltaic, CCGT – combined cycle gas turbine.

5.2. Renewable capacity

India has already begun its low-carbon power transition. Falling costs for renewables, along with state and national policy support, have aided the construction of 42GW of utility-scale wind and 68GW of utility-scale solar by 2022.

Under the ETS, total solar and wind capacity rises to 1,692GW by 2050, driven primarily by their relative economic competitiveness. Solar makes up most of this capacity growth with 977GW of utility-scale PV and 125GW of small-scale PV operational in 2050. Onshore wind capacity grows to 556GW in 2050 and an additional 35GW of offshore wind is also installed. Overall, under the ETS, wind and solar represent 57% of total capacity installed in India in 2050.

Total solar and wind capacity to reach 3TW by 2050 under the NZS

Achieving net zero by 2050, however, will require even more wind and solar capacity. In the NZS, wind and solar account for nearly 3TW of installed capacity by mid-century, or 1.8 times that installed in the ETS. Utility-scale solar experiences the largest growth, with 1,789GW of capacity operating in 2050. Installed onshore wind capacity rises to 1,047GW, with 37GW of offshore wind in 2050.

Our modeling shows an opportunity for offshore wind closer to 2030 in India. The much higher levelized cost of electricity, or LCOE, for offshore wind compared to onshore wind and solar in the long term is the main reason behind the slow uptake of offshore wind in India[11]. Onshore wind and PV have already achieved tipping point 1 – meaning it is already cheaper to build a new PV or a wind power plant, than building a new coal or gas power plant. LCOE of PV and onshore wind fall below short-run marginal costs of existing coal plants in the mid-2030s.

Figure 25: PV and wind LCOE vs coal LCOE (Tipping Point 1 – new renewables vs new coal plants)

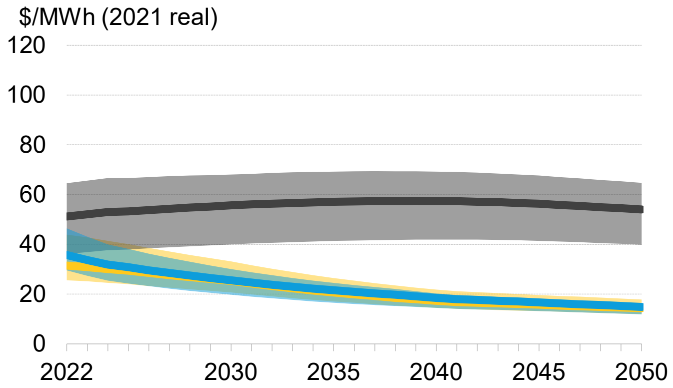
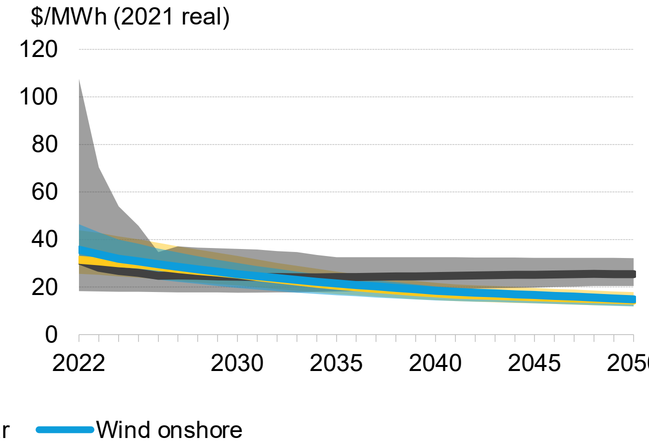


Figure 26: PV and wind LCOE vs short-run marginal cost of existing coal (Tipping Point 2 – new renewables vs existing coal plants)

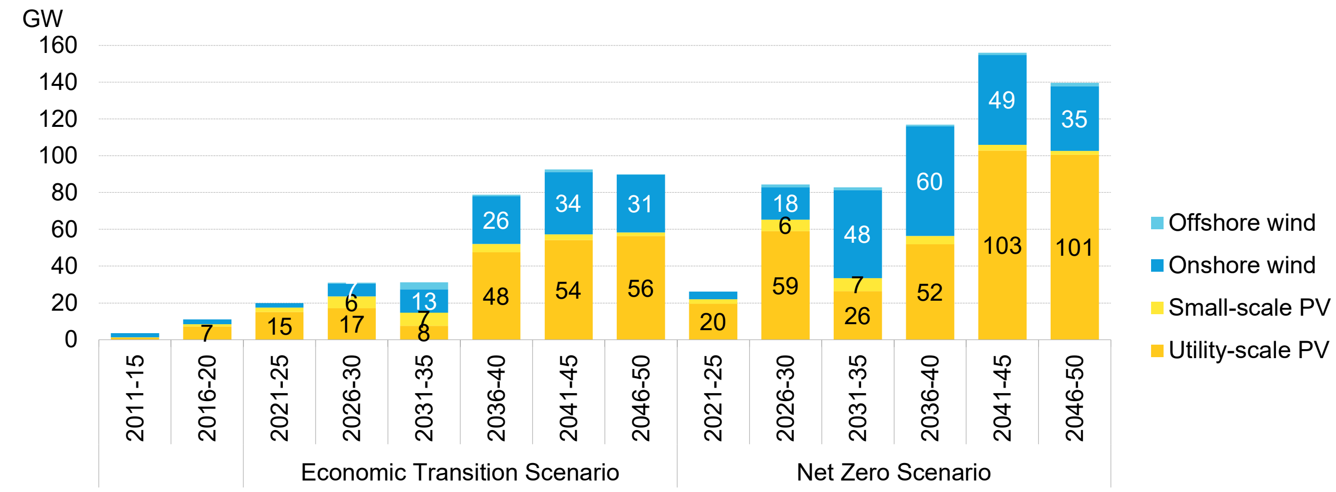


Source: BloombergNEF.

Wind and solar represent 71% of total capacity by 2050 under the NZS

Despite the higher capacity factor and more stable generation profile of offshore wind, the cost of onshore wind is falling faster. Offshore wind may play a larger role if land and grid are constrained, which were not incorporated into our cost-based modeling. Overall, wind and solar represent 71% of total capacity installed in India by mid-century.

Figure 27: Average annual gross capacity additions for wind and solar in India



Source: BloombergNEF. Note: PV – Photovoltaic.

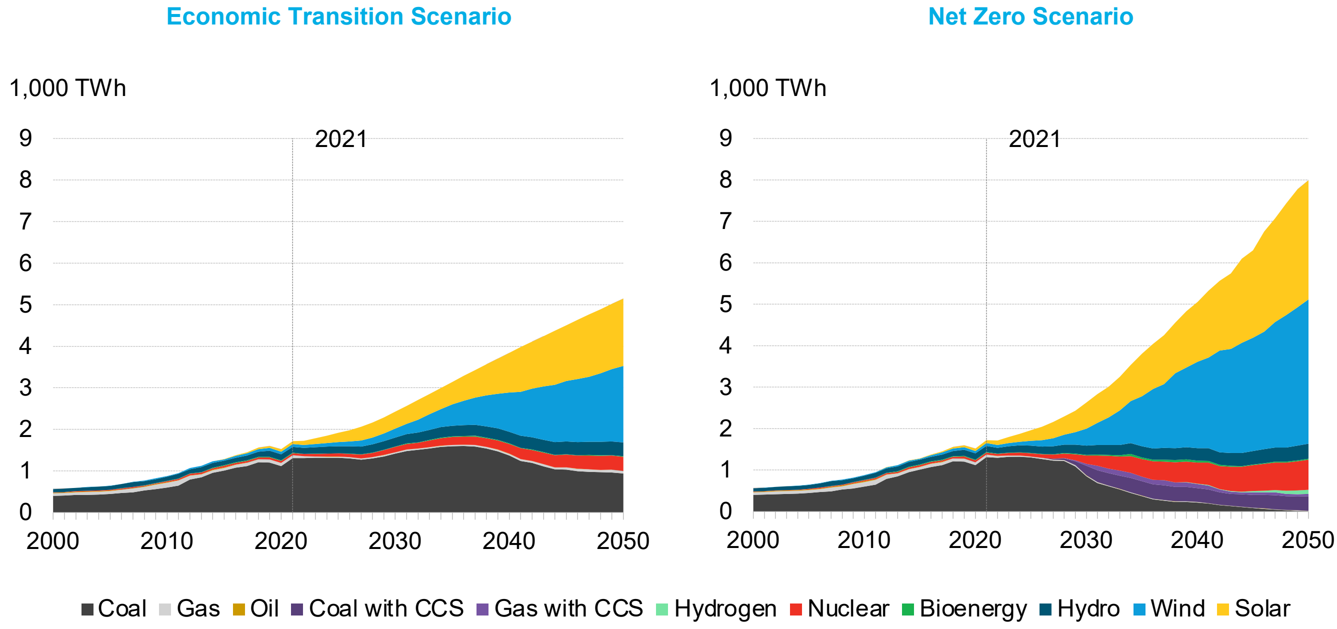
[11] For the latest LCOE comparison, see *LCOE 1H 2023* (web | terminal)

5.3. Generation

Future generation mix is built around renewables

Both scenarios show a rapid increase in India's power generation and a fundamental shift in its power mix. Total generation in India will triple from 1,718TWh today to 5,148TWh by 2050 under the ETS. By comparison, total generation will increase by 365%, to 7,994TWh by 2050, under the NZS. Achieving net zero by 2050 means the NZS is not merely an evolution of the ETS – it will have to function like a completely different power system (Figure 28).

Figure 28: Electricity generation in India by technology/fuel



Source: BloombergNEF. Note: CCS – Carbon capture and storage.

Wind and solar rapidly scale from 8% of total generation in 2021 to 67% by mid-century under the ETS and 80% under the NZS. Under the ETS, solar accounts for 32% of generation compared to 36% for wind. In the NZS, wind accounts for 44% of all generation in 2050, compared to 36% for solar.

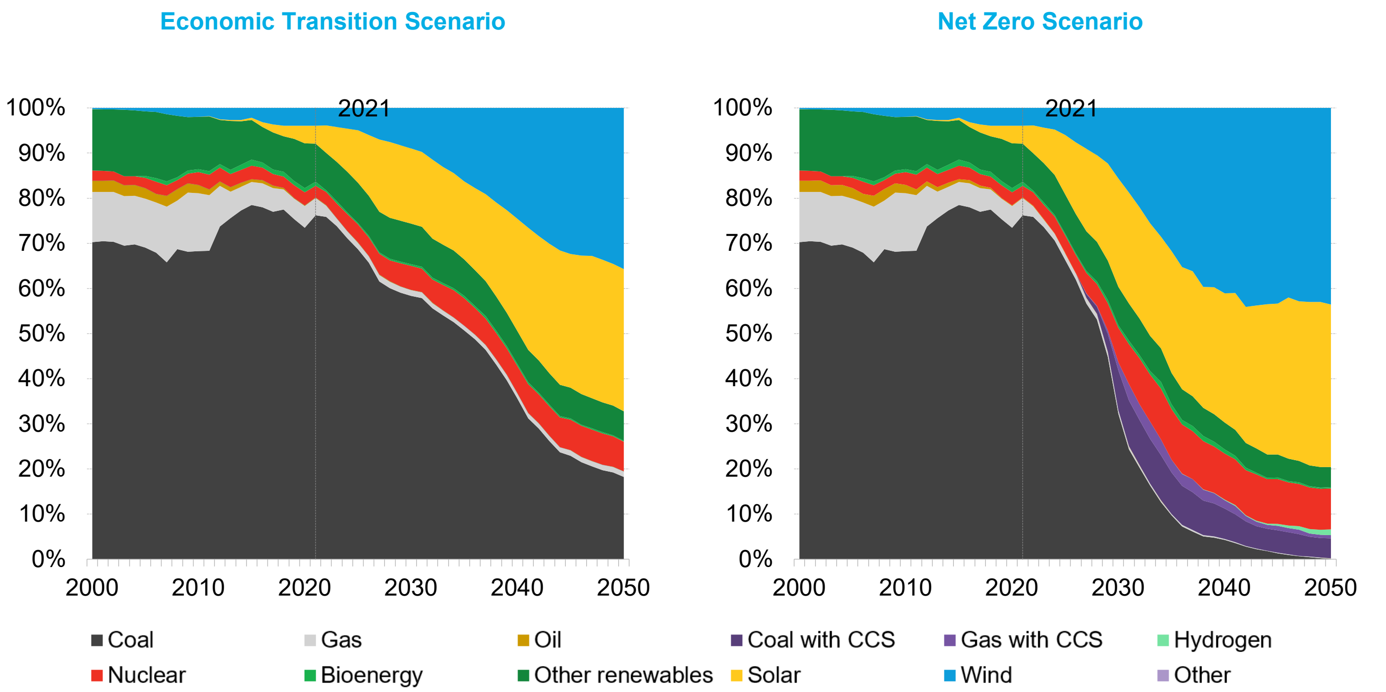
Coal accounts for three-fourths of India's electricity generation today. In both scenarios, existing sub-critical and some supercritical coal projects, beset with lower operational flexibility, will struggle to compete with new renewable energy generators. Unabated coal's share of the generation mix drops to 18% by 2050 under the ETS, and 0.1% under the NZS.

Inefficient or under-utilized coal projects will struggle to compete with new renewable energy generators

Gas continues to struggle to compete with other sources, specifically as cheaper renewables supply more bulk generation for the Indian power system. Instead, gas moves from baseload to a peaking role – supplying high value, low volume electricity to the power system at times of need. By 2050, unabated gas accounts for only 1% of all generation under the ETS and 0.1% under the NZS, down from 4% today.

Coal and gas paired with carbon capture and storage play a role only in the NZS – accounting for 4% and 1% of total generation in 2050, respectively.

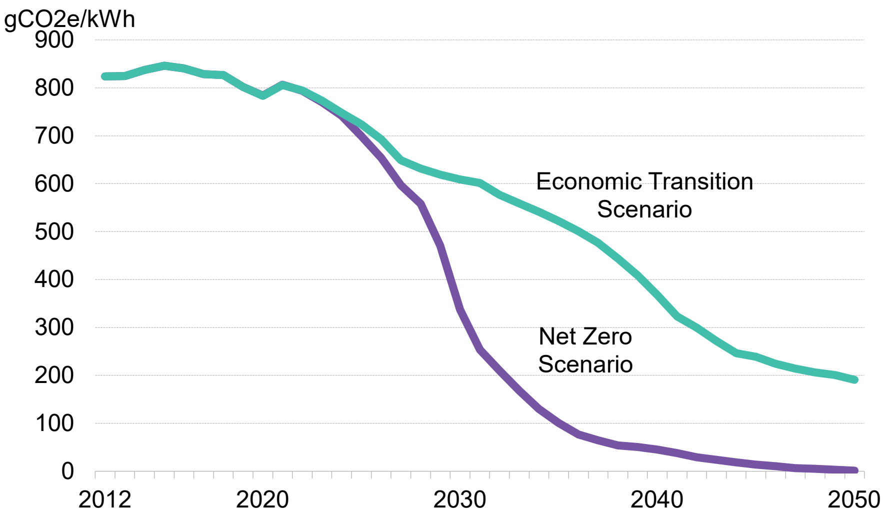
Figure 29: Share of electricity generation in India by technology



Source: BloombergNEF. Note: Includes electricity generation for hydrogen production. 'Other renewables' includes all other non-combustible renewable energy in electricity generation, including hydro, geothermal and solar thermal. CCS – Carbon capture and storage.

Driven by higher penetration of renewables, the emission intensity of the grid reduces dramatically, dropping to 191gCO2/kWh in 2050 under the ETS, from 807gCO2/kWh in 2021. Under the NZS, it drops further to near zero, reaching 1.4gCO2/kWh by mid-century.

Figure 30: India's emission intensity of electricity generation under both scenarios



Source: BloombergNEF

BloombergNEF

5.4. Dispatchable capacity

New flexible capacity from batteries and hydrogen

As India transitions away from fossil fuels and toward variable renewables, its power system will require additional dispatchable capacity as back up and balancing.

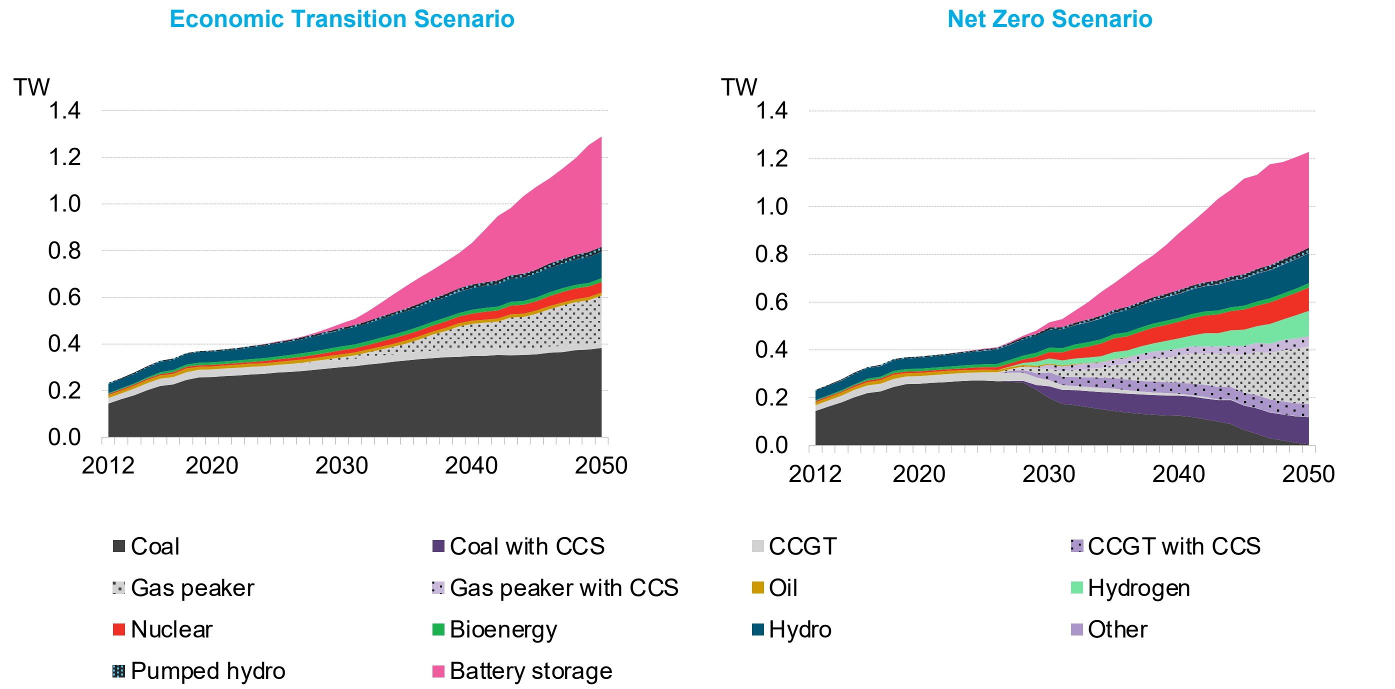
In the ETS, total dispatchable capacity increases by 30% from 377GW to 489GW between 2021 and 2030 with 74% of it contributed by capacity additions of 38GW from coal, 25GW from hydro and 20GW from batteries. Between 2031 and 2050, total dispatchable capacity continues to increase driven by rapid expansion of pumped hydro and batteries that rise to 495GW.

Under the NZS, total dispatchable capacity increases even more – 37% to 515GW between 2021 and 2030 and nearly 138% to 1,227GW from 2031 to 2050. Unabated coal plants are retired in the NZS, with only 5GW remaining in the power system by mid-century. Additional hydrogen capacity expansion along with batteries and some pumped hydro provide new forms of flexibility in the system in the face of accelerated retirement of coal generation. The capacity of utility-scale batteries deployed under the NZS by 2050 at 401GW is smaller compared to the ETS at 473GW. This is driven by greater flexibility on the demand-side due to the growing use of electric vehicles and hydrogen electrolyzers in the NZS compared to the ETS.

106GW of hydrogen-fired power generation capacity to be added by 2050 under the NZS

In addition, 106GW of hydrogen-fired generation capacity is installed by 2050 compared to none in the ETS. India also adds a relatively large amount of gas peakers to help manage peak summer demand during critical hours. Under the NZS, 114GW and 54GW of CCS-paired coal and gas plants are installed by 2050, with an additional 44GW of CCS-paired peaker plants installed.

Figure 31: India's dispatchable capacity by scenario



Source: BloombergNEF. Note: 'Other' includes geothermal and interconnectors. CCS – Carbon capture and storage, CCGT – Combined cycle gas turbine

Thermal capacity is still necessary to get to net zero

Under the NZS, total thermal firm capacity (including nuclear) – that is, fully dispatchable capacity – doubles from today's 315GW to 661GW in 2050. Oil-fired capacity is completely phased out in mid-2030s. Near complete retirement of unabated coal plants is offset by an increase in CCS-paired coal and gas capacities, with a cumulative installed capacity of 114GW and 54GW, respectively, in 2050.

India's coal fleet and CCS conversions

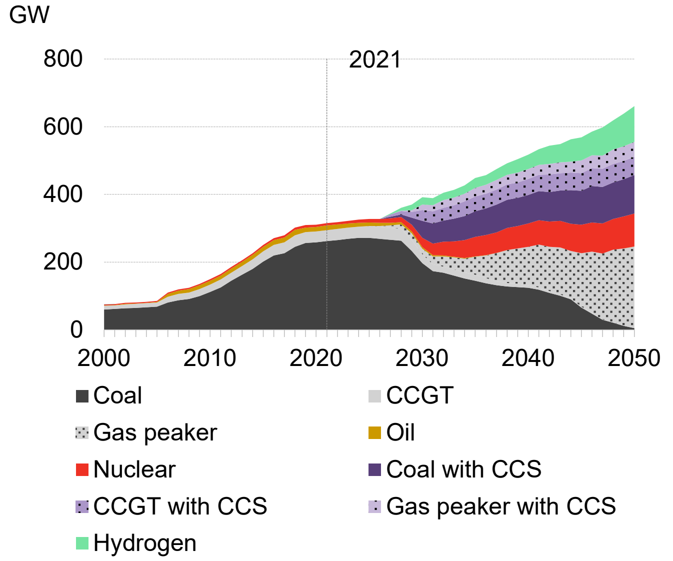
India has some of the youngest coal fleet in the world, with some 80% of coal plants aged 20 years or less. The share of coal plants younger than 20 years is similarly high in China and Indonesia, while it is as low as 11% in the US and about 25% in Poland or Germany.

Although BNEF did not explicitly model CCS conversions for coal or gas capacity (the cost can be significantly lower than a new plant, but also higher due to local factors), it is reasonable to assume that in markets like India a high proportion of new coal with CCS capacity in our modeling will be conversions of existing plants, where possible.

In addition, 106GW of clean hydrogen-fired capacity is installed. In the ETS, hydrogen and CCS-paired coal and gas capacity are always more expensive than the incumbent alternatives, and so see no development out to 2050.

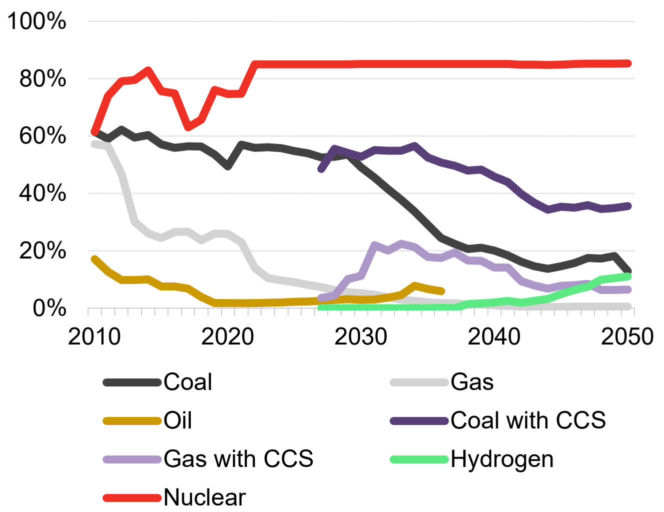
In the NZS, load factors for thermal fleets decline dramatically between 2021 and 2050. During this period, load factors for unabated gas fall from 23% to 1%. In the same period, unabated coal load factors drop from 57% to 13%. The CCS-paired counterparts have higher load factors until mid-2030s but from then on begin a steady decline until 2050. The load factor for hydrogen-fired capacity rises to 11% by 2050 as it increasingly provides critical backup to renewables during periods of low supply.

Figure 32: Firm thermal capacity in India, Net Zero Scenario



Source: BloombergNEF. Note: CCS – Carbon capture and storage, CCGT – Combined cycle gas turbine.

Figure 33: Load factors for firm capacity in India, Net Zero Scenario



Source: BloombergNEF. Note: CCS – Carbon capture and storage.

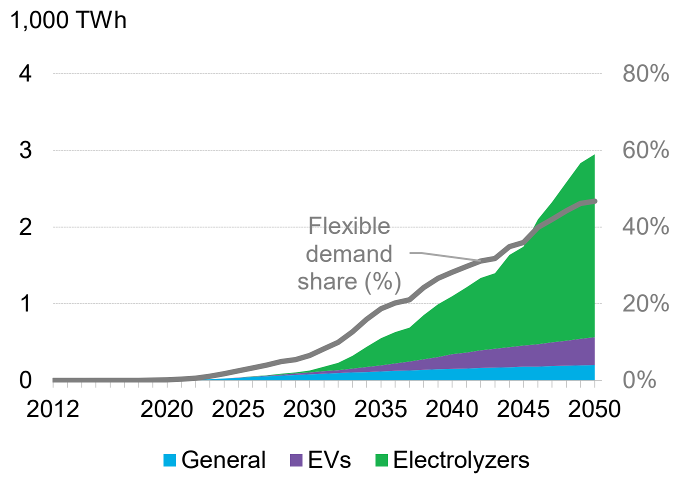
5.5. Flexibility

New sources of flexibility are not just confined to the supply-side. As India's power system marches rapidly toward decarbonization, dominated by variable renewables, the importance of demand-side flexibility also increases as new forms of demand emerge. Particularly in the NZS, consumption patterns change to take advantage of low-cost electricity available during periods of high renewable output. A key example of this is the emergence of flexible demand from electrolyzers and electric vehicles.

Electrolyzers can be a new source of demand-side flexibility

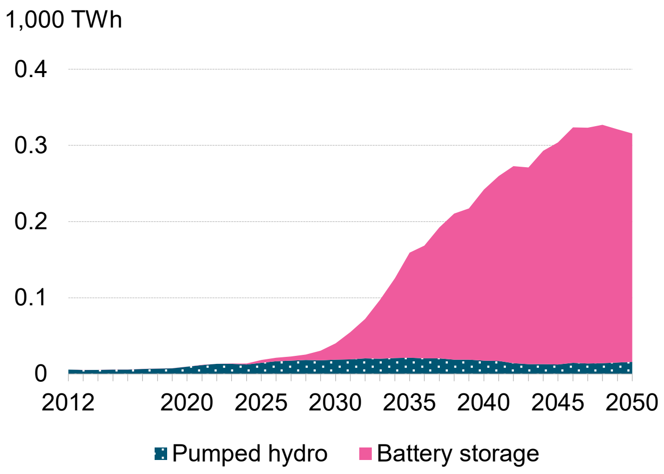
In the NZS, flexible electrolyzer demand rises from virtually nothing in 2021 to nearly 2,385TWh by mid-century to produce clean hydrogen. In our modeling we assume electrolyzers are fully flexible and able to produce during low-cost hours. This introduces a large new source of demand-side flexibility. Low-carbon hydrogen can aid the decarbonization of hard-to-abate sectors like the steel industry and shipping, as well as provide some firming capacity to complement variable renewables. Similarly, as the road sector decarbonizes, we assume a share of charging will be able to respond flexiblyto system needs, especially for home charging during night hours. Flexible demand from electric vehicles rises to 362TWh by 2050 with the increasing electrification of India's transport sector – this means by 2050 there are more batteries in vehicles connected to the grid in India than utility and behind-the-meter batteries.

Figure 34: Flexible demand in India, Net Zero Scenario



Source: BloombergNEF. Note: EV demand flexibility varies by user group and charging patterns.

Figure 35: India's flexible non-thermal supply, Net Zero Scenario



Source: BloombergNEF. Note: Battery storage includes utility and behind-the-meter installations.

5.6. Power grids

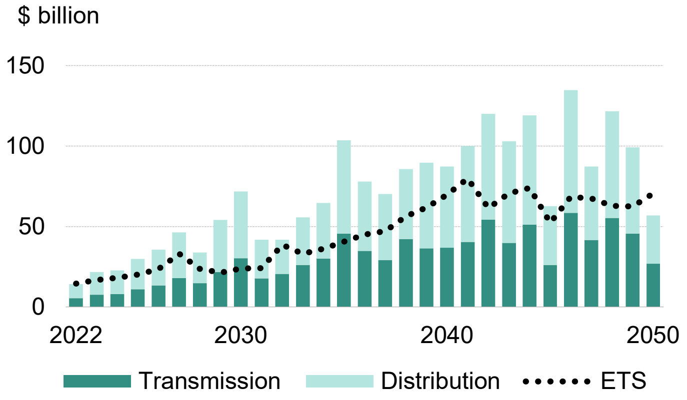
As more renewables are added to the Indian grid, new investment will be needed to support the country's transition. India's power grid undergoes a rapid transformation under both the ETS and NZS as the power system shifts from large, centralized power plants to a more decentralized system. Under the ETS, $1.3 trillion is invested in grids up to 2050, of which $804 billion is allocated toward system reinforcement and asset replacement, and $513 billion to new connections. Achieving net zero in India calls for $2.1 trillion of grid investment between 2022 and 2050, of which $1.2 trillion is spent to sustain the existing grid and replace assets, and $897 billion to expand the grid for new electricity consumption.[12]

In the NZS, the length of the grid doubles to over 20 million kilometers between 2022 and 2050. Around 5,000 kilometers of submarine cables are installed after 2027 to support the commissioning of offshore wind capacity. India's grid development is shaped by demand growth along with the addition of renewables.

Annual grid investment levels off through the 2030s as new renewable energy connections stabilize. Grid investment averages $100 billion per year in the 2040s as ageing infrastructure and electrification starts warranting more investment. Accelerated electric vehicle deployment also drives growth in spending, most notably after 2030. The number of EV connections in our forecast grows from less than 1 million in 2030 to over 16 million in 2040, and then nearly 40 million by 2050. Further, India's hydrogen economy gains appreciable scale. By 2050, electrolyzers contribute 545GW to peak load, which exceeds India's peak demand today but represents only 14% of national peak demand in 2050.

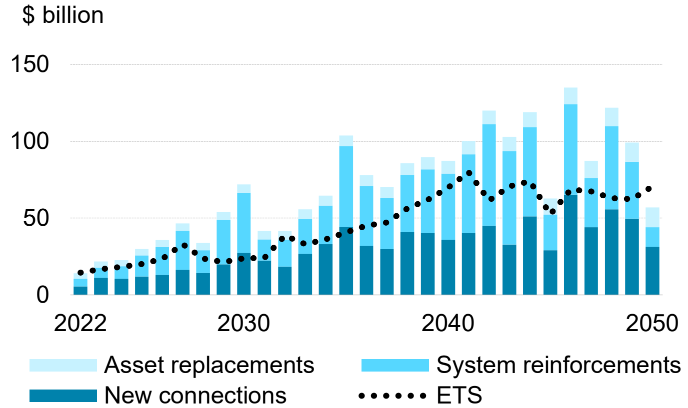
High-voltage direct current (HVDC) transmission in India grows to 30,520 kilometers by 2050 while ultra high-voltage (UHV) rises to 62,710 kilometers. Historically, India's electricity grid was broken into several asynchronous grids. Synchronization of these grids in 2013 ended an era of regional self-sufficiency in favor of a national grid where electricity can easily flow between regions. India will need to invest in expanding regional interconnectors to connect generation with demand across regions.

Figure 36: India's grid investment by voltage class, Net Zero Scenario



Source: BloombergNEF. Note: ETS – Economic Transition Scenario.

Figure 37: India's grid investment by driver, Net Zero Scenario



Source: BloombergNEF. Note: ETS – Economic Transition Scenario.

[12] *New Energy Outlook: Grids* (web | terminal)

Section 6. Hydrogen and CCS

In the NZS, hydrogen is crucial for India to cut emissions in hard-to-abate sectors, like steel and shipping. Its consumption rises sharply after 2030, when hydrogen from clean power gets cheaper and is more available. CCS also plays an important role, with a rapid ramp-up in our modeling from the 2030s to decarbonize industry, in particular cement, petrochemical and steel production.

6.1. Hydrogen

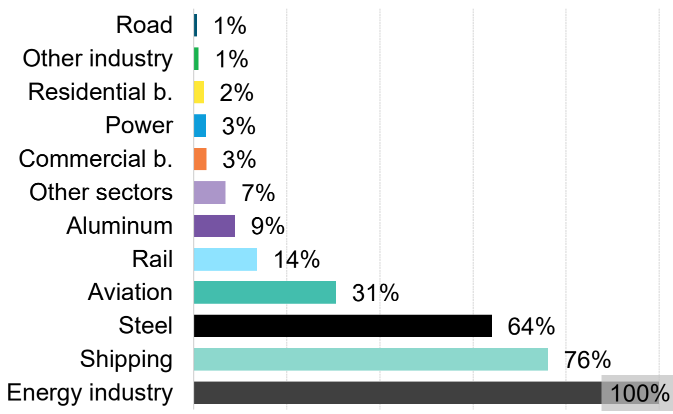
Hydrogen helps decarbonize shipping and steel but remains niche elsewhere

Hydrogen use reaches 53Mt of H2 in 2050 under the NZS, nearly 13 times levels in 2050 under the ETS

India's hydrogen use reaches 53Mt of H2 in 2050, nearly 13 times of that in 2021 under the NZS and about 10% of global demand. Hydrogen plays a strategic role in decarbonizing steel making and shipping, where it meets 64-76% of final energy demand in 2050 (Figure 38). The availability of iron ore should not arise as a concern given that India is rich in high-grade iron ore deposits. Under the NZS, hydrogen-fired direct reduction furnaces produce more than half of all steel output in 2050. In fuel refining, hydrogen can serve both as a feedstock and process fuel.

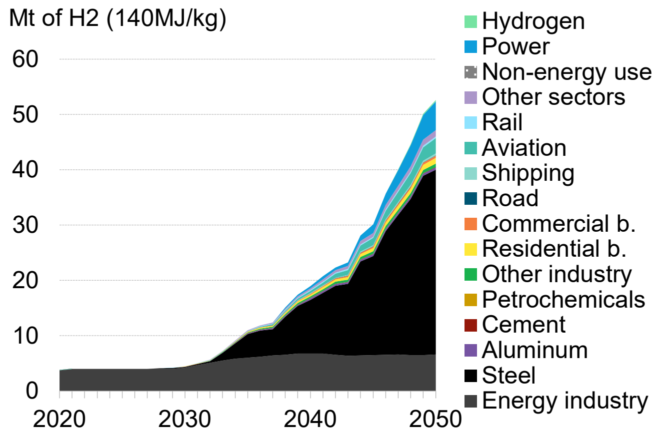
However, hydrogen is less competitive where alternatives already exist or are emerging. This includes the power sector, buildings and industrial sectors outside of steel, such as petrochemicals (excluding use as feedstock) and cement. Hydrogen plays a limited role in heavy road transport. In rail, it can help to decarbonize operations on tracks that cannot be electrified.

Figure 38: Share of hydrogen in final energy consumption in India in 2050, Net Zero Scenario



Source: BloombergNEF. Note: 'Energy industry' includes legacy uses (eg, as feedstock for ammonia and methanol production or in oil refining) as well as own use for energy producing industries, such as process heating, lighting, and equipment operations. Commercial b. – Commercial buildings, Residential b. – Residential buildings.

Figure 39: India's hydrogen consumption, Net Zero Scenario



Source: BloombergNEF, IEA. Note: 'Energy industry' includes legacy uses (especially as feedstock for ammonia and methanol production or in oil refining) as well as own-use for energy producing industries, such as process heating, lighting, and equipment operations. Commercial b. – Commercial buildings, Residential b. – Residential buildings.

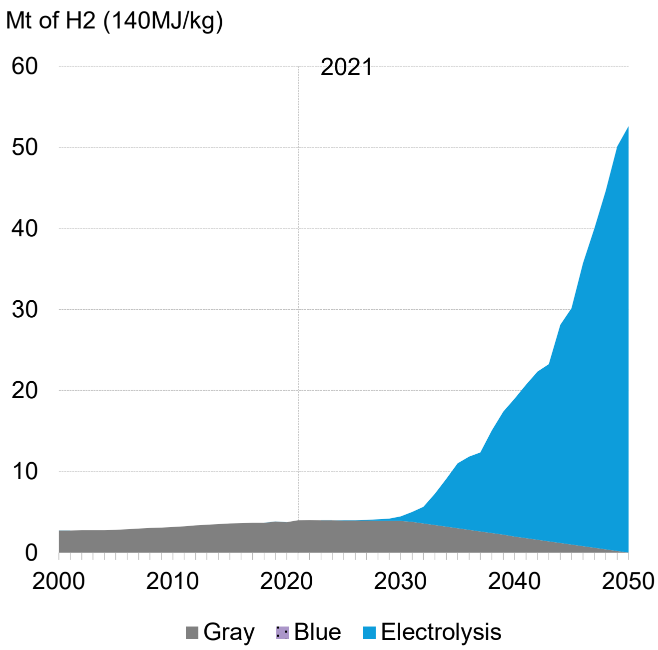
Solar and wind generation supply 91% of electricity consumed for hydrogen production by 2050 under the NZS

Hydrogen produced in India in our modeling is predominantly from domestic grid-connected eletrolyzers using mostly low-carbon energy sources.[13] As the grid decarbonizes, the carbon-intensity of the energy mix during hours of operation drops fast and reaches near-zero by 2045. Solar and wind generation represents over 91% of the electricity consumed to produce hydrogen in India in 2050 (Figure 41). Around 1% of the electricity generated to produce hydrogen will come from coal paired with CCS, with the rest from nuclear.

Dedicated off-grid electrolyzers may also play a role in the near- to medium-term, but are not covered in our modeling. These would require oversizing of generation capacity or under-sizing of electrolyzer capacity.[14]

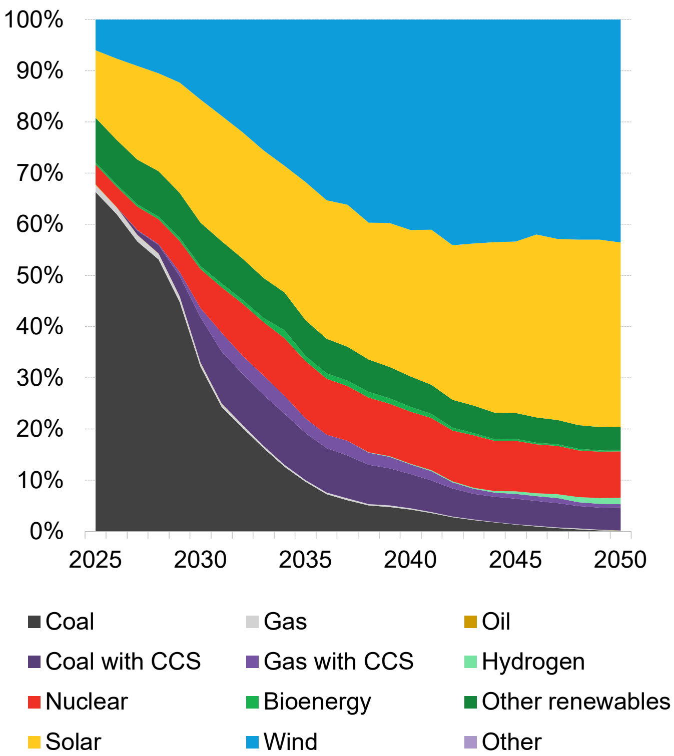
Existing gray hydrogen production is phased out by 2050 as India reaches net zero.

Figure 40: India's hydrogen production by type, Net Zero Scenario



Source: BloombergNEF

Figure 41: Share of fuel mix in India's hydrogen production, Net Zero Scenario



Source: BloombergNEF. Note: CCS – Carbon capture and storage.

[13] Includes solar, wind, nuclear, bioenergy and other renewables, such as hydro and geothermal sources.

[14] BNEF has developed a tool that determines the optimal off-grid renewable power solution for a new electrolysis project used to produce green hydrogen. See *Hydrogen Electrolyzer Optimization Model (H2EOM)* (web | terminal)

6.2. CCS

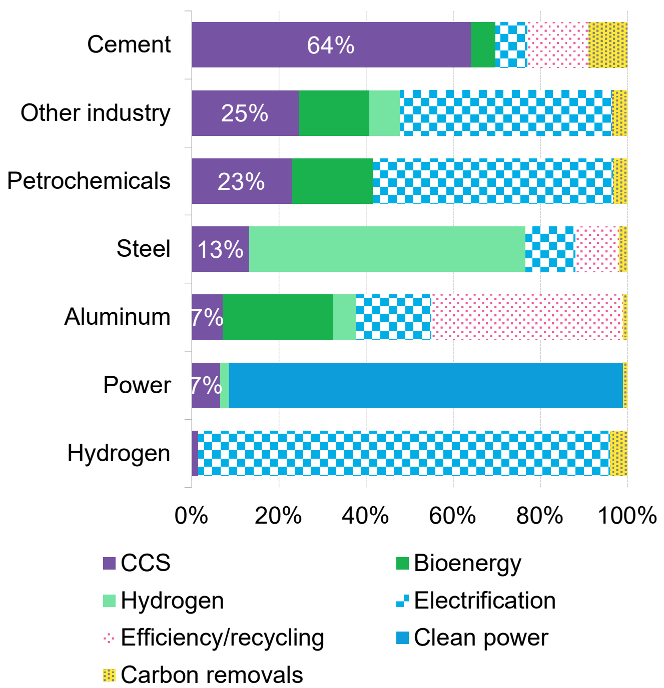
CCS spurs decarbonization in industry, with some uptake in clean hydrogen and electricity production

CCS responsible for nearly two-thirds of emissions abated by 2050 in cement industry

Carbon capture and storage (CCS) for emissions abatement is limited to use in the power sector and domestic industry in our modeling. In 2050, CCS is responsible for 64% of emissions abatement in cement, 23% in petrochemicals and 13% in steel production. In hydrogen production, it accounts for 2% of emissions reductions through use of CCS paired power plants. In the power sector, fossil fuel plants equipped with CCS abate about 7% of all emissions in 2050.

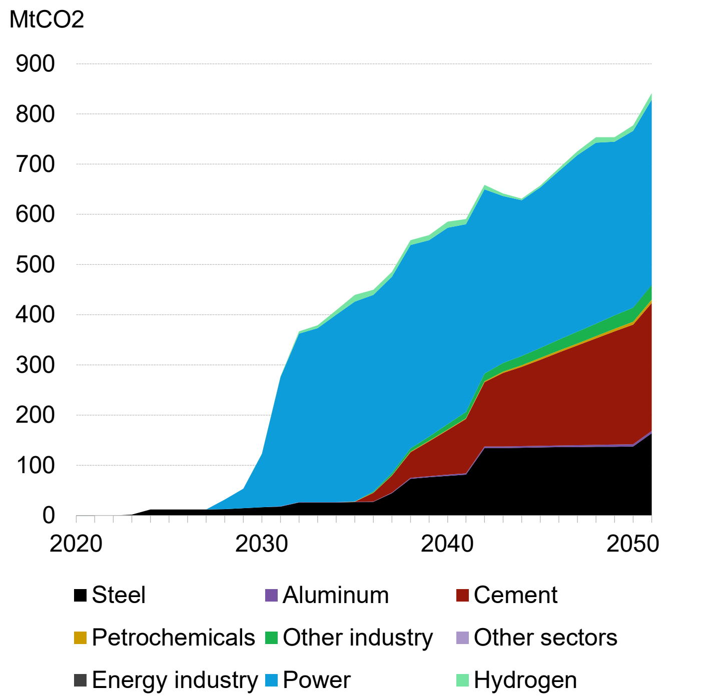
The annual rate of emissions captured by CCS grows from very low levels in 2022 to 221MtCO2 in 2030, 465MtCO2 in 2040, and 664MtCO2 in 2050. Cumulatively, around 12GtCO2 are captured by CCS between 2022 and 2050, with 61% originating in power, 18% in cement, 16% in steel manufacturing and the rest in other sectors.

Figure 42: Share of CCS in emissions abatement in India in 2050, Net Zero Scenario



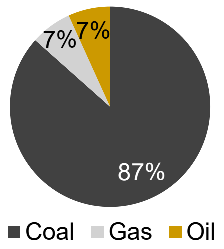
Source: BloombergNEF. CCS – Carbon capture and storage.

Figure 43: India's annual CO2 emissions captured by CCS by sector, Net Zero Scenario



Source: BloombergNEF. Note: Pre-2020 levels not shown in data.

Figure 44: Cumulative CO2 emissions captured by CCS in India by fuel type, NZS



Source: BloombergNEF

CCS yields the greatest emissions reductions when it captures CO2 from carbon intensive processes, such as in coal-fired power plants or industrial furnaces. Coal in particular has a high emissions intensity, releasing around 69% more CO2 per unit of energy than natural gas. In the NZS, around 87% of India's total cumulative captured emissions are from processes combusting coal, with 7% each from gas and oil. We assume in our modeling that CCS systems will be able to capture 90% of emissions, irrespective of the fuel or application.

Section 7. End-use sectors

In the NZS, end-use sectors experience very different emission reduction pathways based on technology readiness and abatement options. Hydrogen, electrification and CCS are the three most important solutions for industry decarbonization. The road transport sector relies more on electrification, but bioenergy and hydrogen are needed for some heavy-duty transport, shipping and aviation. Electrification contributes the most to decarbonization in buildings.

7.1. Industry

Expanding economy will make India the fastest-growing market for industrial materials

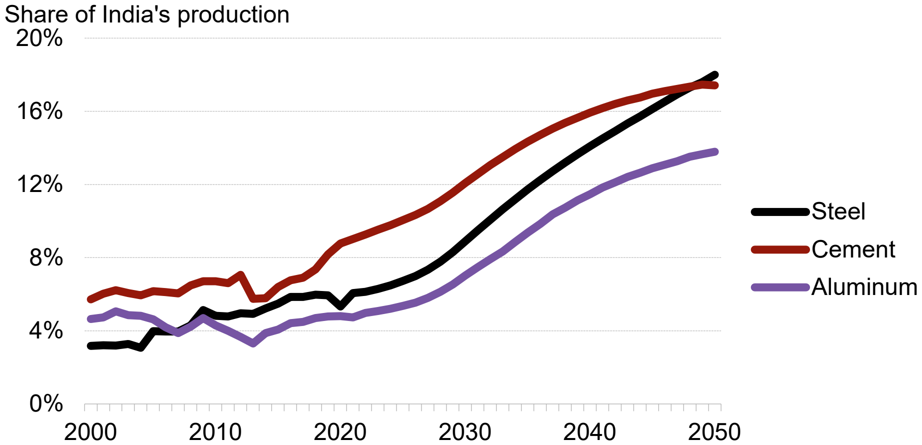
India is a relatively small producer of industrial materials today but will be one of the fastest growing markets over the next three decades. Production of steel, aluminum and petrochemicals all grow exponentially in our scenarios as India's economy grows.

A large portion of India's steel supply currently comes from recycled materials. It is one of the largest steel scrap importers, though new export controls on scrap metal in the EU could soon change this. It has very little secondary production in plastics, aluminum or cement but should make rapid progress in plastic and aluminum recycling from 2030 onward.

India's production of industrial materials is expected to scale up to mid-century forced by a growing economy, with India's share in global steel production tripling to 18% by 2050 from current 6%. Similarly, cement production doubles in the same period and aluminum triples.

India has the potential to become a large low-carbon materials producer, with access to abundant clean energy, high quality iron ore, low-cost hydrogen and a small base of existing polluting assets. However, it needs to commit to 'building clean' from now on to achieve this.

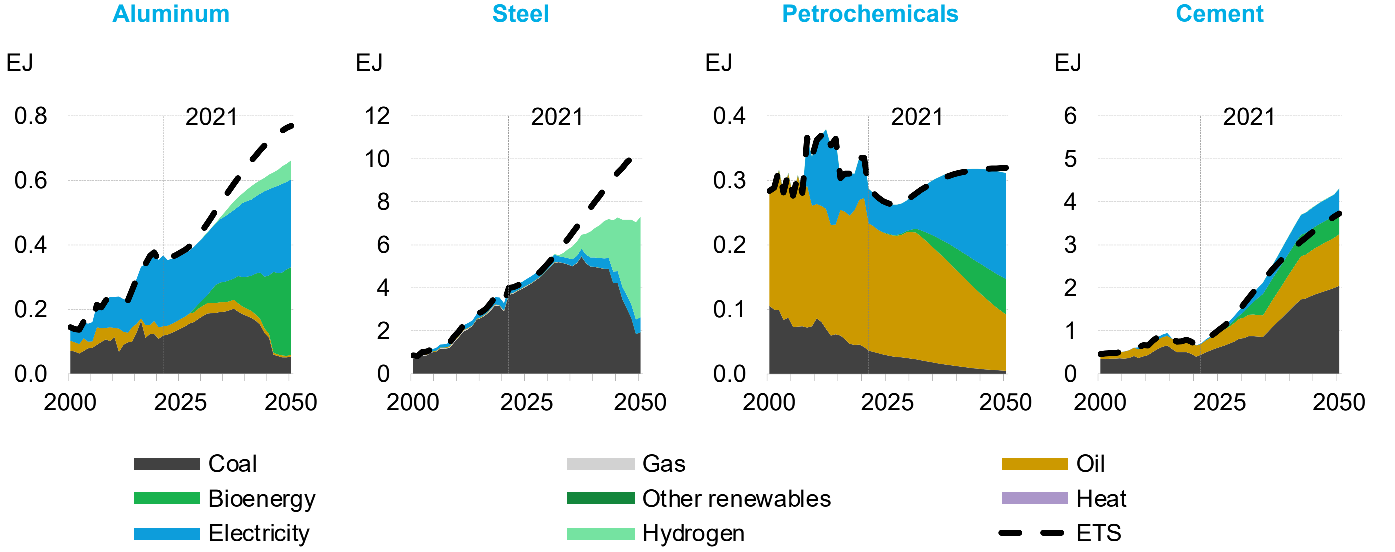
Figure 45: Indian share in global production of industrial materials



Source: BloombergNEF.

India has a steep hill to climb in industrial decarbonization. In a business-as-usual scenario, its emissions from material production would more than double. It also has very little existing infrastructure for either hydrogen or CCS.

Figure 46: India's final energy consumption by industry subsector, Net Zero Scenario



Source: BloombergNEF. Note: y-axes differ in scale. Note: ETS – Economic Transition Scenario.

In the NZS, the use of bioenergy increases rapidly in the aluminum sector by 2050 and accounts for 41% of final energy demand. In the steel sector, hydrogen use expands to reach 64% of the final energy demand in 2050. Under the ETS, there is almost no emissions abatement from industry in India. Most materials will require policy support, a green premium, or a technology breakthrough to decarbonize.

Under NZS, most of India's industrial decarbonization comes from hydrogen thanks to the makeup of its steel sector. CCS is also a large contributor, mostly for the cement industry.

Industry sector modeling in NEO 2022

Our industry modeling covers steel, aluminum, cement, petrochemicals and other industry (aggregated from pulp and paper, other non-ferrous metals, other non-metallic minerals and other industries).

We have switched several sectors from trend-based models to least-cost models in NEO 2022. For steel, aluminum and cement we use a proprietary least-cost optimization model that determines the cheapest combination of new-build and retrofit capacity to meet future demand, as well as primary and secondary demand.

For steel, the model uses levelized cost forecasts for blast furnace - basic oxygen furnace (BF-BOF), direct reduction - electric arc furnace (DR-EAF) and scrap EAF (with both conventional and clean fuels; the net-zero modeling also accounts for molten oxide electrolysis). For aluminum, the model uses levelized cost forecasts for alumina, smelting and recycling (with both conventional and clean fuels).

Aluminum and steel

Aluminum and steel have clear pathways to net-zero among the industrial sectors. In the aluminum sector, recycling aluminum is the best near-term step to reduce its emissions[15]; between 2022 and 2030, recycling accounts for nearly all of abated emissions, and by 2050, accounts for 50% of all abated emissions. Post-2030, bioenergy and electrification play a role in abatement, contributing to 22% and 16% of the sector's emissions reductions.

Figure 47: End-use CO2 emissions abatement for aluminum in India, Net Zero Scenario

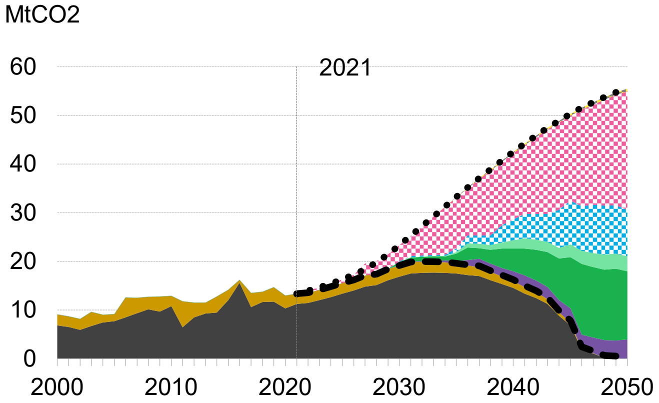
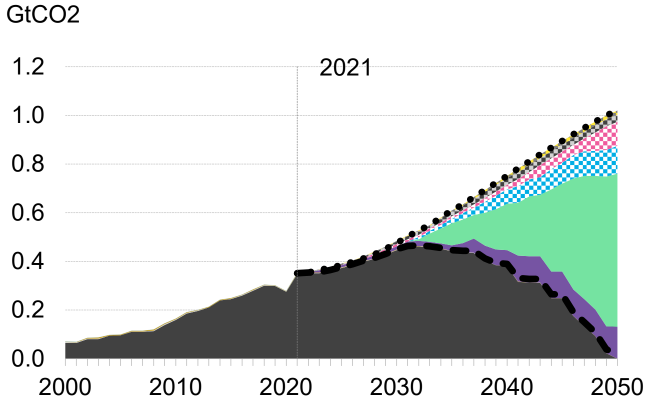


Figure 48: End-use CO2 emissions abatement for steelmaking in India, Net Zero Scenario



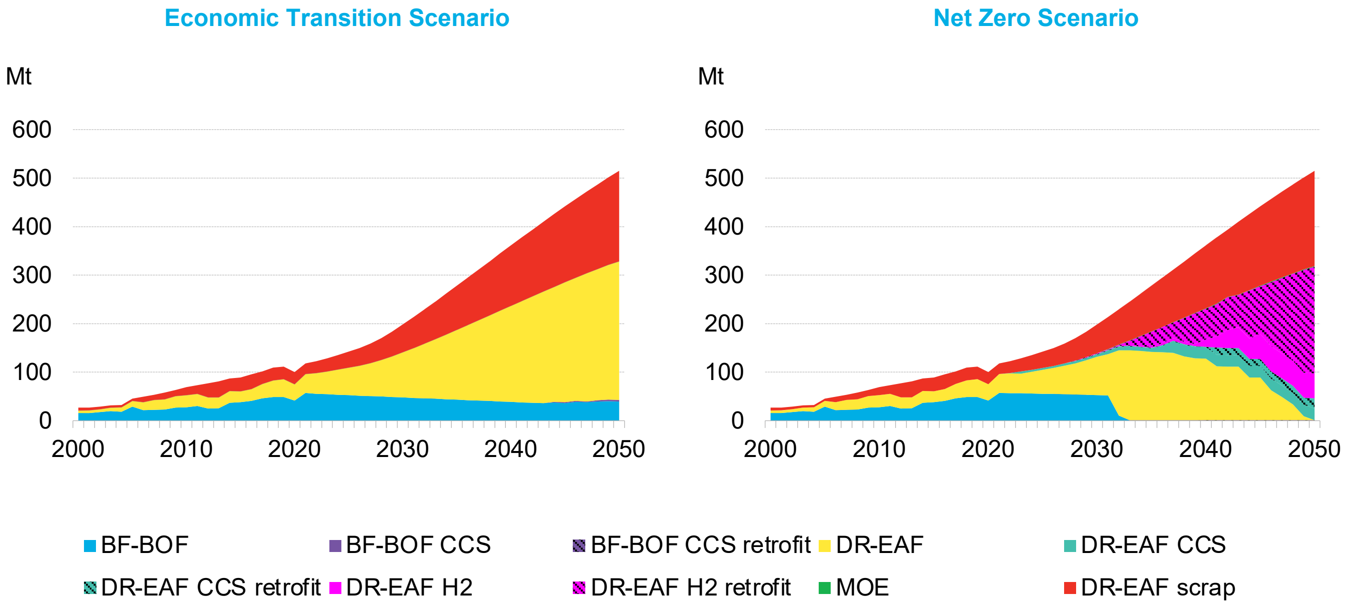
Coal | Gas | Oil | CCS
Bioenergy | Hydrogen | Other | Electrification
Efficiency/recycling | Fuel switching | Carbon removals | No transition
NZS

Source: BloombergNEF. Note: y-axes differ in scale. CCS – Carbon capture and storage, NZS – Net Zero Scenario.

India's steel sector is unusual in having a very high proportion of direct-reduction electric arc furnace (DR-EAF) capacity. These plants currently use coal but could be switched to natural gas or hydrogen with some modifications. It will also see most of its production growth in the 2030s and 40s, when costs for emerging technologies should have fallen, thanks to deployment in other regions. This should make a better case for Indian companies to choose clean technologies for their new capacity.

[15] *Decarbonizing Aluminum: Technologies and Costs* (web | terminal)

Figure 49: Steel production in India



Source: BloombergNEF. Note: BF-BOF – Blast furnace basic oxygen furnace route, DR-EAF – Direct reduction electric arc furnace, CCS – Carbon capture and storage, H2 – Hydrogen, MOE – Molten oxide electrolysis.

Under the ETS, emissions reduction in steel production in India is mainly through fuel switching. Under the NZS, India progresses through several stages. By 2040, unabated blast furnace-basic oxygen furnace (BF-BOF) plants are phased-out and unabated DR-EAF end by 2050. Until 2030, CCS accounts for the highest emission reductions, but only 17% between 2022 and 2050. Some 9% of all steel produced in India is from CCS paired plants by mid-century.

Hydrogen reduces 56% of emissions in the steel sector by 2050

Hydrogen contributes the most to direct-use emissions abatement in the long-term for the steel sector and accounts for about 54% of all emissions reduced by 2050. Half of all steel produced in India uses hydrogen in 2050. Hydrogen also brings with it greater electrification, as hydrogen-fired DR furnaces are paired with clean-energy powered EAFs replacing basic oxygen furnaces.

Petrochemicals and cement

The petrochemicals sector is the most technically difficult to abate.[16] A combination of electrification, CCS and bioenergy will be needed to decarbonize the sector by 2050. Direct-use electrification provides 62% of the cumulative abatement from 2022-50, but the contribution from CCS starts to grow post-2030. During that period, CCS contributes 17% of abatement, reducing emissions from fossil-fuel feedstocks like ethane and naphtha, as bio and recycled feedstocks are in limited supply.

16 *New Energy Outlook: Industry* (web | terminal)

Figure 50: End-use CO2 emissions abatement for petrochemicals in India, Net Zero Scenario

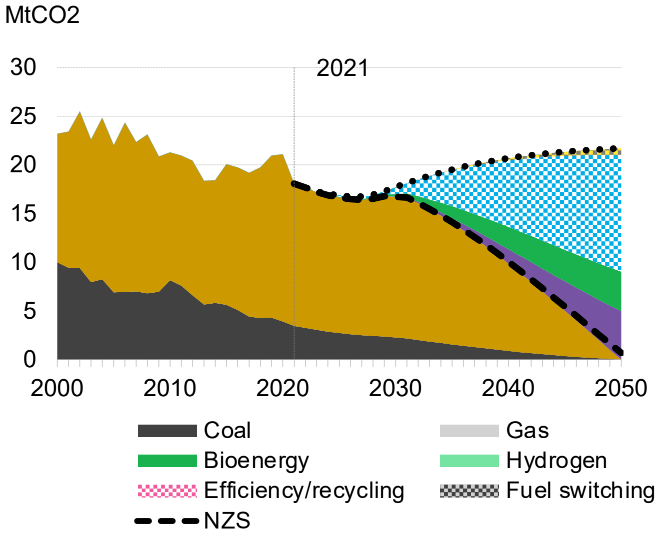
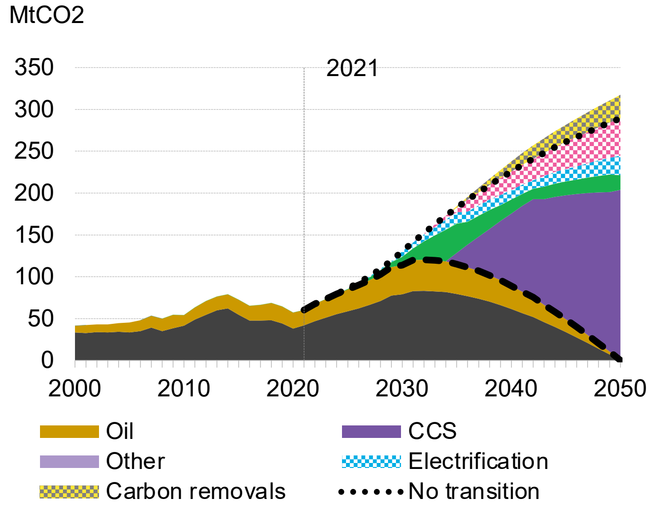


Figure 51: End-use CO2 emissions abatement for cement in India, Net Zero Scenario



Source: BloombergNEF. Note: y-axes differ in scale. CCS – Carbon capture and storage, NZS – Net Zero Scenario.

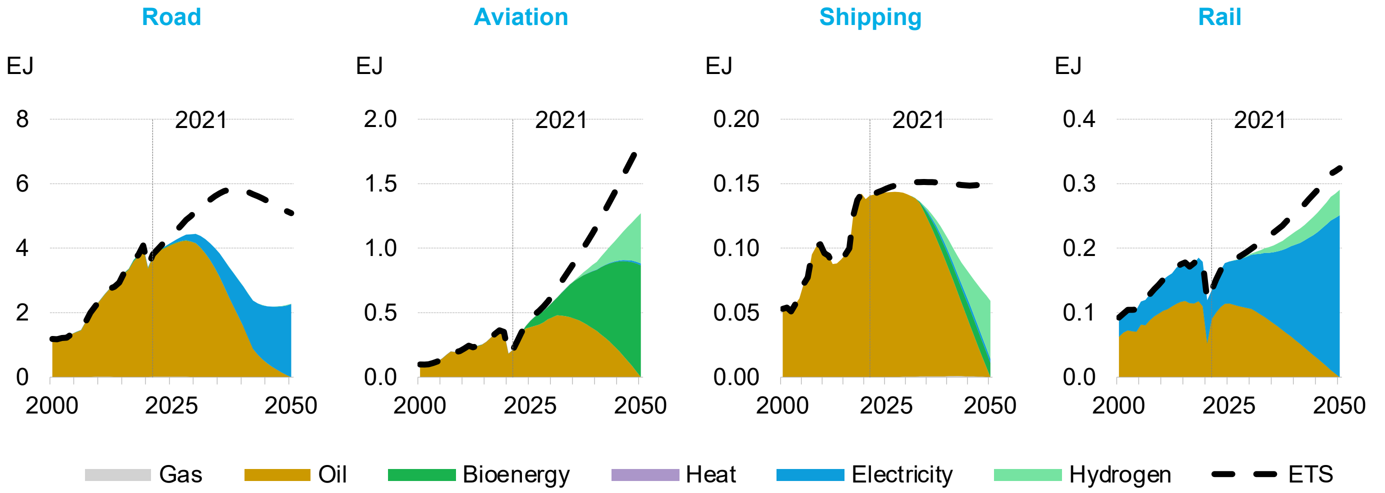
In the NZS, CCS plays a significant role in decarbonizing cement, with the technology contributing 56% of abated emissions from the sector between 2022 and 2050. However, CCS only takes off post-2030. Over 2022-30, bioenergy and electrification together account for 99% of the sector's abated direct-use emissions. Between 2031 and 2050, they account for 21% of emissions abated as the adoption of CCS accelerates[17].

7.2. Transport

Under the NZS, India's direct CO2 emissions from the transport sector are set to peak in 2028, on account of declining road transport emissions. The road segment is the largest emitter of CO2 within transport responsible for 89% of emissions in 2021. In shipping, emissions peak in 2027. In aviation, an increasing share for sustainable aviation fuels in final energy consumption sees direct CO2 emissions peak in 2031. In rail, emissions peak in 2025.

[17] *Circular Strategies for Construction and Demolition Waste* (web | terminal)

Figure 52: India's final energy consumption by transport sub-sector, Net Zero Scenario



Source: BloombergNEF. Note: y-axes differ in scale. Bioenergy in Aviation is sustainable aviation fuel. ETS – Economic Transition Scenario.

India's passenger vehicle fleet to be all-electric by 2050 under the NZS

Electrification of road transport is the key driver of decarbonization. Relative to the ETS, we see an even faster uptake of EVs in the NZS: by the late 2030s, 100% of all new passenger vehicle sales are EVs. By 2050, 100% of India's vehicle fleet is electric. The higher cost of hydrogen fuel cell vehicles makes their uptake insignificant in India. See the India Road Transport Electrification Outlook 2022 (web | terminal)

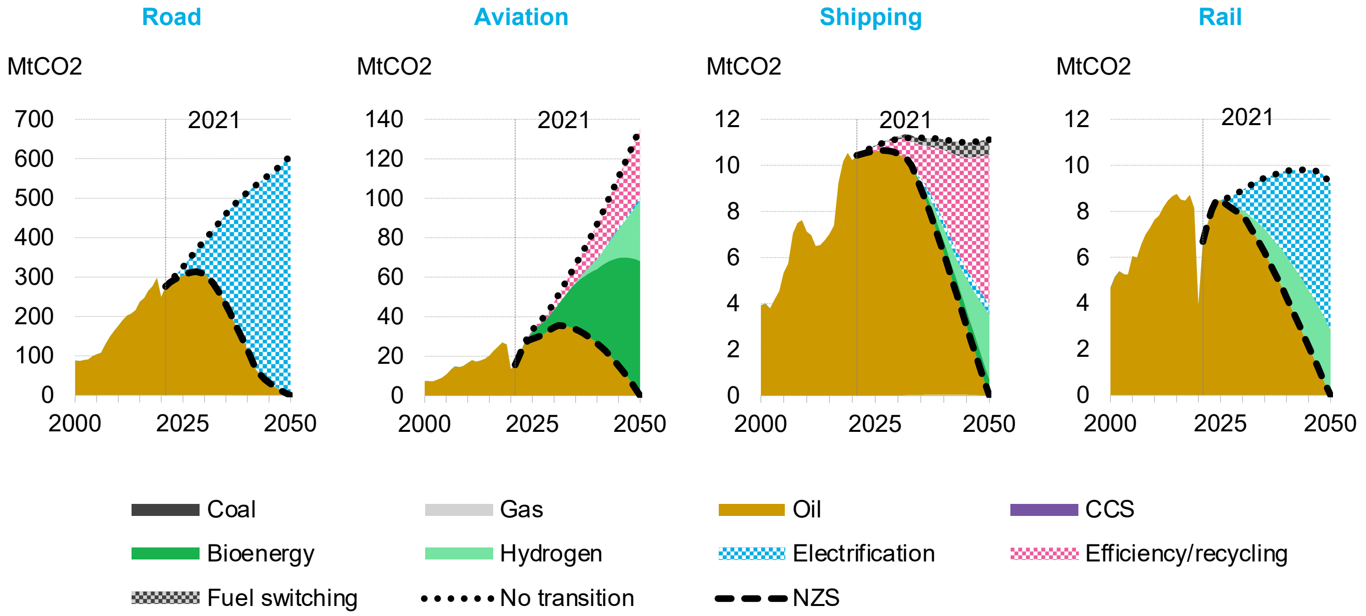
Differences in BNEF's Net Zero Scenarios for road transport

Our Net Zero Scenario for road transport in this report differs from that in our *Electric Vehicle Outlook 2023 (EVO)* (web | terminal). The EVO 2023 report charts a possible pathway to achieve a global vehicle fleet with no direct tailpipe CO2 emissions by 2050, but without meeting a carbon budget or global warming target. Its outcome is best understood as achieving a net-zero-capable fleet by 2050.

In contrast, in the New Energy Outlook, all sectors in the energy economy need to reach carbon neutrality and must collectively stay within a global temperature target. For the road transport sector, this means a 1.75C-aligned sectoral carbon budget, which requires an even more rapid switch to zero-emission vehicles, particularly in the late 2020s and early 2030s, as well as other measures. The result is a steeper uptake of annual EV sales across all road transport sub-sectors, impacting investment requirements, metals demand and other results. The transport sector results in the NEO NZS are best understood as a 1.75C-compliant fleet.

In Indian aviation, our Net Zero Scenario sees an expansion in the use of sustainable aviation fuels (SAF) in this decade. SAF is shown as 'bioenergy' in the chart below. By 2030, 20% of aviation fuel is met by SAF. By 2050, SAF grows to 68%. From 2035 onward, hydrogen aircraft emerge to serve on short- to medium-haul distance flights, reaching 31% of total fuel use in 2050. Electric planes are niche, only being used for commuter and regional flights. They represent 1% of fuel use in 2050. Across all segments, better airplane fuel efficiency and per-passenger efficiency contribute to a 31% efficiency improvement on final energy in comparison to the ETS, lowering overall fuel demand.

Figure 53: India's end-use CO2 emissions in transport subsectors, Net Zero Scenario



Source: BloombergNEF. Note: y-axes differ in scale. Bioenergy in Aviation is sustainable aviation fuel. NZS – Net Zero Scenario, CCS – Carbon capture and storage.

In shipping, the strongest lever to reach net-zero is greater efficiency, with operational and technical improvements accounting for 62% of emissions abatement in the sector in India by 2050. On the operations side, this includes more efficient vessels, vessel operation and better route optimization. The cargo industry is already relatively efficient, but there is room for improvement in the container sector. Lower travel speed ('slow steaming') can also improve fuel economy. On the technical side, hull retrofits, turbulence/drag reduction and better engine design are key measures to improve efficiency. But operational improvements are expected to deliver greater gains than technical enhancements.

The deployment of marine vessels running on LNG is negligible in India. Oil-fired vessels are replaced by ships using hydrogen-derived fuels like ammonia and methanol (labeled as 'hydrogen' in the chart above) as well as biofuels, which start to emerge from the mid-2030s. Hydrogen-derived fuels represent 76% of fuel use in Indian shipping by 2050, followed by 19% bioenergy and 5% electricity. Electric ships are mostly used to serve domestic routes and, to a lesser extent, spoke routes.

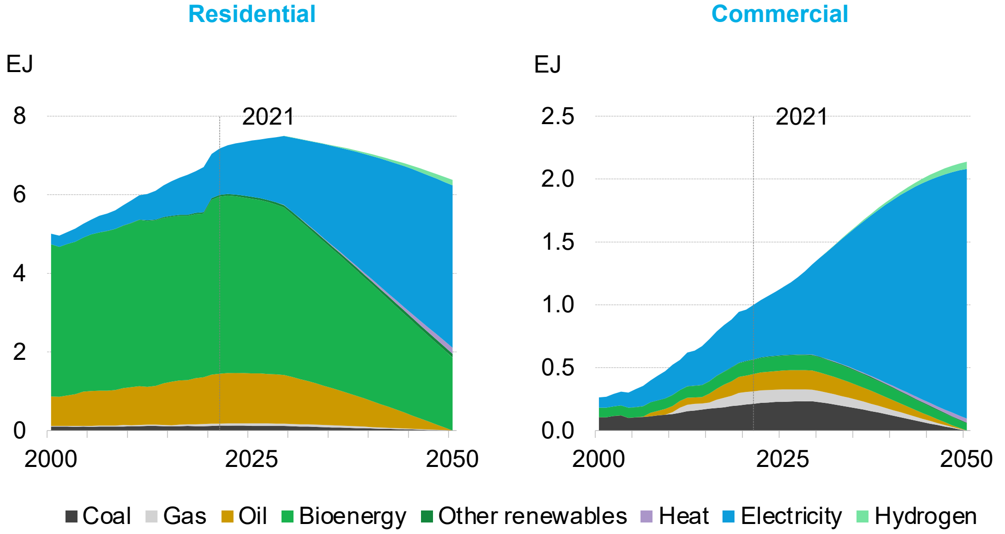
Electrification of rail is the most effective technology to reduce India's emissions in this sector: 69% of abatement comes from electrifying diesel trains, resulting in 86% electricity use in final consumption in 2050. Hydrogen is used wherever building overhead lines is uneconomic; its fuel use is 14% in 2050.

7.3. Buildings

Final energy consumption in India's buildings sector is expected to rise in the NZS from 8,177PJ in 2021 to 8,515PJ by mid-century thanks to the use of more efficient appliances and improved building design.

Under the NZS, energy consumption peaks in 2029 at 7,498PJ for residential buildings, whereas commercial buildings continue to increase energy consumption till 2050.

Figure 54: India's final energy consumption by building sub-sector, Net Zero Scenario



Source: BloombergNEF. Note: Other renewables includes solar thermal.

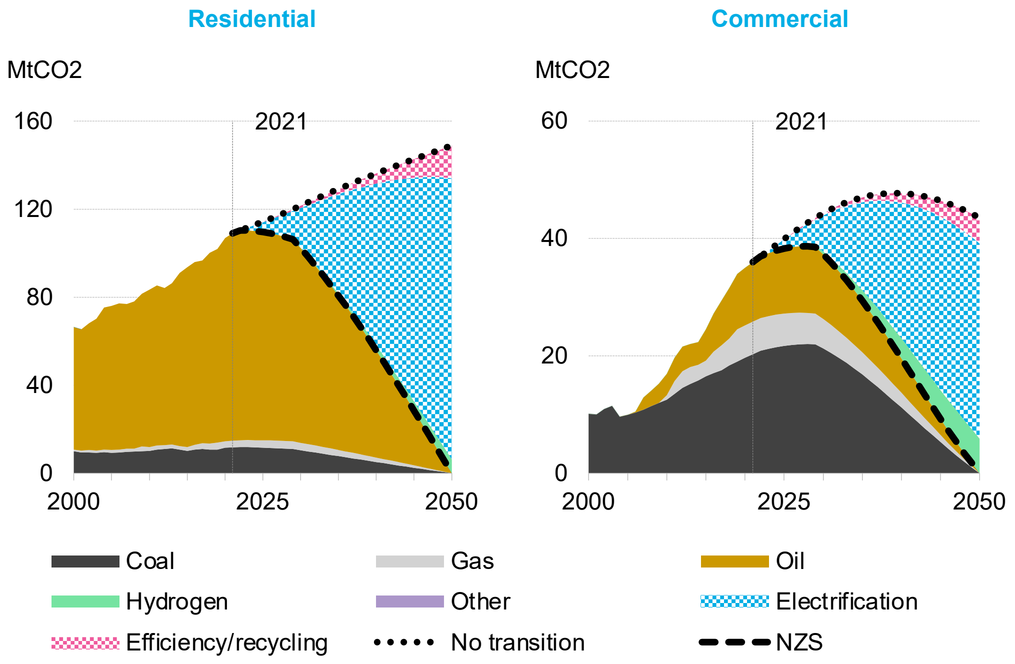
Electrification is an essential route to decarbonize the buildings sector. Electricity consumption in buildings accounts for 65% of final energy in residential buildings and 93% of energy in commercial buildings in 2050.

Electricity share in final energy demand grows from 20% in 2021 to 72% by 2050 under the NZS

The deployment of heat pumps where appropriate and electric cooking over bio-based fuels provides around 90% of buildings' emissions abatement to 2050 in India. Improved building efficiency, both from new construction and higher renovation rates, provides 7%.

Electricity provides the largest share of final energy to the buildings sector in India, growing from 20% in 2021 to 30% by 2030, and then 72% by 2050. Bioenergy declines from 56% of final energy in 2021 to less than a quarter in 2050.

Figure 55: End-use CO2 emissions in buildings sub-sectors by type/technology, Net Zero Scenario



Source: BloombergNEF. Note: NZS – Net Zero Scenario.

Section 8. Fuel demand

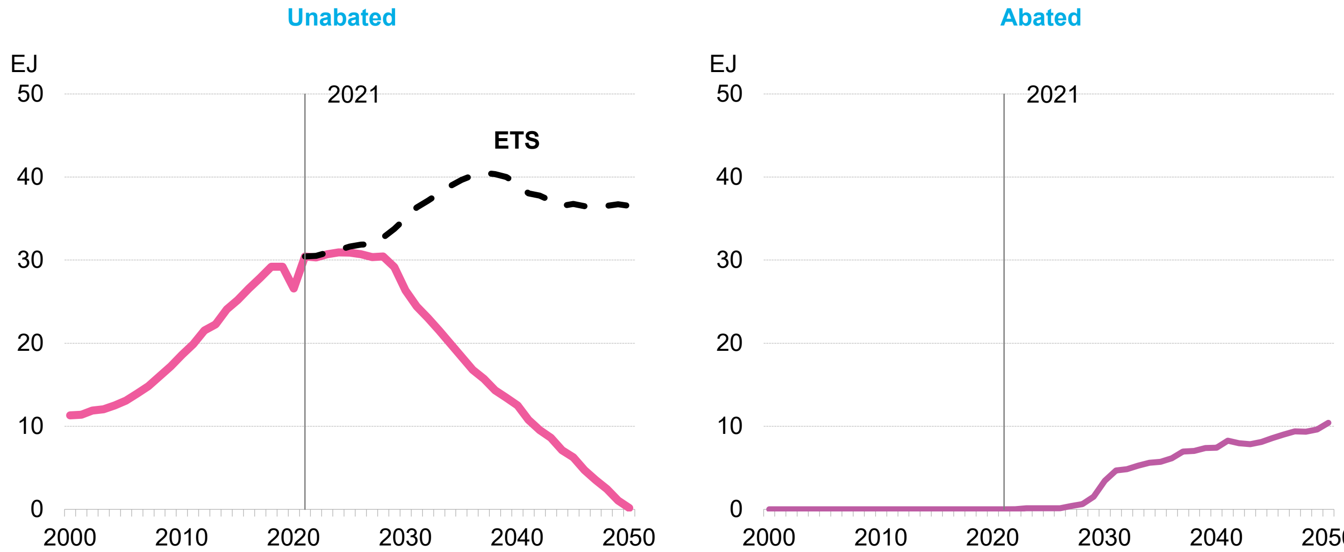
Coal demand needs to peak by the mid-2020s in order for India to get on track for net zero. By 2050, fossil fuels continue to be used in conjunction with CCS and as feedstock for industrial purposes. Hydrogen grows to become a major fuel after 2030 to decarbonize hard-to-abate sectors, such as steel.

Fossil fuel demand in India is yet to peak

Unabated fossil fuel use is expected to peak by the middle of this decade (Figure 56) in the NZS. From the peak, unabated fossil fuel consumption falls on average 18% per year until 2050 under the NZS. Clean energy processes and technologies rapidly displace carbon-intensive equivalents in our NZS, but fossil fuels still play a role in 2050 (albeit much diminished), either with emissions abatement (CCS) or as a feedstock.

CCS technologies without additional policy support are almost always more expensive than conventional processes, and so abated fossil fuel for energy use remains negligible in the ETS.

Figure 56: India's fossil fuel use for energy use in Net Zero Scenario



Source: BloombergNEF. Note: Does not include use of fossil fuels as feedstock. Abated fossil fuel use is energy use where CO2 emissions from fuel combustion are captured with carbon capture and storage.

Coal consumption in 2050 drops to 42% of demand in 2021 under the NZS

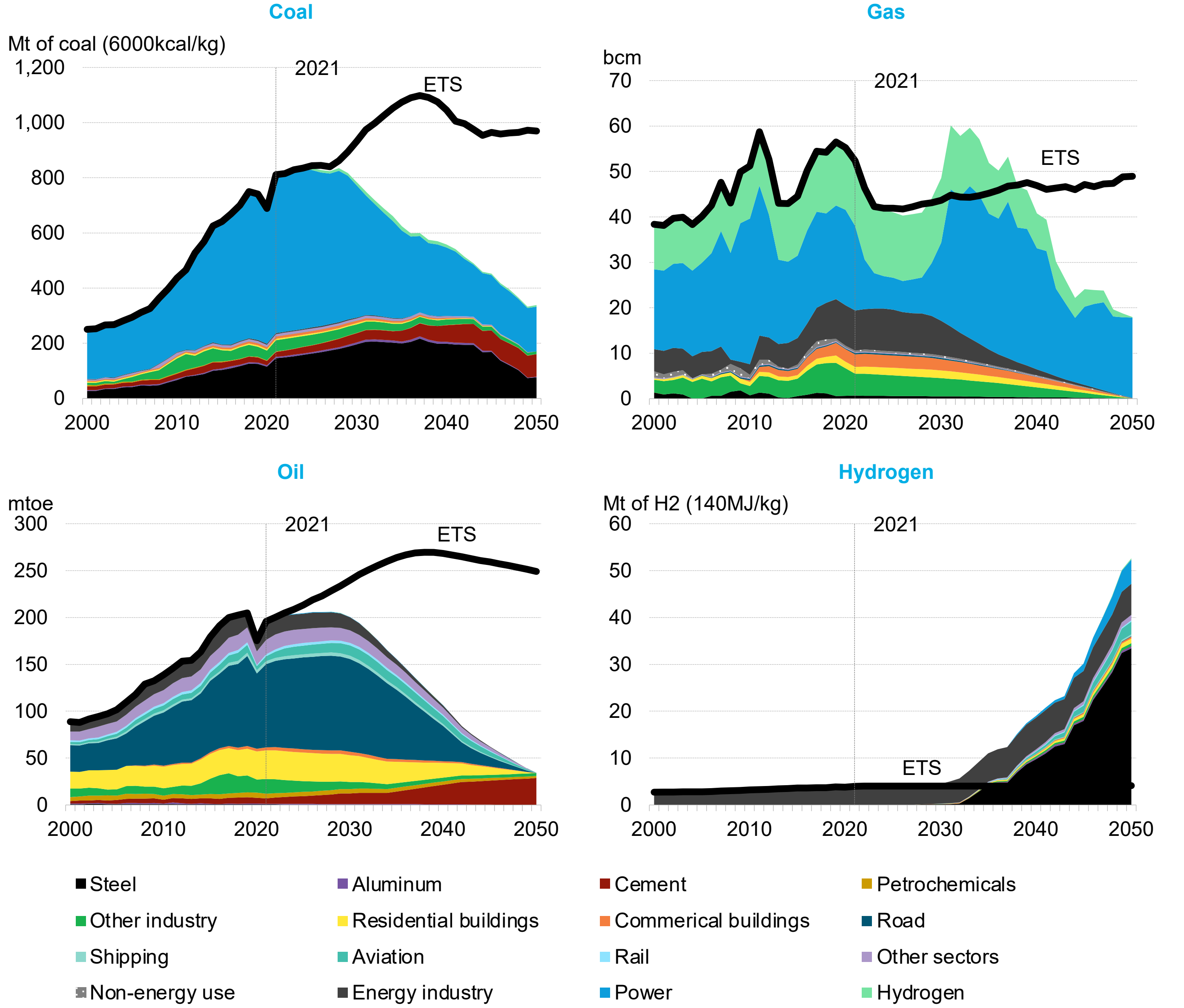
In 2050, under the NZS, India consumes around 339Mt of coal (6,000kcal/kg), equivalent to 42% of demand in 2021 (Figure 57). Under the ETS, the consumption in 2050 is 970Mt of coal, equivalent to three times the consumption in the NZS.

India's gas use declines by 66% from 2021 levels by 2050 in the NZS, while it remains relatively flat in the ETS. In the NZS, demand stands at just 18bcm by mid-century – a 70% decline from the peak in the early 2030s. India experiences no significant coal-to-gas switch in power in the NZS due to the relatively higher costs of gas compared with coal. In late 2020s, existing coal and gas capacities are retired or retrofitted with CCS.

Oil use declines the most of all energy commodities in the NZS, falling 83% from 2021 levels compared to an increase of 27% in the ETS. This is due to a complete phase-out in the transport sector and the availability of alternative clean technologies, like hydrogen, in the NZS.

By 2050, India's domestic demand for hydrogen increases nearly 13 times to 53Mt of H2 (140MJ/kg) under the NZS. Consumption rises rapidly during the last two decades in the scenario to meet the carbon constraint to approximate net zero emissions. In the ETS, where the relative economic competitiveness of technologies is the primary driver for adoption, hydrogen demand remains flats through 2050 as there are no additional applications on economic grounds other than existing legacy applications.

Figure 57: Fuel use in India by sector, Net Zero Scenario



Source: BloombergNEF. Note: Historical and current hydrogen demand is estimated based on petrochemical feedstock production. ETS – Economic Transition Scenario

BloombergNEF

Section 9. Investment

Large investments in energy infrastructure are needed in both the Economic Transition Scenario and Net Zero Scenario. The total investment opportunity in India over the next three decades is around $7.6 trillion in the ETS, with annual spending reaching more than a quarter of a trillion dollars. Cumulative investment in the NZS is 67% higher at $12.7 trillion, equating to an average annual spend of $438 billion between 2022-50. The investment analysis covers low-carbon and fossil fuel supply-side investments, as well as low-carbon demand-side investments in transport, buildings and industry.

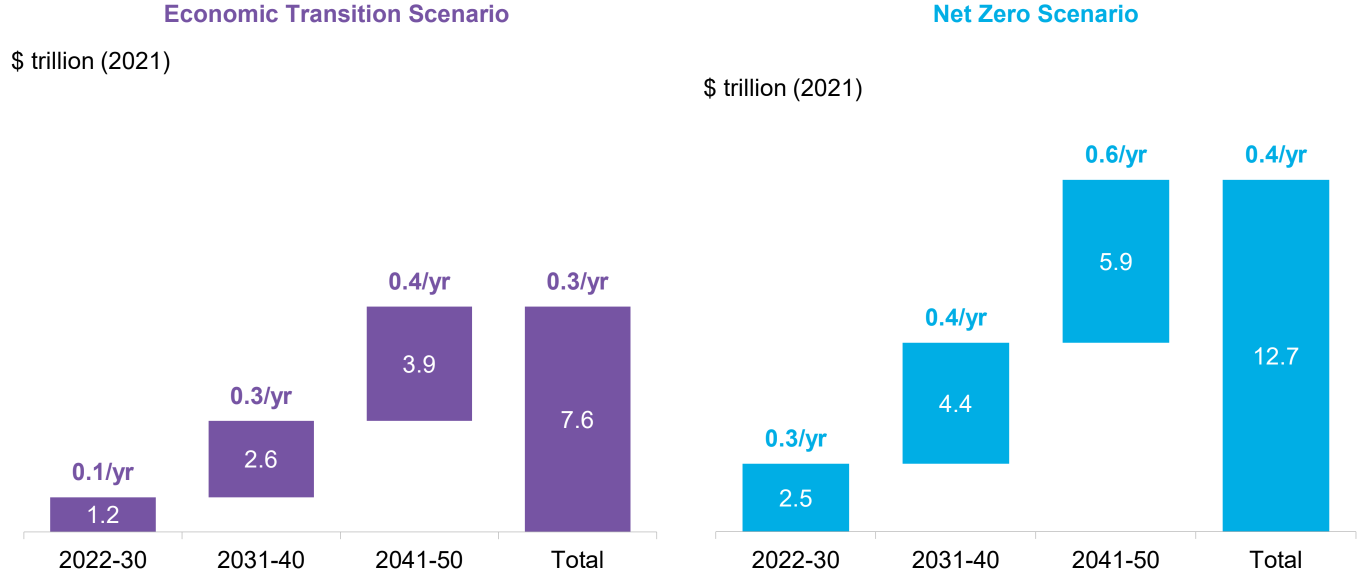
India must significantly ramp up energy transition spending

The investment required to power the transition falls into two broad categories: energy supply and demand. Historically, greater emphasis has been placed on the supply side to shift expenditure from fossil fuels to low-carbon sources of energy. However, the dramatic increase in spending flowing toward the rollout and sale of EVs signifies the investment potential on the demand side.

Reaching net zero by 2050 requires spending of $438 billion per year

Investment in energy supply and demand in the ETS requires $262 billion to be spent on average each year. Reaching net-zero emissions by mid-century increases the annual average spend to $438 billion per year in the NZS (Figure 58). A substantial shift and acceleration in capital deployment is needed to decarbonize India’s economy, which will establish new sectors, particularly on the demand side, as major investment opportunities.

Figure 58: Investment in India’s energy supply and demand



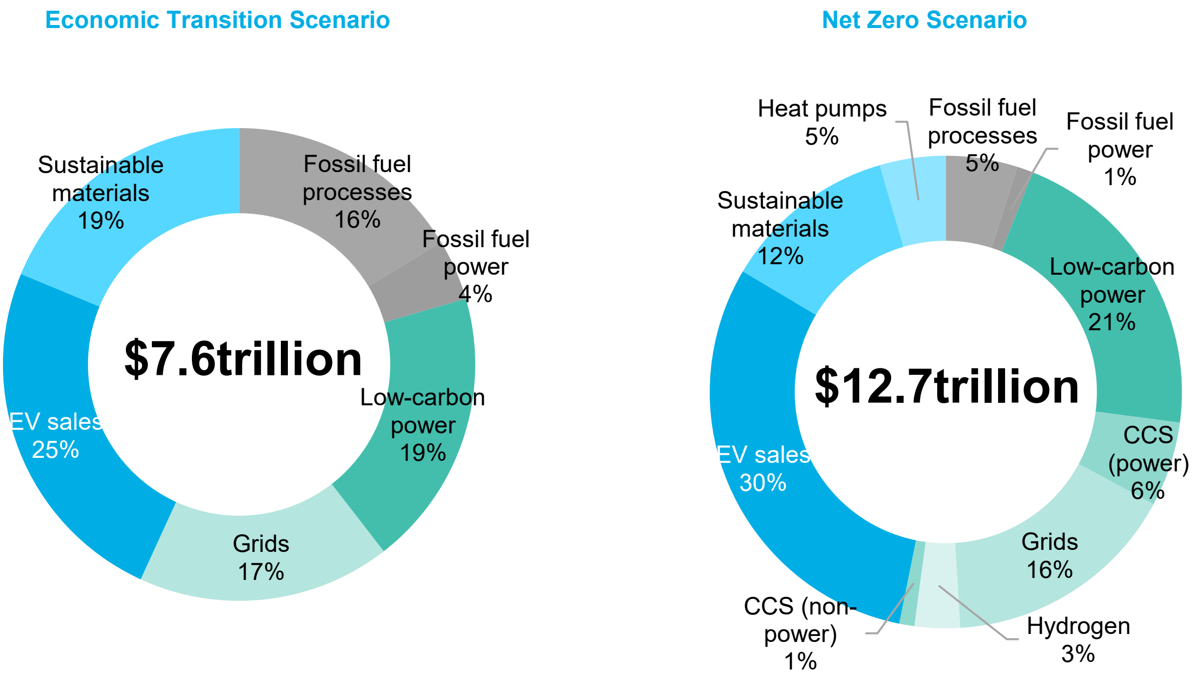
Source: BloombergNEF. Note: The numbers inside the bars show the annual investment in each decade and the ones above indicate average annual investment.

The contrasting level of ambition and net-zero compliant sector carbon budgets across the two scenarios are not only reflected in the total amount of capital deployed, but also in how the investment is split across sectors. The NZS sees a cumulative spend of $3.4 trillion on low-carbon power and CCS in power generation by mid-century, equivalent to 27% of the scenario's overall capital expenditure. That is nearly 2.5 times the $1.4 trillion investment in this area in the ETS. The ETS sees no spending on CCS.

Conversely, capital requirements for fossil fuel processes total $1.2 trillion in the ETS, representing 16% of overall investment. This drops to $0.6 trillion and a 5% share in the NZS, demonstrating India's shift from reliance on these conventional sources of energy.

In both scenarios, the growing uptake of EVs represents significant spending, amounting to $64 billion per year on average in the ETS and $133 billion per year in the NZS, between 2022 and 2050. In cumulative terms, reshaping India's mobility to run on electric powertrains creates an investment opportunity of $1.9 trillion and $3.9 trillion in the ETS and NZS, respectively, accounting for around 25-30% of total spending between now and 2050.

Figure 59: India's investment in energy supply and demand from 2022 to 2050



Source: BloombergNEF. Note: CCS – Carbon capture and storage. "CCS (power)" includes carbon capture and storage investment for fossil fuel plants and CCS equipment. "CCS (non-power)" includes CCS equipment in blue hydrogen production and industry as well as transport and storage across all sectors. Fossil fuel processes refers upstream, midstream and downstream components of coal, oil and gas processes. Sustainable materials refers to investment in recycling facilities for aluminum, cement, plastics and steel.

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Client enquiries:

- Bloomberg Terminal: press <Help> key twice
- Email: support.bnef@bloomberg.net

Siddharth Shetty	Analyst, India
Allen Tom Abraham	Head, Sustainable Materials
Shantanu Jaiswal	Head of Research, India
David Hostert	Head of Modeling and Energy Economics

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