New Energy Outlook 2020

Executive Summary

October 2020

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Welcome to the 2020 New Energy Outlook

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The New Energy Outlook (NEO) is BloombergNEF's annual long-term scenario analysis on the future of the energy economy.

This year we have gone beyond our traditional focus on the electricity sector, to include detailed chapters on industry, buildings and transport and offer a full-coverage assessment of the energy economy and its drivers to 2050. We hope this will make NEO an even more valuable input to support strategy development and long-term planning.

One of the things that sets NEO apart is its focus on technology. This includes proprietary project data, market-price surveys and detailed, bottom-up, component-by-component project-cost modeling. Another is coverage of consumer uptake for electric vehicles, small-scale PV, batteries and heat pumps, and in particular how falling costs and growing market penetration creates imitation effects that can drive exponential growth. The study leverages the Bloomberg Terminal for commodity prices, asset data, industry fundamentals, financing rates, macroeconomic forecasts and trade-flow information. And finally, NEO is built by more than 65 analysts from 12 countries who help construct a bottom-up, sector-by-sector and country-by-country analysis from which our global conclusions emerge.

The New Energy Outlook 2020 has three major components:

1. The Economic Transition Scenario (ETS) is our core economics-led scenario that employs a combination of near-term market analysis, least-cost modeling, consumer uptake and trend-based analysis to describe the deployment and diffusion of commercially available technologies. Over the long-term we remove policy drivers to uncover the underlying economic fundamentals of the energy transition. As such, this scenario does not bake in climate targets, nor does it mandate aspirational national energy policies

2. Our NEO Climate Scenario (NCS) investigates pathways to reduce greenhouse gas emissions to meet a well-below-two-degree emissions budget. This year we have focused on a clean electricity and green-hydrogen pathway. In future analysis we will look at other pathways to deep decarbonization.

3. The final section is called Implications for Policy. This offers the BNEF perspective on some of the most important policy areas that emerge from our ETS and NCS scenarios.

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Energy & Emissions

Energy

Energy - 1.

Total final energy use in our Economic Transition Scenario rises 24% from 419EJ in 2019 to 516EJ in 2050. This is around 0.7% year-on-year. The Covid-19 pandemic pushes final energy demand down 5% in 2020, before demand returns to pre-crisis levels in 2022.

Energy - 2.

Building energy grows most in our Economic Transition Scenario, up 42% to 2050. Roughly 58% of the growth in absolute terms comes from the residential sector, although demand from commercial buildings grows faster. Final energy use is up 22% in industry, with growth in all energy-intensive sectors. Steel sees the least increase, thanks to a 45% jump in recycling, which has one-fifththe energy intensity of production.

Energy - 3.

Final energy in transport sees the most change. It peaks in 2035 and then falls 0.6% year on year to 2050, when it is just 5% above 2019 levels. This is due to the road sector, where demand is eroded by the combination of more energy efficient electric vehicles, tighter fuel-economy standards for internal combustion engine vehicles and, crucially, a slowdown and decline in new global new car sales driven by demographic shifts, urbanization, and shared mobility. Final energy for aviation is up 95% and rail rises 33%. Shipping slips 2% from a peak in 2037 as a result of slowing growth in global cargo-ton miles, and a gradual increase in fleet fuel efficiency.

Energy - 4.

Fossil fuels drop from 67% of total final energy in 2019, to 61% in 2050. The use of oil products declines by 3%, from 41% of final energy in 2019, to 32% in 2050. Electricity use is up 50% over the outlook, accounting for 24% of final energy in 2050, up from 20% in 2019. Part of this is the shift to electric vehicles, which pushes up electricity use in road transport by a factor of 45 from 2019 levels. More significant in absolute terms, however, is the 60% growth in electricity use in buildings, which expands with population and GDP.

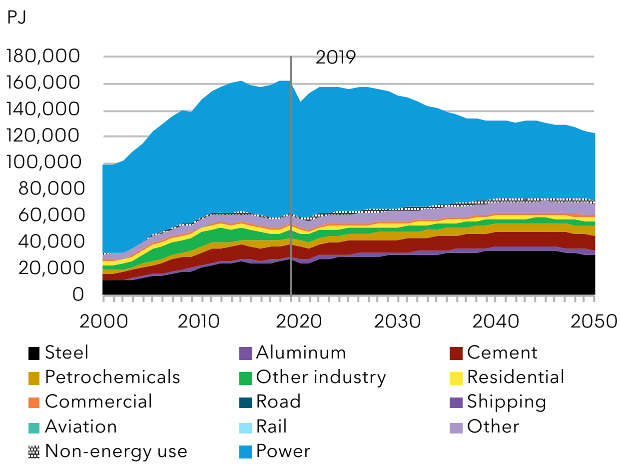
Energy - 5.

Primary energy grows 9% to 679EJ in 2050, from 623EJ in 2019. Fossil fuels grow less than 1% over the period in absolute terms, however, their share of the primary energy mix falls from 80% to 70%. In contrast, renewable energy increases by a factor of more than four to make up 14% of primary energy, compared with 4% today. Nuclear and bioenergy and zero-emissions sources together account for 27% of the primary energy supply in 2050, from 17% today.

Energy - 6.

Primary oil demand peaks in 2035 at 211EJ as growth in petrochemicals and aviation is offset by decline in road transport and better machine efficiency. From there it drops 0.7% year on year to return to 2018 levels, at 189EJ, in 2050. At this time it makes up 28% of primary energy.

Figure 1: Primary coal demand, by end-use sector



Source: BloombergNEF

Energy - 7.

Primary coal demand appears to have peaked back in 2018. This coincides with the peak in coal-fired power generation, as demand for thermal coal, hit hard by the Covid-19 pandemic, struggles to return to pre-crisis levels. In 2050, coal is down 24% from 2019 levels and makes up just 18% of primary energy.

Energy - 8.

Gas demand grows 0.5% year on year throughout our Economic Transition Scenario. Decline in the power sector is met with ongoing growth in buildings and industry, where there is a lack of cost-competitive low-carbon alternatives. In 2050, gas demand is up 15% but it still makes up just 24% of primary energy.

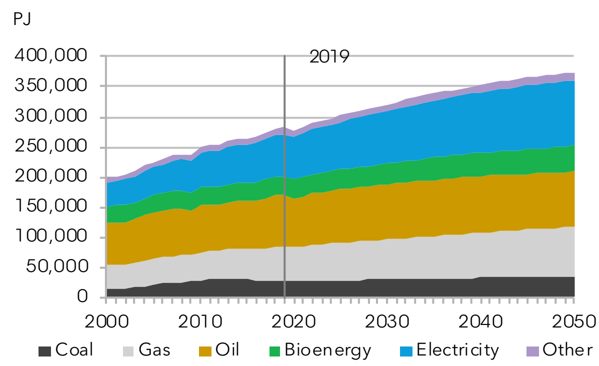
Energy - 9.

At present, around 28% of primary energy is lost in its transformation to final energy. The majority of this is in the power sector, where most coal and gas-fired generators are between 35% and 47% efficient. Losses decrease over time from 33% in 2019 to 24% in 2050 as a result of renewables growth. Similarly, losses in final energy are around 33% in 2019. The vast majority of these come from the transport sector, from the use of diesel and gasoline in conventional internal combustion engine vehicles that are between 12% and 40% efficient.

Energy - 11.

Considered together, around 55% of primary energy is wasted either in the production of electricity, refined fuels, or in end-use machines. The vast majority of these losses come from the use of coal, gas and oil. The difference between final and useful energy shows how end-use electrification reduces energy demand for the same output. In other words, we can do the same with less. In addition, using more renewable energy reduces the energy throughput between primary and final energy.

Figure 2: Total useful energy, by source



Source: BloombergNEF

Energy - 12.

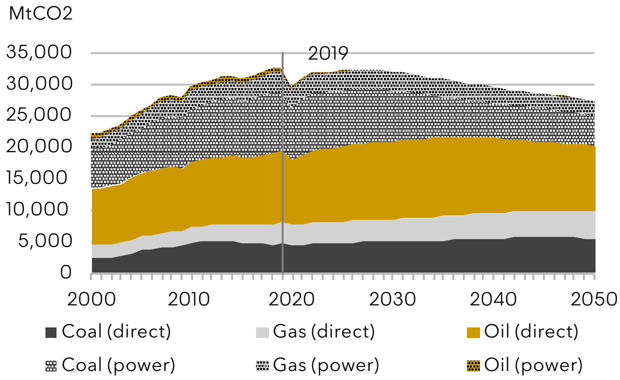
Looking at primary energy can also mask rapid changes downstream, where growth is occurring from a low base. For example, renewables made up just 4% of primary energy in 2019, far smaller than oil, which was at 32%. With downstream losses taken into account, we see a more balanced picture, with wind and PV together growing to 19% of useful energy in 2050 in our Economic Transition Scenario, compared to oil, at 25% and gas, at 22%.

Emissions

Emissions - 1.

Emissions from fuel combustion in power, transport, industry and buildings peak in 2019 at 31.9GtCO2 in our Economic Transition Scenario, as the energy transition in the power sector offsets growth in the end-use sectors. Energy emissions drop 8.6% in 2020 as a result of the Covid-19 pandemic and then rise again to a lower peak in 2027. Emissions then fall at around 0.7% per year to 26.8GtCO2 in 2050, which is 16% below 2019 levels.

Figure 3: Global CO_2 emissions from fuel combustion, by source



Source: BloombergNEF

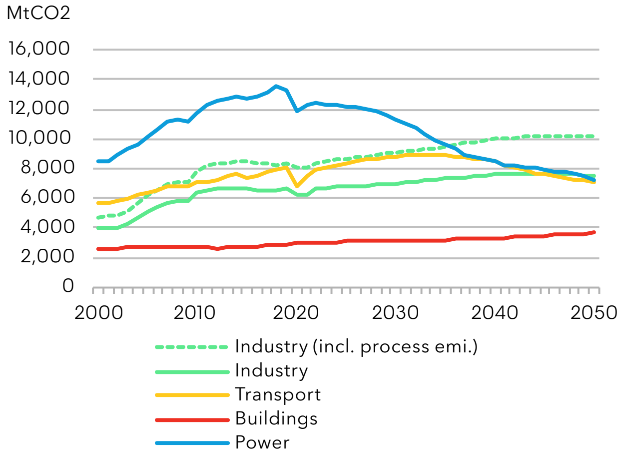
Emissions - 2.

The power sector currently makes up around 42% of emissions from fuel combustion, split mostly between coal and gas. Emissions from power drop furthest, having peaked in 2018, the same year as coal, they decline 2% year on year to 2050. By then emissions are down 46% from their peak and account for 27% of emissions from fuel combustion.

Emissions - 3.

Emissions from all transport peak in 2033, two years after the road segment, as a result of ongoing growth in aviation and shipping. Emissions from fuel combustion in buildings grows steadily at 0.7% year on year from 9% of emissions in 2019 to 14% in 2050.

Figure 4: Global CO_2 emissions from fuel combustion, by sector



Source: BloombergNEF

Power

Power - 1.

The Covid-19 pandemic has brought forward a triple peak in the power sector. Despite a post-crisis recovery, coal use and emissions both peak in 2018 and gas in 2019, under our Economic Transition Scenario, and don't return to pre-Covid levels. Power demand in 2020 is down 5%, and returns to 2019 levels again by 2022. Overall, the pandemic reduces cumulative power-sector emissions by 12% through 2050, the equivalent of getting back almost three years' worth of emissions to tackle climate change.

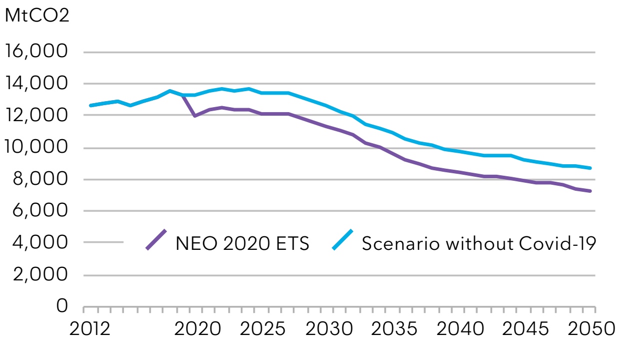
Power - 2.

Wind and PV supply 56% of electricity globally in 2050, up from 9% today, with nuclear, hydro and other renewables providing a further 20%, under our Economic Transition Scenario. This takes zero-carbon sources to 76%. Cheaper solar, wind and batteries drive a ten-fold increase in variable renewables generation over the next 31 years. Fossil fuels fall to just 24% of generation over the same period, down from 62% today.

Power - 3.

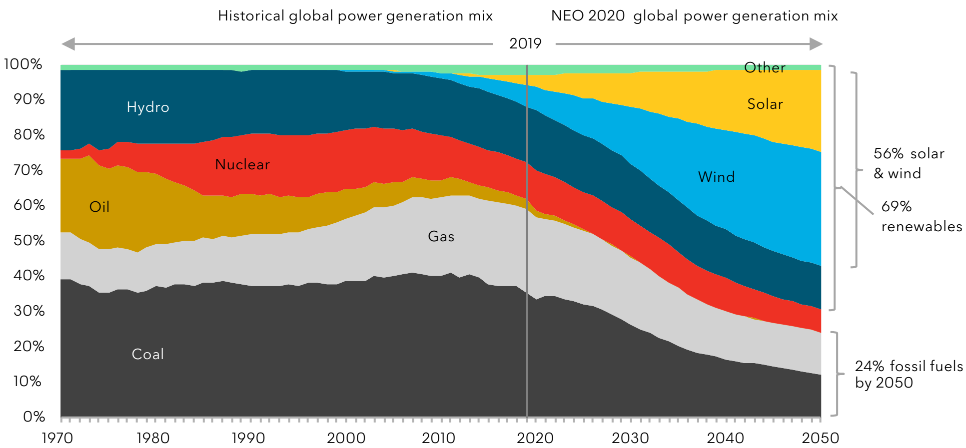
This transition is driven by cheap renewable-energy technologies. Today, either wind or PV are the cheapest new sources of electricity in countries making up around 73% of world GDP. And as costs continue to fall, we expect new-build wind and PV to get cheaper than running existing fossil-fuel power plants. In China, unsubsidized renewables undercut coal in 2023-24, and in the U.S. they undercut natural gas in 2024-25.

Figure 1: Global power sector emissions with and without Covid-19



Source: BloombergNEF

Figure 2: Global electricity generation mix



Source: BloombergNEF, IEA

Power - 4.

Power demand rises 60% worldwide to 2050, under our Economic Transition Scenario, driven most strongly by expanding non-OECD economies. Electricity demand drops by about 5% in 2020 as a result of the Covid-19 pandemic, which is 7.9% below our pre-crisis estimates. The pandemic rebases electricity demand over the remainder of the outlook, pushing aggregate demand down 6-7% from pre-crisis levels.

Power - 5.

Electric vehicles grow to make up 11.5% of electricity demand worldwide by 2050, but there is a wide regional spread. In China, EVs account for 13% of demand by the end of the outlook, in Europe it is 21%, in the U.S. 17%, and in India just 6%. We assume that almost half of this is dynamic and can shift to times of abundant low-cost renewables, helping to integrate more wind and PV. Air conditioning accounts for 12.8% of demand in 2050, rising fastest in India, Southeast Asia and Mexico, and is well correlated with PV. In contrast, heat-pump uptake to electrify building heat remains negligible without policy support.

Power - 6.

The combination of these trends results in a global electricity system that flips from being based on large conventional plants running at baseload capacity factors, supported by smaller peaker units, to a new paradigm of cheap, but inflexible, bulk renewable energy. This is supported by flexible demand, batteries, peakers and conventional, large fossil-fuel plants running at low capacity factors, and other dedicated flexible units.

Power - 7.

The growth of cheap wind and PV defines the terms on which other technologies compete to fill the gaps. The 44% of electricity demand, or 18,000TWh, not met with these technologies in 2050 has a very distinct load shape that needs to be met by flexible capacity that can ramp up to provide maximum power on demand, for relatively few hours in the year.

Power - 8.

As renewables grow, there is less space for competitive baseload-type generators. Combined-cycle gas turbine (CCGT) plants adapt to this new environment by becoming more flexible and running during high-value hours, rather than baseload. This also opens up opportunities for gas as a source of back-up: the capacity of peaker gas plants, such as open-cycle gas turbine plants and reciprocating engines, grows 314% over the next three decades.

Power - 9.

Dispatchable units run for relatively few hours in the year, but those hours are by far the most valuable. In our Economic Transition Scenario, fossil-fuel generation provides the bulk of this back-up, though hydro and interconnectors can also do so economically. Even in the absence of emissions policy, gas emerges as the main source of firm capacity by 2050. Gas peakers and combined-cycle gas stay in the system, not for the hours of highest demand, but for those of lowest renewable generation. Total firm capacity requirements fall to about 75% of maximum peak demand.

Power - 10.

Wind-capacity grows at 5.7% year-on-year to 2050, with annual average deployment of 147GW. Growth for PV is 5.3% year-on-year, or average annual deployment of 246GW – this is fast, but PV grew 10.8% per year between 2015 and 2020, albeit from a lower base. These technologies complement each other for most of the outlook, eventually, however, they compete for the ever-shrinking share of remaining generation. At this point cost becomes less important than how well resources correlate with demand, or inversely correlate with prevailing weather. This gives wind an advantage, as it can meet residual evening hours more cheaply than batteries added to PV.

Power - 11.

Cheap renewables and batteries appear to reach an economic limit between 70% and 80% penetration in most markets. This is the result of two related dynamics. First, as new renewables eat into the run-hours of existing coal and gas plants, the most expensive mid-merit generators are displaced first, making the next MW of renewables marginally less competitive. Second, since renewables all generate together when the conditions are right, at high penetration each additional plant tends to increase fleet-wide curtailment, which lowers capacity factors and weakens the economic case for the next plant.

Power - 12.

PV creates an opportunity for wind and batteries by collapsing wholesale prices during the day, forcing traditional thermal plants to ramp down and even shut off. The additional costs incurred in ramping back up for the evening push power prices back up, creating high-value hours that wind or batteries can access.

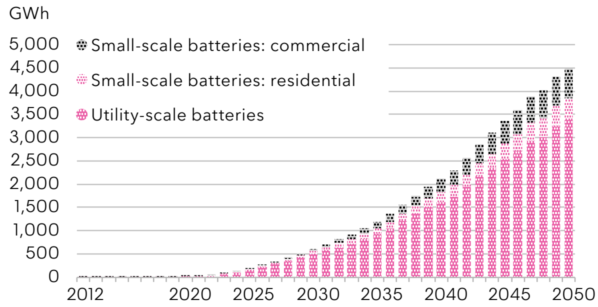
Power - 13.

Storage batteries get cheaper over the outlook via synergies with growing battery demand for electric vehicles. Batteries take advantage of a peakier intraday net load curve, predominantly pairing with PV in sunny regions to meet demand after the sun sets. This is particularly true where other types of peaking capacity is expensive and where wind resources are strongly seasonal. We see significant battery deployment in the Middle East, Southeast Asia and Japan in our Economic Transition Scenario. Overall, there are around 4,500GWh of storage for load shifting by 2050.

Power - 14.

Coal-fired power declines throughout our Economic Transition Scenario. In 2019, coal accounted for 35% of total electricity generation worldwide. Major economies such as China and India that year ran 64% and 72% on coal, respectively. There is some near-term growth in coal use in China, India and Southeast Asia, but this is offset by declines in the U.S. and Europe, where by 2050 coal is down to less than 10% of what it is today. Overall, our numbers now suggest coal in the power sector may have peaked back in 2018, and its share drops to just 12% in 2050 as plants retire and the technology becomes increasingly uncompetitive. By 2031 wind and solar produce more electricity worldwide than coal plants.

Figure 3: Global cumulative battery storage energy capacity, 2020-2050



Source: BloombergNEF

Power - 15.

Power generation from gas appears to have peaked in 2019. It recovers after the Covid-19 pandemic to reach a lower peak in 2025, but doesn't again reach pre-crisis levels. Growth in the U.S. and the Middle East offsets declines elsewhere for a few years. However, from around 2030 gas starts to retreat, dropping 0.8% year-on-year to 2045, when gas use stabilizes. All this time, electricity demand grows, which means the share gas has in generation drops to 12% in 2050, from 23% in 2019, and 19% in 2030. In contrast, gas capacity rises throughout the outlook, led by combined-cycle units and then strong growth in peaker gas units from 2030. The role of gas as a provider of flexible supply can be seen in global average capacity factors, which drop to 27% for CCGTs in 2050, from 46% in 2019.

Power - 16.

The clean-power transition goes furthest and fastest in Europe, where wind and PV account for 74% of electricity in 2050. Some markets, such as Germany, get beyond 80%. Wind dominates across the continent, making up about 40% of generation in 2030, and more than 50% in 2050. Solar PV is prominent in southern European countries, such as Spain and Portugal, where it provides over 30% of generation in 2030. Coal declines ahead of formal retirement schedules and all but disappears by 2030. Gas use grows to 2024 from its Covid-19 low, before falling to just 10% of generation in 2050.

Power - 17.

Gas remains dominant in the U.S. throughout our Economic Transition Scenario, rising to 42% of generation in 2035. It still accounts for 33% in 2050. Wind grows steadily to 17% in 2030, and 24% in 2050, from 8% in 2019. PV booms from 2040. Coal continues its historic decline in the U.S., despite rebounding in 2021 and 2022 in the aftermath of the Covid-19 pandemic. Nuclear remains a major part of the mix until the early 2030s. Coal-to-gas switching drives early emissions reductions, but then gas becomes a barrier to further decarbonization. The U.S. trails India and China in renewables for most of the outlook.

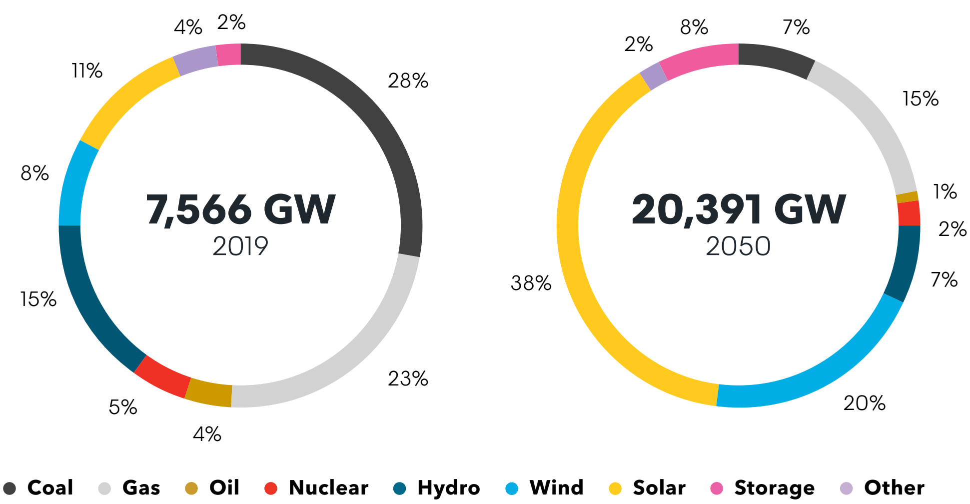
Power - 18.

Coal-fired power peaks in China in 2026, then falls to 16% of total generation in 2050, a plunge from 64% of generation today. At the same time, renewables grow, with 45GW of wind and 62GW of PV installed per year. They make up 41% of capacity and 27% of generation in 2030, and 59% and 54%, respectively, in 2050. Nuclear and hydro also expand but much more slowly. By the end of the outlook, China's electricity mix is 82% zero carbon, and emissions are 62% below 2019 levels.

Power - 19.

Overall, worldwide power capacity almost triples between 2019 and 2050. Renewables surge from 35% in 2019 – almost half of which is hydro – to 68% in 2050, as wind and PV expand rapidly. Fossil-fuel power capacity drops to just 24% in 2050, from 56% in 2019. Capacity also becomes much more distributed, with behind-the-meter consumer PV and batteries accounting for 13% of installed capacity. In some places, such as Australia and Iberia, this approaches 40%. Consumer decisions play an increasingly important role in our Economic Transition Scenario. Household decisions to add PV, behind-the-meter batteries or purchase an EV are few initially but grow exponentially. This uptake is driven by cheaper technology and imitation effects.

Figure 4: Global installed capacity mix, 2019 and 2050



Source: BloombergNEF

Power - 21.

Trends in decentralization, system integration, digitalization and electrification shape the future grid. The median power-plant size across the world drops by a factor of by 2050 to 158MW, driven by the decommissioning of large coal, gas and nuclear plants and the adoption of wind and PV. Also, smaller power plants tend to connect directly to the distribution grid. This is seen most in Europe, where the median power-plant size falls from 562MW in 2020 to 32MW in 2050, when 67% of power generated is injected into the distribution grid, compared with 24% today. In contrast, the U.S. and China see around one-third of electricity in 2050 flow directly to the distribution grid.

Power - 22.

Utility-scale power plants often cluster in areas where resource quality is high and development costs are low. This can create surpluses of renewable energy that far exceed local demand and require more investment in transmission. This can be seen today in Germany, where wind resources in the north of the country far exceed local demand; in China, where renewable resources in the northwest are being redistributed to the south and east via ultra-high voltage and high-voltage direct-current technology lines; and in Australia, where losses from bringing electricity to demand nodes from a growing fleet of remote renewables are getting worse.

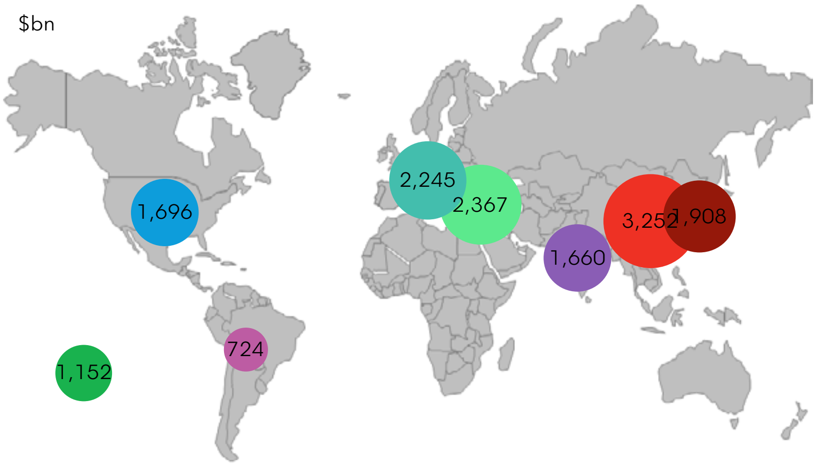
Power - 23.

Around $15.1 trillion is invested in new power capacity to 2050 in our Economic Transition Scenario, at an average of $486 billion per year. Of this, 92% goes to generating capacity and 8% to storage. Around $11 trillion, or 73%, goes to renewables, with wind seeing $5.9 trillion and PV $4.2 trillion. Asia Pacific sees 45% of all new capital, with China and India accounting for 72% of that. Europe and the Americas invest $2.2 trillion and $2.4 trillion, respectively. There is around $1.7 trillion invested in gas power plants, with 58% going to new CCGT, and 42% to peaker plants, such as OCGT and reciprocating engines. Coal investment sits at $607 billion over 2020-2050, more than half of which is spent in the next 10 years.

Power - 24.

Grid investment to 2050 is around $14 trillion in our Economic Transition Scenario. Around 41% of this, or $5.8 trillion, is sustainment capital to replace ageing assets. Around 38% goes to grid reinforcements and 21% to new connections. Together, these latter two categories are growth capital and sum to $8.2 trillion. Total annual investment more than doubles to $636 billion in 2050, from $235 billion today. This is a compound annual growth rate of 3.4%. This rapid increase in investment supports a growing power system. Global peak demand increases 1.7-times by 2050. The number of asset replacements increases 2.4-times.

Figure 5: Investment in capacity by region, 2020-2050



Source: BloombergNEF. Note: includes investment in generating and storage capacity

Power - 25.

Global power-sector emissions peak in 2018, at the same time as coal generation, before dropping 45% to 2050. The Covid-19 pandemic pushes emissions down 10% in 2020. Emissions rebound to 2025 but then fall 2% year-on-year over the remainder of the outlook. China emissions in 2050 are down 65% from a peak in 2026, and India's emissions in 2050 are down 7% from their peak in 2030, and 2% from 2019 levels. Despite different trajectories, India emits 71% less than China over the period and sees the most dramatic reduction in emissions per kWh – which are down 71% by 2050. Europe's power emissions in 2050 are down 74% from 2019 and the U.S. is down 59%.

Transport

Transport - 1.

Demand for passenger mobility broadly doubles between 2019 and 2050, and freight transport grows 37%. Despite this, final energy demand from transport peaks at 3.2 gigatons of oil equivalent (Gtoe) in 2035, rising from 2.8Gtoe in 2019, and ultimately drops again to 2.9Gtoe by 2050. Over the period, transporting goods becomes a third less energy intensive as lighter, more-fuel efficient, and sometimes larger freight vehicles are rolled out. For road transport, rapid electrification of the global vehicle fleet means the passenger-car segment gets almost 60% more energy efficient. In commercial aviation, higher occupancy following the pandemic, light-weighting and other operational improvements translate into a 27% improvement in passenger-kilometer efficiency of the sector.

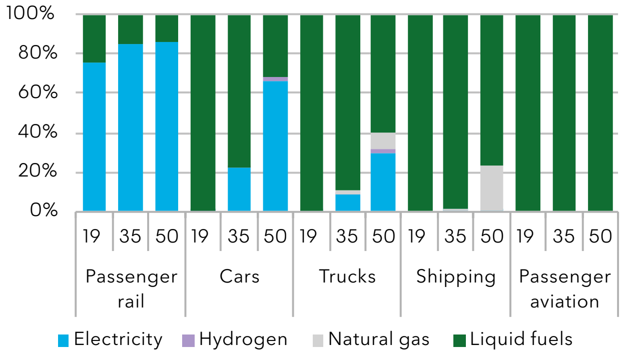
Transport - 2.

Demand for oil products in the transport sector peaks in 2033 at 2.90Gtoe, or 61.9 million barrels of oil per day, up from 2.64Gtoe in 2019. This is driven by both electric vehicles and tightening fuel-economy standards in the road sector, which accounts for three quarters of the total. By 2050, demand falls to 46.6 million barrels per day, or 18% below 2019 levels. Oil demand for road transport peaks in 2031, whereas aviation grows to 2050 and sees its share in transport-related oil consumption rise from 13% in 2019 to a third by 2050.

Transport - 3.

Electrification is the main driver of transition in the transport sector to 2050. It is strongest in road and rail, where cheaper lithium-ion batteries and the improved performance of electric drivetrains make it most competitive. But it is weakest in shipping and aviation, where the combination of weight and distance require significant improvements in battery energy density for electrification to become commercially viable. By 2050, transport accounts for 13% of total electricity demand, or 4,589TWh.

Figure 1: Global transport activity by fuel, 2019-50



Source: BloombergNEF. Note: Activity reflects vehicle kilometers traveled for cars and trucks, passenger kilometers for aviation and rail, and ton kilometers for shipping.

Transport - 4.

Road transport accounts for 75% of energy consumed in the transport sector overall in 2019, but this falls to 59% in 2050 with growth in more energy-efficient electric drivetrains. Adoption of passenger EVs accelerates in the 2030s, and by 2050, some 65% of all passenger-vehicle kilometers traveled are electric, in our Economic Transition Scenario. For two-wheelers, this reaches 74%, and for city buses it reaches 76%.

Transport - 5.

Electric ships and planes are limited to short-distance operations, such as ferries and light aircraft, this side of 2050. Sustainable aviation fuels and ammonia also do not emerge as cost-competitive solutions in our Economic Transition Outlook. Both will require further policy support to play a major role powering ships and planes. By 2050, LNG carves out a role in shipping, but the bulk of activity in these sectors continues to run on oil, in other words heavy fuel oil and diesel.

Transport - 6.

Beyond the near-term impact of the Covid-19 pandemic, demand for mobility and freight transport grows in road, rail, shipping and aviation out to 2050. Passenger mobility is tied closely to population and GDP and broadly doubles over the period. Freight grows at a slower pace, driven both by GDP and the need to move commodities such as coal and oil, demand for which declines over the outlook.

Transport - 7.

Direct emissions from transport peak in 2033 at 8.9 gigatons of CO2 equivalent (GtCO2e) in our Economic Transition Scenario. That is up 10% from 8.1GtCO2e in 2019. The growth in EVs in the 2030s and 2040s then pushes emissions down to 7.2GtCO2e by 2050, 20% below the peak and 12% below pre-pandemic levels. But this is still far from a climate-safe trajectory.

Road

Road - 1.

Demand for road transport increases worldwide in line with population and income growth. By 2050, the number of kilometers traveled by passenger vehicles hits 30 trillion, up 81% from 2019, led by growth in emerging economies. Freight demand rises 76% over the same period, but with different regional patterns. Light- and medium-duty freight grows faster in wealthy countries – driven by the rise of e-commerce – and heavy-duty freight grows faster in emerging economies.

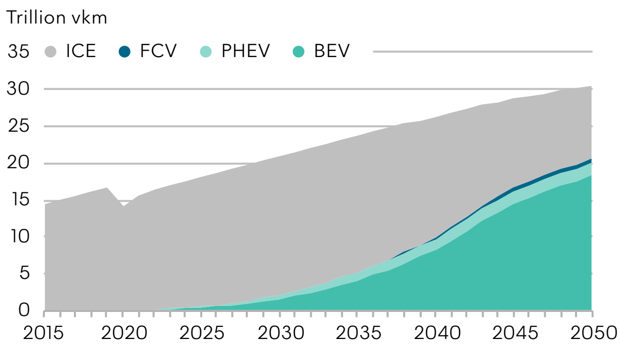
Road - 2.

Electrification is already having an impact on road transport. Only 0.7% of the global passenger-vehicle fleet is electric today, but 19% of two- and three-wheeled vehicles on the road, and 31% of the global municipal bus fleet, are already electric. The current EV fleet is already displacing one million barrels per day of oil demand.

Road - 3.

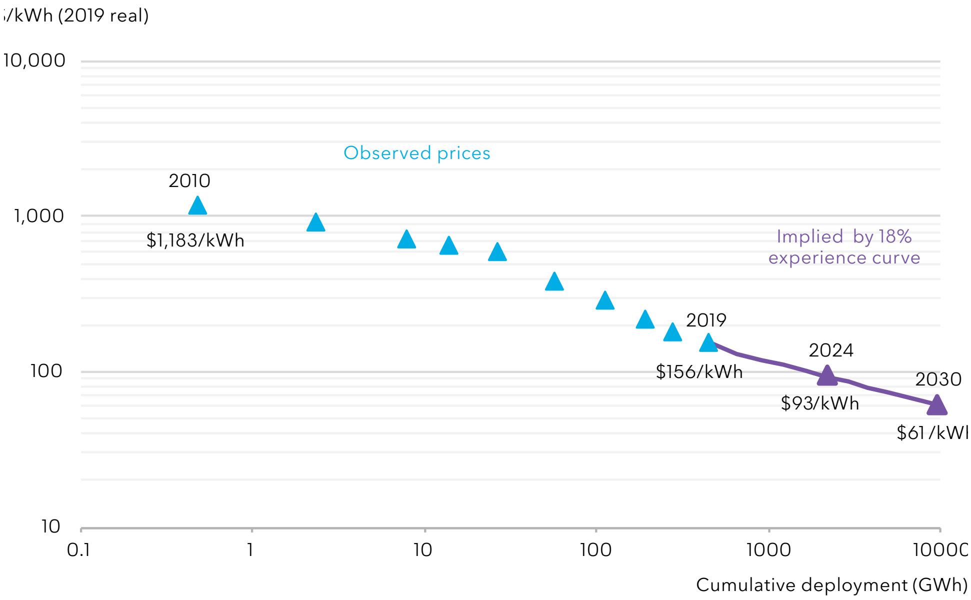
Over the next three decades, electric road mobility more than meets the incremental global demand growth from passenger vehicles. By 2050, EVs capture 73% of all sales. They make up 54% of the global passenger-car fleet, and in some regions go higher, reaching between 56% and 80% in Europe, the U.S. and China. By 2050 there are just above 800 million passenger EVs on the road, out of a total passenger-vehicle fleet of 1.5 billion.

Figure 2: Global passenger vehicle kilometers travelled, by drivetrain



Source: BloombergNEF. Note: ICE is internal combustion engine, FCV is fuel-cell vehicle, BEV is battery-electric vehicle. PHEV is plug-in hybrid electric vehicle

Figure 3: Lithium-ion battery pack price outlook



Source: BloombergNEF

Road - 4.

This transition is driven by better and cheaper lithium-ion battery technology. Battery-pack prices have fallen 18% for every doubling of cumulative manufactured volume, and we expect this relationship to hold for at least the next 10 years. This will lead to battery-pack prices of $93/kWh by 2024 and $61/kWh by 2030, down from $156/kWh today and $1,183/kWh in 2010. The adoption of new cell and pack designs, higher energy-density cathodes, and more efficient manufacturing will continue to drive the per-kWh cost down.

Road - 5.

High-nickel battery chemistries will quickly dominate the passenger-EV market over the next 10 years, but other chemistries will also play a role. Lithium-iron phosphate will remain in high demand because of its use in commercial EVs, electric buses and stationary storage. Battery demand reaches 2TWh by 2030, up from less than 230GWh in 2019. This will require a dramatic increase in battery manufacturing capacity and supply of raw materials.

Road - 6.

Passenger EVs reach up-front price parity with comparable internal combustion vehicles in most segments by the mid-2020s, but this varies by vehicle type and geography. We think sales of internal combustion passenger vehicles peaked in 2017 and are now in permanent decline, but the ICE fleet keeps growing until 2030. Overall passenger-car sales peak in 2036 due to combination of urbanization, demographic trends and shared mobility.

Road - 7.

Fully autonomous vehicles begin to impact road transport from the mid-2030s onward. Convenience and favorable costs mean they increase demand for mobility overall, but reduce the number of vehicles needed to deliver it. By 2050, shared mobility accounts for 36% of all kilometers traveled by the passenger-vehicle fleet, up from 5% today.

Road - 8.

EVs are already competitive on a total-cost-of-ownership basis in lighter commercial vehicles and become attractive in heavier segments in the 2020s and 2030s. Electrified road-freight activity jumps from 5 billion vehicle-kilometers globally in 2019, to 2.30 trillion in 2050. By then, more than one third of commercial-vehicle kilometers are electric, made up mostly of light- and medium-duty vehicles, though heavier vehicles used in urban-duty cycles also go electric.

Road - 9.

Heavy-duty long-haul trucking is the most difficult segment of road transport to electrify. A range of drivetrains play a role in the heavy-duty segment, including natural gas, hydrogen fuel cells and diesel.

Road - 10.

The combined impact of fuel-economy improvements, EVs, fuel-cell vehicles, biofuels and shared mobility cause oil-product demand from road transport to peak in 2031 at 47.0 million barrels per day. This falls to 27.7 million barrels per day by 2050.

Road - 11.

Tailpipe CO2 emissions peak at 6.66GtCO2e in 2031. By 2050, direct emissions are 30% lower than in 2019 and falling fast. To reduce emissions faster, policy makers need to focus on commercial vehicles, charging infrastructure, and supporting faster uptake of passenger EVs in emerging economies.

Shipping

Shipping - 1.

Demand for global maritime freight rises 22% between 2019 and 2050. The current rate of growth is likely to slow over the coming decades.

Shipping - 2.

The most significant shift in the marine-fuel mix is an increase in the share of LNG. The use of LNG as a marine fuel increases from negligible levels at present to account for over a fifth of the marine-fuel mix and a quarter of cargo-ton miles by 2050.

Shipping - 3.

The fuel efficiency of merchant shipping improves 22% out to 2050, on a cargo-ton-miles basis, as vessels serving international routes between hubs continue to grow in size, and more fuel-efficient technologies are adopted across the fleet.

Shipping - 4.

Final energy consumption in global shipping peaks in 2037, and demand for oil products peaks in 2035 at 305 million tons of oil equivalent (Mtoe), or 6.1 million barrels per day, and declines to 215Mtoe, or 4.3 million bpd, by 2050. Direct CO2e emissions from maritime shipping peaks with oil use at 964MtCO2e in 2035, up from 879MtCO2e in 2019, before falling 17% to 809MtCO2e in 2050.

Shipping - 5.

The role of other marine fuels, such as ammonia, or electricity, is insignificant in our Economic Transition Scenario. Low-carbon policies and regulatory price signals will be necessary to drive adoption of zero-carbon fuels.

Aviation

Aviation - 1.

There is very little change in the energy mix used to supply aviation out to 2050, with fossil-derived jet fuel accounting for over 98.5% of all aircraft kilometers flown in 2050. Oil-product demand in the aviation sector almost doubles to over 14 million barrels per day in 2050. This is more than China's total oil-product demand in 2019.

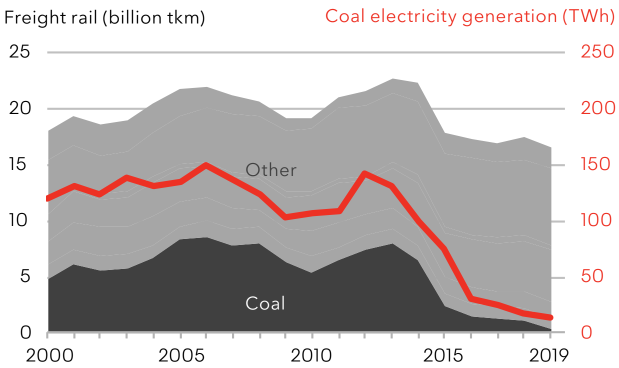
Aviation - 2.

Clean-powered aviation, using sustainable aviation fuels and electric drivetrains, does not arrive at economic parity with fossil aviation fuels for larger commercial aircraft this side of 2050 under our Economic Transition Scenario. However, we expect e-planes will make an impact in smaller aircraft categories. We have not assessed the role of hydrogen in aviation in this year's outlook.

Aviation - 3.

Battery-pack energy densities of 600-1,200Wh/kg are required to power commercial narrow-body aircraft, such as the Airbus 320neo or Boeing 737. Lithium-sulphur or lithium-air batteries could in theory reach that level, but so far the highest reported battery density is 500Wh/kg, with most reaching a maximum of 175Wh/kg. Even if commercially available batteries do achieve high energy densities, there are still safety concerns as well as weight and space limitations to overcome.

Figure 4: Freight rail activity by commodity vs coal-fired power generation, U.K.



Source: BloombergNEF, U.K. ORR

Aviation - 4.

Growth in air-travel demand drives emissions to just above 2GtCO2e in 2050, a 94% increase from 1.07GtCO2e in 2019. This is despite aircraft fuel efficiency improving 15% on a passenger-kilometer basis over the period. Light-weighting and hybridization with batteries for taxi-operations, as well as higher passenger occupancy after the pandemic, contribute to making flying more fuel efficient.

Aviation - 5.

Despite the ambitions of the United Nations and some regions like the EU to limit or reduce emissions growth, policy makers will need to introduce stricter carbon-emission schemes, fuel mandates and jet-fuel taxes so low-carbon alternatives can play a material role.

Rail

Rail - 1.

Demand for passenger rail doubles to around 8 trillion passenger kilometers by 2050, driven by mostly China and India. In China, economic growth and urbanization pushes up rail demand by a factor of 2.3. In India, a sevenfold surge in economic activity and a 20% rise in population combine to double demand for passenger rail to 2.5 trillion pkm by 2050. In Europe it rises 60% and in the U.S. 62%.

Rail - 2.

Coal accounts for as much as 58% of overall freight-rail tonnage in China, 48% of the tonnage in India, and 31% in the U.S. With the competition from renewables, coal consumption in the power sector drops through 2050. This impacts freight rail, which grows at a slower rate globally, adding only 1.5% annually between 2019 and 2050, compared to 2.7% per year between 2000 and today. Looking forward, not coal, but cargo such as containers, metals and construction materials drive the market for freight-rail transport.

Rail - 3.

Around 76% of passenger rail is electric today. This reaches 84% by 2050 due to ongoing growth in catenary electric trains. These are trains powered by electricity running through an overhead wire. Recent deals suggest battery-electric and hydrogen fuel-cell trains may be becoming more commercially viable. By our numbers, battery electric trains can be more cost effective than catenary electric trains on lower-traffic routes below 100km as they avoid costly infrastructure investment needed to electrify line segments.

Rail - 4.

Diesel accounts for 44% of freight-rail today, and has been particularly competitive for long-distance haulage as it avoids the infrastructure cost of electrifying lines.

Rail - 5.

Some 70% of freight rail is electric by 2050, compared with just 56% today, in our Economic Transition Scenario. This growth is driven by the expansion of electrified dedicated freight corridors, where trains can be plugged into the high-voltage grid to reach higher power output and carry heavier loads that unlock better economies of scale. These feature particularly in India, China and Europe.

Rail - 6.

Rail, in terms of emissions, is already small compared with other transport sectors, and its direct emissions drop from 79MtCO2e in 2019 to 68MtCO2e in 2050. By then, half of rail-related emissions come from diesel freight trains in the U.S., where low retail prices for oil products, and the high cost of capital for private railway companies, limits new infrastructure investments in electric railways.

Buildings

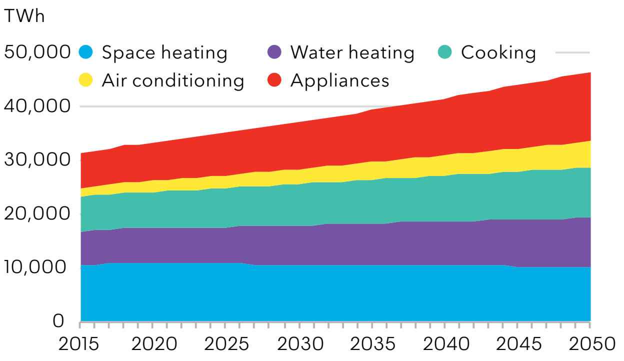
Buildings - 1.

Demand for energy in residential and commercial buildings grows 42%, reaching 47,000TWh by 2050, in our Economic Transition Scenario. This is up from around 33,000TWh in 2019. Growth is driven largely by rising population and GDP, which outweigh the impacts of efficiency gains and warmer winter temperatures. Residential buildings account for around 70% of energy use in the sector over the period, but energy use in commercial buildings grows faster, climbing 62% between 2019 and 2050.

Buildings - 2.

There is strong growth in energy use for air conditioning and appliances. The latter overtakes space heating in 2040 to become the largest single source of energy demand in buildings. Energy demand for cooling grows faster, more than doubling by 2050.

Figure 1: Global final energy demand from buildings by end-use, 2015-2050

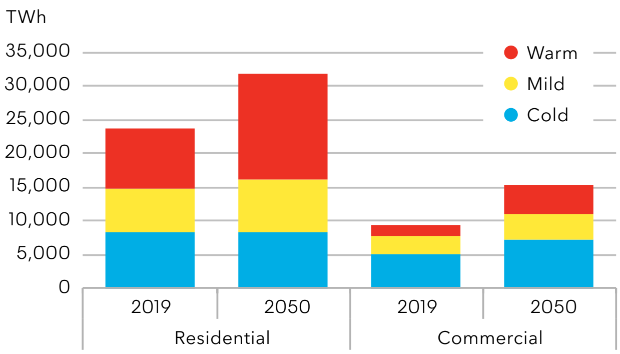


Source: BloombergNEF

Buildings - 3.

The growth in energy demand from buildings is largely from poorer, warmer countries that become more populous and wealthier over the outlook. Residential-building energy demand rises 76% in these countries to 2050, with strong growth from air conditioning use. In contrast, the combination of better energy efficiency, slower population growth and a warming climate keeps residential energy demand in colder climates relatively unchanged between 2019 and 2050. Demand grows faster in commercial buildings in these countries, rising 37% to 2050.

Figure 2: Global final energy demand from buildings by building type and climate, 2019 vs 2050



Source: BloombergNEF

Buildings - 4.

Energy use for space heating falls 6% by 2050, compared to 2019 levels. This is partially due to weaker population and economic growth in richer, colder weather countries. It also reflects a trend toward milder winters, which can be seen from around 1988. Efficiency improvements in gas boilers and furnaces, alongside greater adoption of high-efficiency heat pumps at the expense of oil, also contribute to the decline in energy demand for space heating.

Buildings - 5.

By 2050, electricity provides just over a third of all energy consumed in buildings, growing 60% from 2019, spurred by growth in the use of appliances and air conditioning. Natural gas for space heating, hot water and cooking grows too in the absence of emissions-reduction policies to push it out of the mix. Bioenergy continues to provide a major fraction of energy consumption for buildings throughout the outlook.

Buildings - 6.

Heat pumps have great potential to reduce energy consumption and emissions from buildings and are competitive today with oil for space heating in most countries. However, they do not compete with natural gas on cost alone until around 2040, even in countries with more expensive gas and cheaper electricity. Heat pumps themselves get cheaper over time but not fast enough without direct government support to see a meaningful uptake over the outlook.

Buildings - 7.

A lack of alternatives for cooking needs, in combination with rapid population growth in developing countries, drives a 43% rise in bioenergy use. Of all bioenergy consumed by 2050, some 86% is in warmer countries where demand growth has been continuous for at least 20 years and is largely met from unsustainable sources. In practice, there are a range of government-funded projects designed to reverse this trend and bring more sustainable and clean-burning fuels to poorer, rural communities both to alleviate air pollution and increase productivity growth.

Buildings - 8.

Natural gas remains the dominant energy source for heating and cooking in the U.S. and Europe, where it grows 27% and 30%, respectively, by 2050, despite less demand for space heating overall. The growth is largely driven by the commercial sector and by new demand for cooking and hot water in the residential sector. Overall, gas use in buildings grows 33% between 2019 and 2050 in our Economic Transition Scenario, but its share of the mix drops one percentage point to 22%.

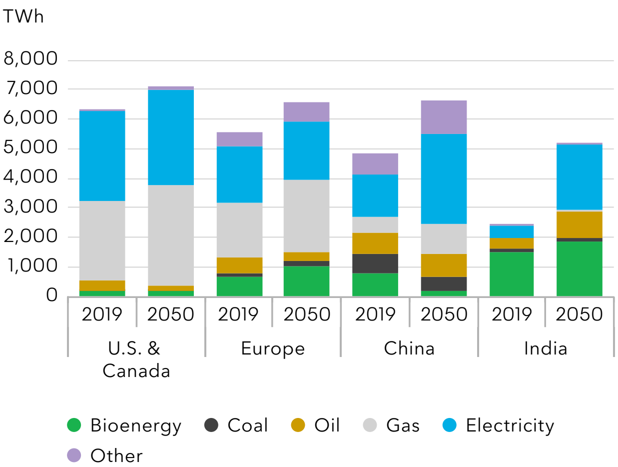
Buildings - 9.

Growth in gas is common to the trajectory of all three major economies. This comes at the expense of old oil units in the U.S. and Europe, and domestic biomass and coal use in China. China has already seen a dramatic energy transition in the building sector. In 2000, energy use in buildings was 18% coal and 65% bioenergy. By 2019, demand had risen 40%, but coal use had dropped to 14% of the mix, and biomass to 16%. This trend continues in our outlook, with coal down to 7% and biomass 3% of building energy in 2050, by which time electricity and gas dominate the sector.

Buildings - 10.

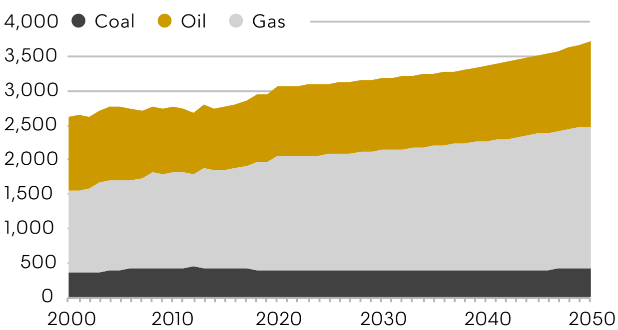
Emissions from energy use in buildings rises 26% between 2019 and 2050 in our Economic Transition Scenario. This is almost all due to growth in gas and oil use in India and other rapidly developing countries. Emissions in China, the U.S. and Europe increase as well, but at a much slower pace. Rising emissions from these countries again largely come from gas, as heat pumps and other low-carbon technologies and fuels fail to make inroads without policy intervention.

Figure 3: Global energy consumption in buildings by country and by fuel



Source: BloombergNEF

Figure 4: Total global CO2 emissions from buildings by fuel, 2000-2050



Source: BloombergNEF

Industry

Industry - 1.

Industry today accounts for 21% of fuel combustion emissions, or 25%, if we take industrial-process emissions into account. The sector includes hard-to-abate areas such as steel and cement, where relatively little has yet been done to reduce emissions. While greater material recycling and better energy efficiency contribute to lower energy use per unit of output over the outlook, there is relatively little change from business-as-usual. By 2050, coal, gas and oil provide 57% of final energy to the sector, compared with 60% in 2019.

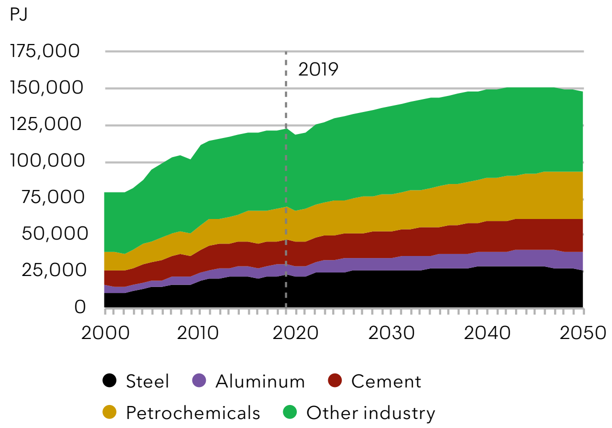
Industry - 2.

Industry consumes 29% of total final energy, with the vast majority used for heat production. Energy consumption grows at an average of 0.6% per year to 2050, reaching 149,000PJ. Energy consumption begins to level off in the mid-2040s, however, as industrial energy intensity starts to offset demand growth, recycling increases, and growth in demand for steel begins to slow and decline.

Industry - 3.

Steel and chemicals are the two largest energy consumers in industry, responsible for 19% and 18% of final energy use in the sector in 2019. They are followed by cement, at 14%, and aluminum, at 6%. A large number of lower-energy-intensity manufacturing sectors and industries account for the remaining 44% of final energy. These include pulp and paper production, food processing and mining, among others.

Figure 1: Global final energy consumption in industry, by sub-sector



Source: BloombergNEF

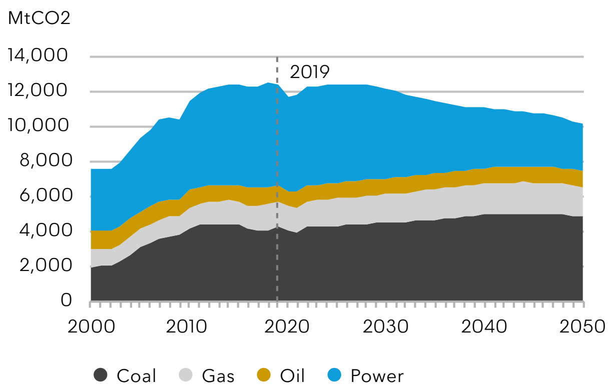
Industry - 4.

Around 12% of all fossil fuels consumed in industry is used as a feedstock for non-energy purposes. This is particularly important for the petrochemicals sector, where oil and natural gas is used to make a variety of products, including plastics. Feedstock makes up around 60% of total primary energy supply to the sector.

Industry - 5.

Direct energy emissions from industry grow 0.4% year on year to 2050, in the absence of policy intervention. In 2050, the sector acconts for around 34% of emissions from fuel combustion, up from 25% in 2019. However, if we also include indirect emissions from upstream electricity used in industry, then the combined emissions peak in around ten years as zero-emissions renewables displace coal and gas in the power sector. These combined energy emissions (excluding industrial process emissions) reach around 10,200Mt in 2050, which is 18% below 2019 levels.

Figure 2: Global CO_2 emissions from industry

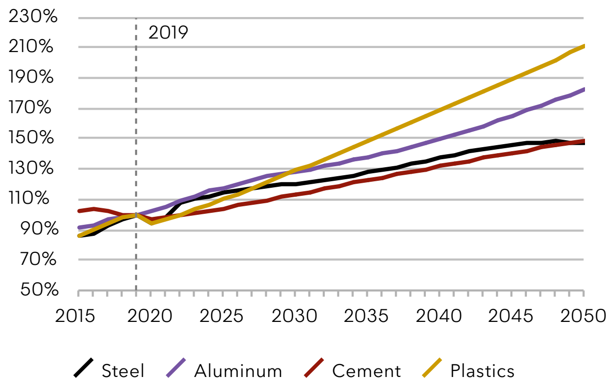


Source: BloombergNEF. Note: Excludes process emissons

Industry - 6.

Steel demand grows 50% through 2050, reaching 2,747Mt in 2050, up from 1,867Mt in 2019. Slowing global economic growth and improved material efficiency, outpace new demand from the mid-2040s onward and slow growth, leading to a slight fall of demand at the end of the outlook. Demand for aluminum grows 80% to 171Mt in 2050, from 93Mt in 2019. Infrastructure construction and increasing demand for consumer products, packaging, and vehicles drive the majority of the growth.

Figure 3: Global growth in material demand



Source: BloombergNEF. Note: Demand is indexed to 2019

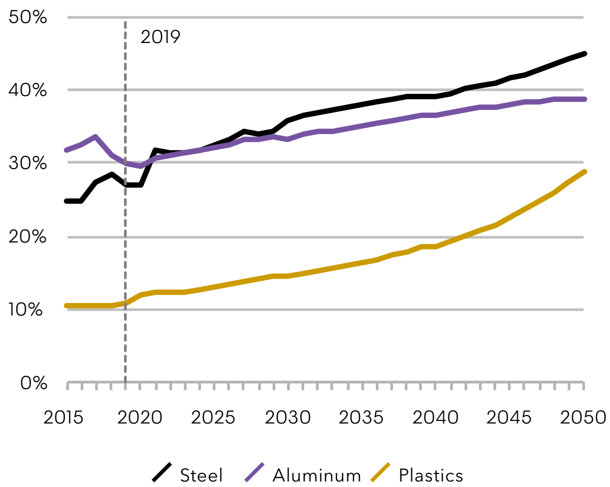
Industry - 7.

Cement demand increases by around 50%, from 4,000Mt in 2019 to almost 6,000Mt in 2050, as economic and population expansion drives the need for public infrastructure and construction, particularly in faster-growing emerging economies.

Industry - 8.

The use of plastics has significantly expanded over the past two decades, specifically, demand for polyolefins is higher. Through 2050, we see the consumption of some of the most important polymers, such as high-density polyethylene, low-density polyethylene and polypropylene, doubles to around 365Mt, from 173Mt in 2019.

Figure 4: Global shares of recycling in total production by material



Source: BloombergNEF

Industry - 9.

The use of recycled materials increases in most major industrial sectors through 2050. Today, steel and aluminum are already widely recycled, with 27% and 30% of total production made from scrap, respectively. These rates increase to 45% in steel and 39% in aluminum production by 2050 in our Economic Transition Scenario. For plastics, the share of secondary production grows the most, from 11% to 29%. However, recycling has its limits, as demand growth often outpaces the availability of scrap, and recyclable material can be locked away in infrastructure for decades.

Industry - 10.

Over the last two decades, China has become the most important consumer and producer of many industrial materials, including steel, aluminum and cement. In our Economic Transition Scenario we see China's dominance wane as the country refocuses its growth policy from industry to services. Demand for cement in China has already peaked, the country's demand for steel plateaus from around 2030, and demand growth for aluminum slows.

Industry - 11.

While India may not become the "new China", it is the fastest growing producer and consumer of industrial products in the outlook. By 2050, it is the second-largest producer of steel, aluminum and cement, behind China. This comes with a fourfold increase in energy consumption, caused not only by greater output but also because of the relatively low energy efficiency of many parts of Indian industry. In 2050, India's share in global energy consumption in these sectors is 13%, up from 8% in 2019.

Industry - 12.

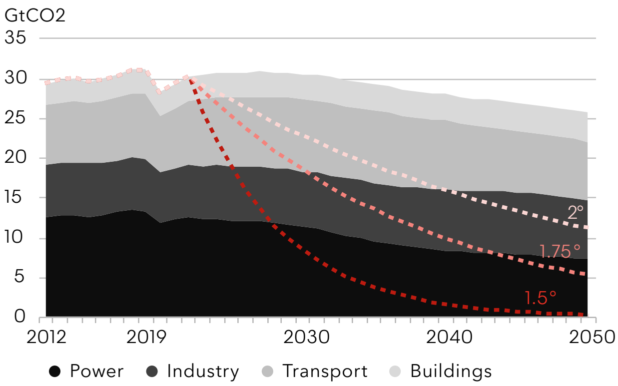
In contrast, the demand for materials in developed economies remains relatively flat, or grows moderately over the oulook. By mid-century, Europe and the U.S. combined consume less than 12% of steel, aluminum and cement worldwide.

NEO Climate Scenario

Climate Scenario - 1.

Emissions from fuel combustion in power, industry, transport and buildings peaked in 2019 at 31.1Gt, under our Economic Transition Scenario. They then fall 0.8% year on year to 25.8Gt in 2050, a drop of 17%. Cumulatively, this amounts to 942GtCO2e of emissions over the outlook – or almost twice the 501GtCO2e the Intergovernmental Panel on Climate Change says is the carbon budget we have remaining for a 67% chance of limiting global warming to less than 2 degrees Celsius above pre-industrial levels. Our Economics Transition Scenario would likely lead to an estimated 2.2 degrees Celsius of global warming by 2050, and a jump of 3.3 degrees by the end of the century.

Figure 1: Emissions in the Economic Transition Scenario, by sector, and a range of carbon budgets



Source: BloombergNEF

Climate Scenario - 2.

Emissions should be reduced by 6% year on year to 2050 to limit warming to well below 2 degrees Celsius. They should be cut by 10% a year to achieve no more than 1.5 degrees Celsius of warming. This is so steep that all sectors and countries must move quickly toward transition. The next ten years are crucial to get on track. Three things need to happen. First, accelerate the deployment of wind and PV in the power sector; second, harness consumer power to drive faster electrification of transport and heating; third, scale up development and deployment of a zero-carbon molecule for widespread deployment beyond 2030.

Climate Scenario - 3.

In this year's NEO Climate Scenario we investigate a clean-electricity and green-hydrogen pathway. The main goal is to explore what a trajectory toward a well-below-2-degrees-Celsius electricity-based energy system might look like. And see the rate and timing of deployment needed to achieve it in order to meet climate objectives.

Climate Scenario - 4.

This is one of a large number of possible pathways that could meet climate targets, and we are neither claiming this is the most likely, nor the least-cost option. In practice, there is likely to be a different set of technologies and approaches, country by country, consistent with existing competitive advantages.

Climate Scenario - 5.

Electricity makes up around 20% of final energy today, and hydrogen less than 0.001%. In our clean-electricity and green-hydrogen pathway to well below 2 degrees, electricity provides around 45% of final energy in 2050, and hydrogen around a quarter. The remaining 30% is a combination of existing bioenergy, as well as residual oil and gas use in aviation and shipping, and coal in industry where neither direct electric technology nor hydrogen act as a substitute.

Climate Scenario - 6.

Electrification by itself is a good way to reduce emissions. Going electric reduces emissions from direct fuel combustion in transport, industry and buildings. However, it increases electricity demand that raises emissions from power generation. Still, the net position is climate positive, with a 34% emissions saving in 2050, or some 124GtCO2 accumulated between 2020 and 2050.

Climate Scenario - 7.

Electrification of end-uses in our Climate Scenario increases electricity demand to 65,894TWh in 2050. This is 25,443TWh, or 63%, more than in our Economic Transition Scenario. Greater electrification also affects seasonal and intraday load profiles. In cold countries, peak demand roughly doubles and occurs toward the end of the day, coinciding with evening heating demand. Heating also makes the seasonal profile more extreme, with demand between November and March almost 50% higher than in summer. In warmer climates, we see the opposite seasonal effect, with peak demand shifting to the middle of the day, coinciding with maximum use of air conditioning. Demand here is around 38% higher in summer than winter.

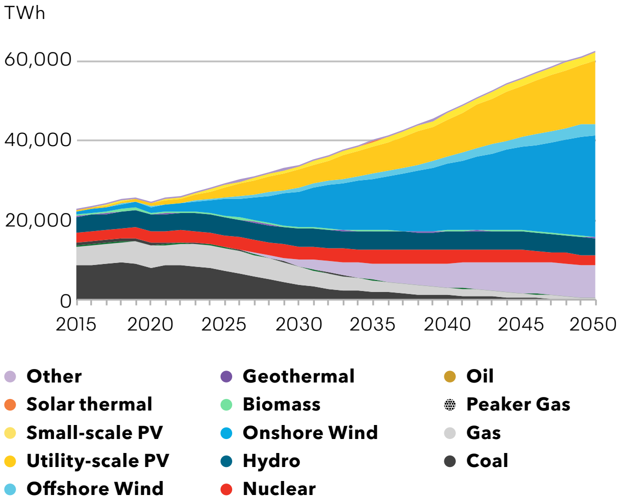
Climate Scenario - 8.

The emissions targets in our Climate Scenario would require the global power sector to expand to 43TW in 2050, double the size compared with our Economic Transition Scenario. Renewable capacity triples to 16TW of PV and 11TW of onshore wind. That means around 540GW of PV and 375GW of wind is added each year. It took two decades to deploy the first terawatt of wind and PV. Our clean-electricity and green-hydrogen pathway requires at least one additional terawatt of renewables every two years over the next two decades.

Climate Scenario - 9.

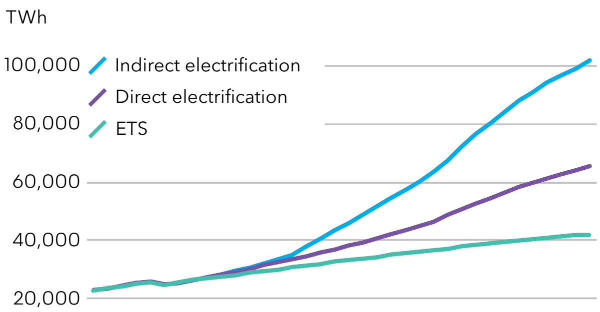
We have new hydrogen-fired combined-cycle turbines emerging from around 2030 in this scenario, amounting to 4TW in 2050. These run at a relatively low capacity factor to complement bulk renewables, much the way gas does in our Economic Transition Scenario. By 2050, hydrogen-fueled power capacity is roughly the same size as all the coal, gas and oil power stations running today put together.

Figure 2: Global electricity generation, NCS-CEHP



Source: BloombergNEF. Note: NCS-CEHP is NEO Climate Scenario: Clean Electricity and Hydrogen Pathway.

Figure 3: Electricity demand from direct and indirect electrification in NCS-CEHP vs ETS



Source: BloombergNEF. Note: ETS is Economic Transition Scenario, NCS-CEHP is NEO Climate Scenario: Clean Electricity and Hydrogen Pathway.

Climate Scenario - 10.

Final electricity generation in 2050 is 75% wind and PV and 13% hydrogen generation. Wind does better than PV in this scenario as its more stable generation profile makes it a better match for growing electricity demand from industry and building heat. This heating demand is higher in the morning and evenings during winter, when the sun is not shining or solar resource is at a minimum.

Climate Scenario - 11.

Global hydrogen demand under our clean-electricity and green-hydrogen pathway reaches 801Mt in 2050. Around 30% of this goes to power generation and another 30% goes to industry. To produce 801Mt of hydrogen via water electrolysis would require over 36,000 TWh of additional electricity – this is 38% more electricity than is produced in the world today. Add this to an already expanded power system and we find that a clean-electricity and green-hydrogen pathway creates a 100,000TWh electricity economy in 2050.

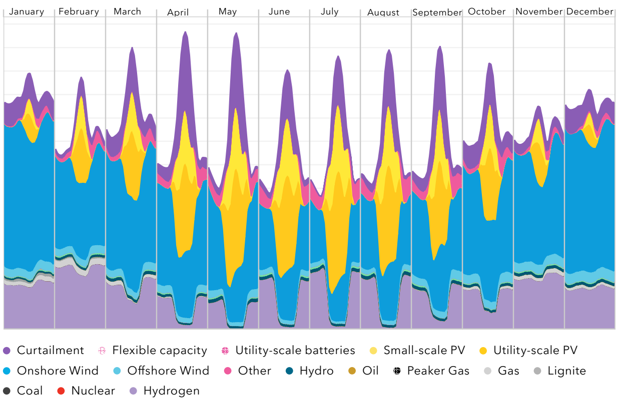
Climate Scenario - 12.

Using variable renewables to manufacture 801Mt of hydrogen would require an additional 14.1TW of wind and PV. This would drive total wind and PV capacity in 2050 to 17.8TW and 23.2TW, respectively. This may be the cheapest option, but would take up almost 3.5 million square kilometers – an area the size of India. Other options include 9.5TW of dedicated industrial offshore wind, or 4.4TW of nuclear.

Climate Scenario - 13.

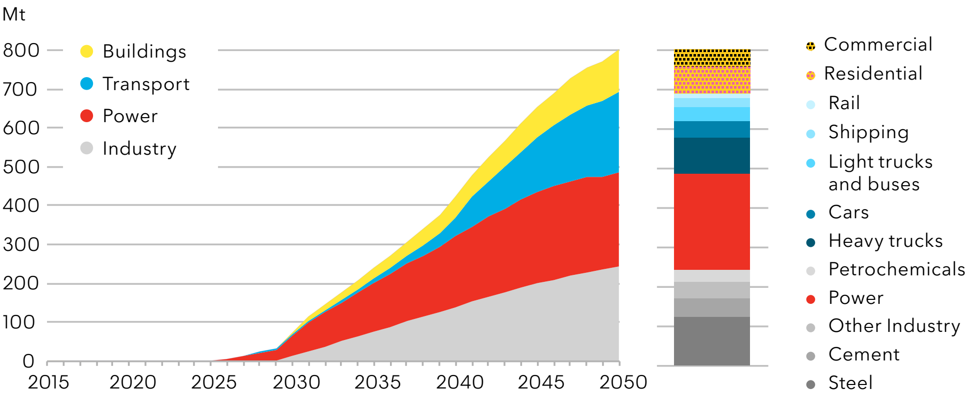
Expanding and decarbonizing the power system to stay on track for warming of as much as 1.75 degrees Celsius would require around $35.1 trillion of investment in power generation assets and batteries over the next three decades. That is almost double the $15.1 trillion needed under our Economic Transition Scenario. Add to this $28.7 trillion for the power grid, between $11.6 trillion and $35.1 trillion for additional, dedicated power capacity to manufacture hydrogen, between $0.7 trillion and $2.7 trillion for hydrogen storage, and between $1.9 trillion and $28 trillion for hydrogen transport. Altogether, our clean-electricity and green-hydrogen pathway to well below 2 degrees requires between $78 trillion and $130 trillion of new investment between now and 2050.

Figure 4: Electricity generation under the NCS-CEHP, Germany, 2050



Source: BloombergNEF. Note: NCS-CEHP is NEO Climate Scenario: Clean Electricity and Hydrogen Pathway.

Figure 5: Hydrogen demand in the NCS-CEHP



Source: BloombergNEF. Note: NCS-CEHP is NEO Climate Scenario: Clean Electricity and Hydrogen Pathway.

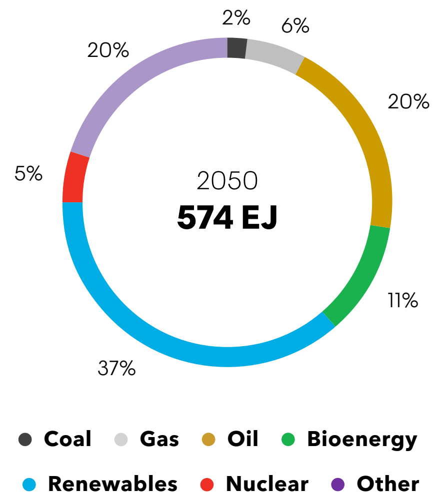
Climate Scenario - 14.

Our clean-electricity and green-hydrogen pathway also brings forward peak demand for oil and gas, which occur in 2028 and 2023. The peak in oil consumption lags a couple of years the uptake of electrification in transport. It only kicks in during the second half of the 2020s as oil consumption in aviation sees continuous growth.

Climate Scenario - 15.

Switching from an energy system which runs mainly on fossil fuels to one that is powered by zero-carbon electricity, either directly in end-use sectors, or indirectly via hydrogen, makes for a more energy-efficient world economy. Primary energy in 2050, under this scenario, is 8% lower than today and 16% less than in our Economic Transition Scenario.

Figure 6: Total primary energy, by fuel, NCS-CEHP, 2050



Source: BloombergNEF. Note: NCS-CEHP is NEO Climate Scenario: Clean Electricity and Hydrogen Pathway.

October 2020

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