In the agricultural sector, a complete phase-out of diesel pumps is needed to support the net-zero transition, replaced by solar and electric pumps. The current momentum in using solar pumps for irrigation in agriculture needs to continue so that by 2050 most water can be pumped without generating emissions.

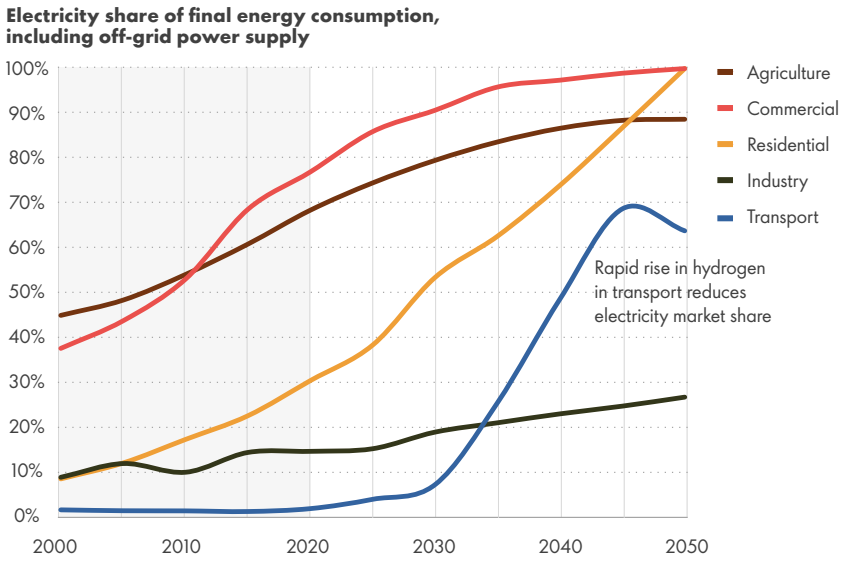
Electric tractors are a potential alternative for decarbonising land preparation activity. Electric tractors, though not fully commercialised, are gaining in popularity in India but are mostly lower-powered models which are currently best suited to battery technology. By mid-century, at least 30% of agricultural tilling should be by electric tractors and the rest by tractors running on biofuel-blended diesel.

The transport sector should adopt the highest possible levels of electrification in all vehicle segments to decarbonise, with rapid progress needed. All two and three-wheeler vehicles should be completely electric by 2030 and the sale of larger passenger vehicles should be restricted to electric only by 2030.

Bus fleets should also be largely electric by 2050, but with support from bio-compressed natural gas – a carbon-neutral fuel – for that fraction of the fleet serving long-distance routes. Railways (both passenger and freight) should also be completely electrified to support the transition to net-zero emissions. Many heavy commercial vehicles should also be electrified, although this may be constrained by payload capacity, in which case hydrogen-powered fuel cell electric vehicles could provide a solution.

In the commercial sector, cooking in hotels and restaurants is the major source of direct emissions. However, commercial establishments are more amenable to policy and regulatory interventions, making it possible to make a complete transition to electric cooking by 2050.

Figure 6: Opportunities to electrify exist in every sector



Source: TERI analysis

> All two and three-wheeler vehicles should be completely electric by 2030 and the sale of larger passenger vehicles should be restricted to electric only by 2030.

Dependence on kerosene and biomass for lighting and cooking in the residential sector has decreased rapidly in recent years through increased electrification and awareness of the health impacts from burning biomass indoors. Cooking fuels have shifted to liquefied petroleum gas and piped natural gas, but the **NZE** scenario requires a complete shift to electric cooking in both urban and rural areas to achieve its goal.

There is also opportunity for electrification in industry, such as the use of electric-arc furnaces for steel recycling, but heavy industry processes such as cement manufacture will still require high-temperature combustion of fuels.

In the **NZE** scenario, nearly 90% of the generation mix comes from renewables by 2050, but this depends on regional grid connectivity and the development and deployment of grid-scale electricity storage for managing solar intermittency. A further feature of the scenario is the sheer scale of electricity infrastructure development: in the space of 30 years the power system grows by a factor of more than four. Similar growth has been the case over the last 20 years, although from a much smaller base.

A hydrogen economy emerges

Although electricity becomes a growing and important energy carrier in India, electrification of all energy services remains elusive. This is not purely an issue in India but a global one. Some industrial processes and various forms of heavy transport need very high temperatures or very high energy-density fuels, which cannot be delivered by electricity technologies in the near term. For a rapidly developing industrial economy like India, this is a crucial factor.

Hydrogen emerges as the solution in the **NZE** scenario. It can be burned directly in furnaces, used to reduce iron ore and offers an alternative to battery-electric systems for heavy transport when used in a fuel cell electric vehicle. Green hydrogen can be produced by electrolysis using renewable energy. While the technologies to deliver a green hydrogen economy exist, scaled deployment into a viable operating network is yet to take place anywhere in the world.

The hydrogen economy begins to operate in the early 2030s, putting India at the forefront of emerging hydrogen industrial technologies.

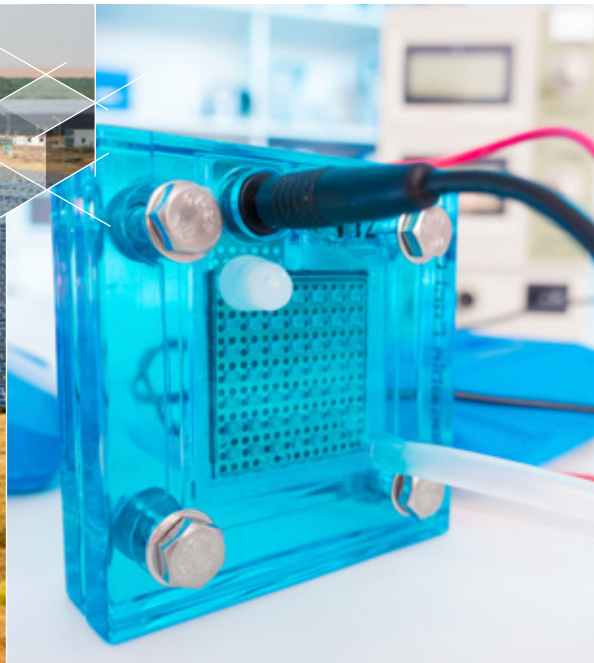
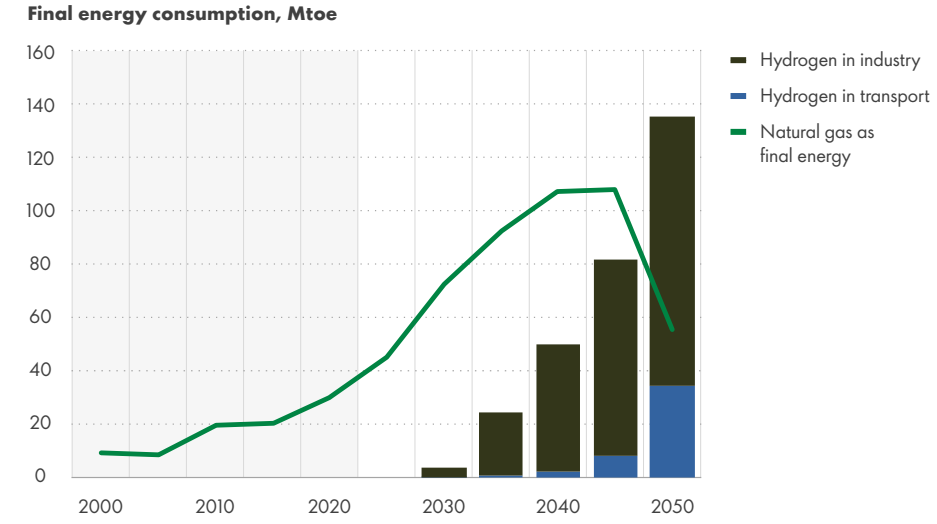


Figure 7: Hydrogen plays a key role in decarbonising industry and transport sectors



Source: TERI Analysis

Businesses will need to take their decisions on hydrogen before the mid-2020s to allow sufficient time for the planning, development and construction of facilities operating with hydrogen in the 2030s. India could become the country to build the first commercial-scale hydrogen-based industries, such as for iron ore smelting, using the early work done on piloting in the EU.

Hydrogen in the transport sector begins to emerge at scale between 2040 and 2045, although the first trucks appear in the mid-2030s. By 2050 some 3 million hydrogen-fuelled trucks are on the road and hydrogen as a final energy carrier exceeds the use of natural gas.

The development of hydrogen as an energy carrier highlights the need for sector-based cooperation within the overall transformation. Those companies developing energy services need assurance that hydrogen supply will be available, and those companies producing hydrogen need to know there will be demand for their product. Coalitions between different parts of the business community, supported by government, can give impetus to sectoral change and in some cases, like hydrogen, are essential to its development.

Transforming biomass use

Across India today, traditional biomass is a major form of energy. Cheap and readily available, it is used for both commercial activities and in many homes, where it makes up more than two-thirds of residential energy use, mainly in rural areas. Using it in the home results in poor indoor air quality and can lead to various health issues.[12]

The **NZE** scenario envisages a transformation in biomass use with much greater cultivation of biomass for liquid fuels, biogas and direct combustion for industrial purposes. Biomass use in homes is replaced by electricity, delivering significant health benefits.

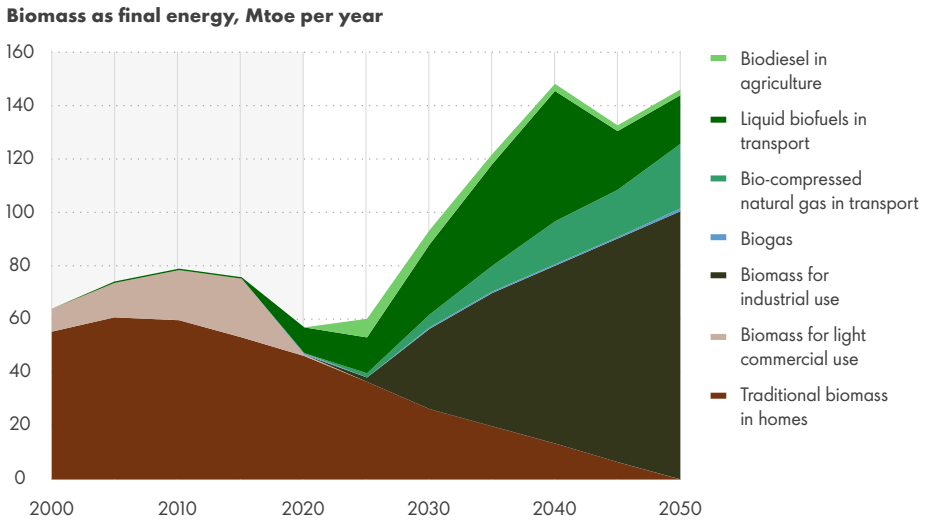
> Biofuel use declines across India as 2050 approaches, due to the shift to electricity and hydrogen in transport.

In the years leading up to 2020, commercial biomass is primarily used for combustion by small enterprises, but this progressively declines as local clean air regulations push businesses towards electricity, LPG and CNG. As larger industries seek to decarbonise, commercial biomass emerges again as an important fuel for some process industries that use cleaner and more efficient combustion technologies.

Up to 2050, the only practical route for decarbonisation of aviation is to make use of sustainable aviation fuels sourced from biomass. While hydrogen could transform the sector in the second half of the century, that will not be possible in the medium term. Transport via inland waterways and coastal shipping could benefit from biodiesel, but electricity and hydrogen fuel cells may also play a role in reducing emissions.

In the **NZE** scenario, liquid biofuel use peaks around 2040, reaching a level close to that of petroleum in transport in 2005-10. Biofuel use declines across India as 2050 approaches, due to the shift to electricity and hydrogen in transport. Unused production capacity provides the country with an opportunity to export biofuels across the region.

Figure 8: Bioenergy is transformed, primarily fuelling transport and industry by mid-century



Source: TERI analysis