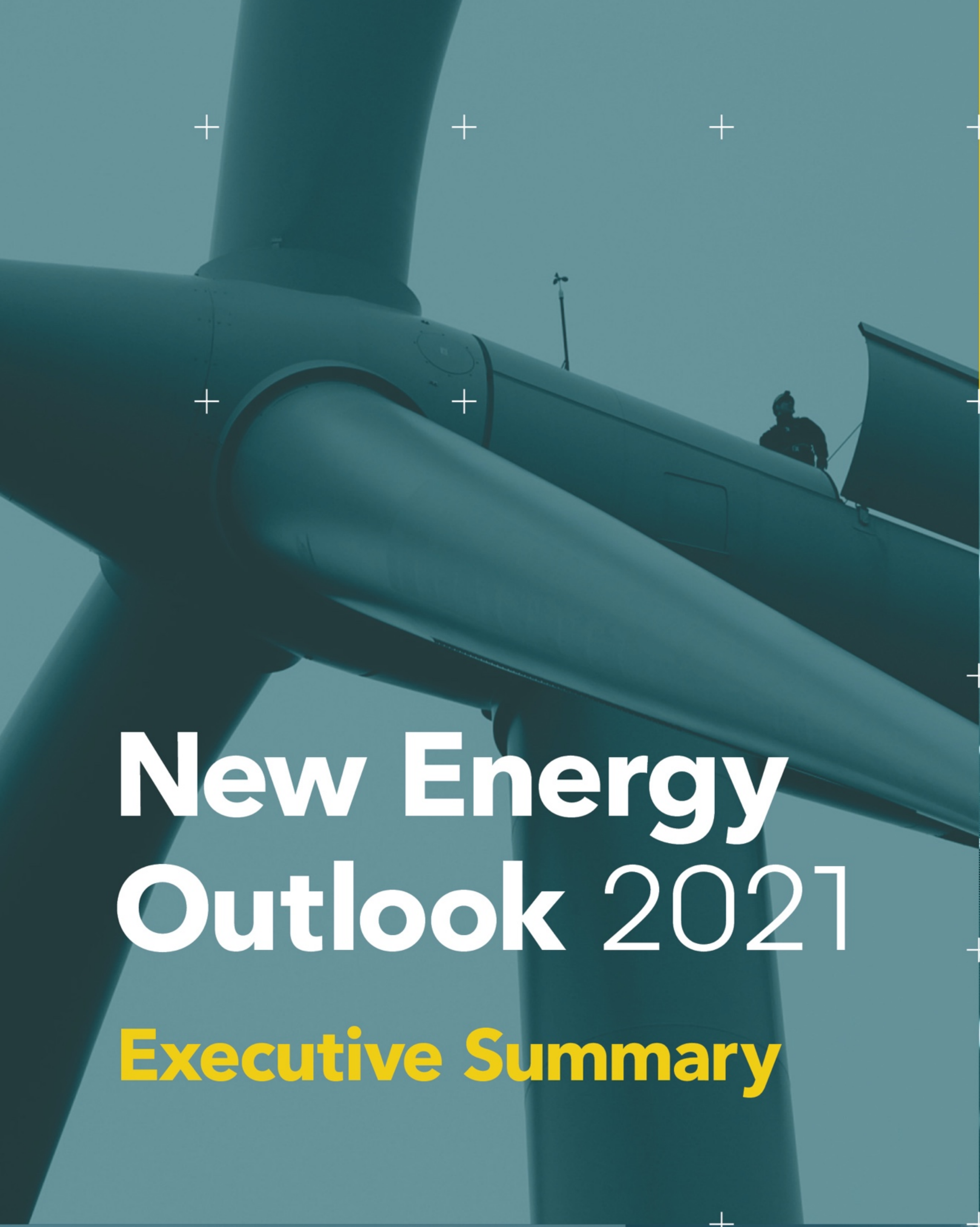
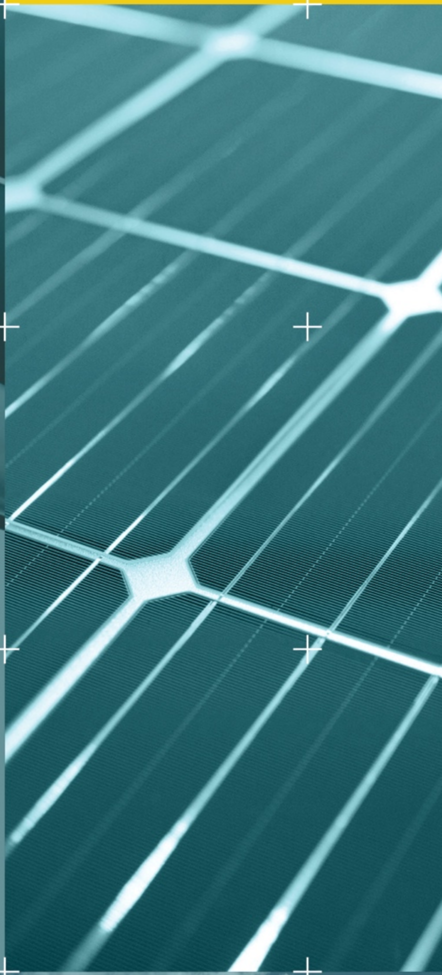




New Energy Outlook 2021

Executive Summary

July 2021
NEO21

BloombergNEF

Preamble

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

In this edition we present scenarios that reach net-zero emissions in 2050 and achieve the goal of the Paris Climate Agreement, reflecting growing interest in climate pathways. With much of the route to net-zero still uncertain, we have designed three climate scenarios that reflect dominant technology paradigms common in the public discourse. We investigate these energy futures and discuss what it means to get on track for net-zero by 2030. We hope this year's analysis is a valuable input to support strategy development and long-term planning, especially in the lead-up to COP26 in November.

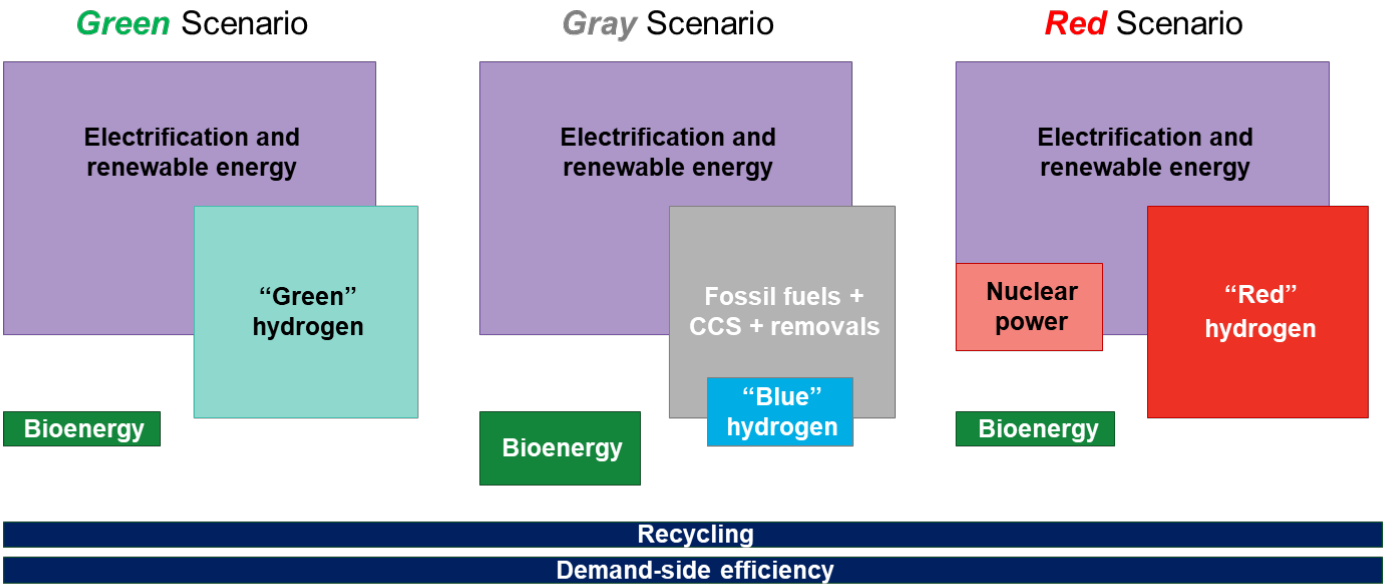
Each of our scenarios combines greater electrification, clean electricity and energy storage batteries, along with a major complementary decarbonization technology – hydrogen, carbon capture and storage, or nuclear power. There is also a role for bioenergy, recycling, efficiency improvements and carbon removals.

- Our ***Green Scenario*** is a clean-electricity and green-hydrogen net-zero pathway. Here, hydrogen produced from water using electrolyzers powered by wind and solar is applied in sectors such as industry and heavy transport, as well as in power generation to complement electrification.
- Our ***Gray Scenario*** is a clean-electricity and carbon-capture-and-storage (CCS) net-zero pathway. In this scenario, in addition to growth in electricity use and renewable power, emissions from fossil fuels in some sectors are abated using post-combustion carbon capture and storage technology. It also includes small amounts of so called 'blue' hydrogen produced from natural gas with carbon capture technology for use in non-stationary energy applications, and greater use of bioenergy.
- And finally, our ***Red Scenario*** is a clean-electricity and nuclear net-zero pathway. This one follows a similar trajectory to the *Green Scenario* except that we deploy small, modular nuclear to complement wind, solar and battery technology in the power sector, and add so-called 'red hydrogen', which is manufactured using electrolysis as in our *Green Scenario*, but this time powered by dedicated nuclear power plants.

In practice, we will probably see a mix of these solutions as each country pursues climate strategies that best suit them, considering their existing domestic economy, international trade and geopolitics. Country-specific climate pathways will be one focus of subsequent iterations of the New Energy Outlook.

This report is split into three parts. **Part 1**: **The Carbon Budget** describes sector-by-sector emissions budgets needed to keep climate change well below two-degrees above pre-industrial levels and reach net-zero emissions in 2050. **Part 2**: **Net-Zero Scenarios** describes the three scenario results in detail, breaking out each sector of the energy economy. It includes long-run growth in electricity, renewables, and batteries, as well as the opportunity for hydrogen, carbon capture and storage, and nuclear. And **Part 3**: **The Next 10 Years** translates our net-zero pathways into near-term actions to get on track by 2030.

Figure 1: Overview of three net-zero scenarios described in NEO 2021

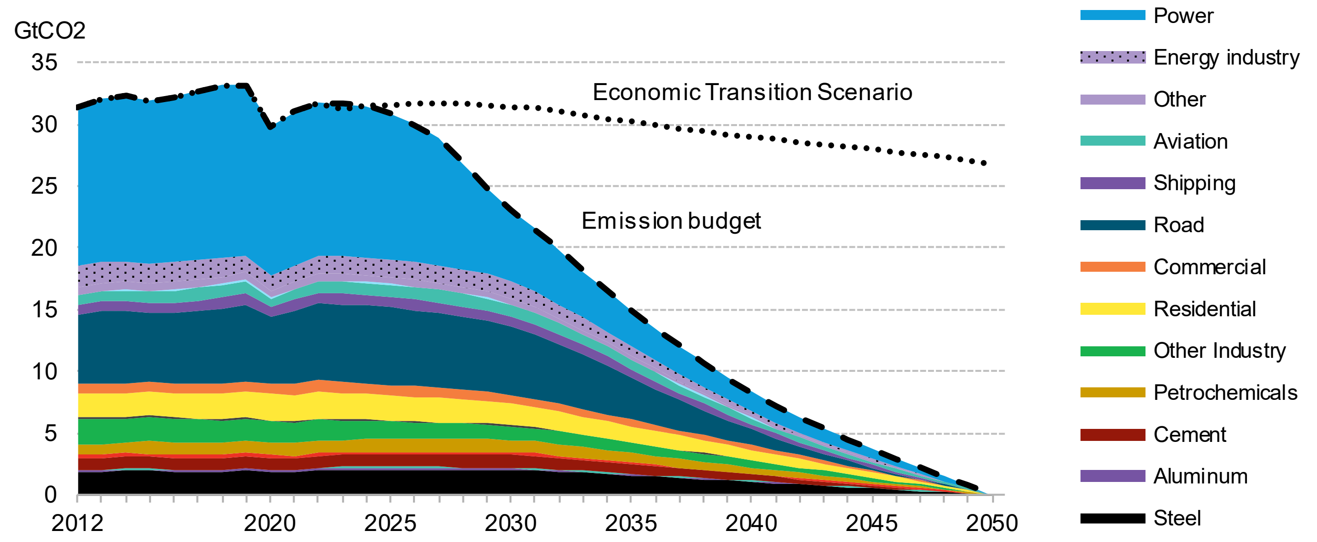


Source: BloombergNEF

The carbon budget

- Energy emissions rose 0.9% year-on-year in the five years to 2020. Based on current trends, we are on track to run out of emissions budget to stay within 2 degrees of warming in 2044. And as soon as 2028, we will have exhausted the emissions budget to stay within 1.5 degrees. This underlines the need for immediate, concrete policy action to accelerate decarbonization today: achieving mid-century climate goals will not be sufficient, unless intermediate milestones are also hit.
- To achieve global net-zero, every sector of the energy economy needs to eliminate emissions completely by mid-century. There can be no free riders. Even the hardest-to-abate sectors will need to adopt carbon-free solutions, only turning to carbon removals where absolutely necessary.
- We have constructed net-zero carbon budgets for each sector of the energy economy that achieves the Paris Climate Agreement and satisfies the principle of an orderly transition, with the rate and timing of abatement varying depending on current emissions trajectory and available abatement options in the near term.
- The resultant budget requires emissions to fall 30% below 2019 levels by 2030, and to drop 75% by 2040 to reach zero in 2050. The power sector goes fastest, following a 1.6-degree equivalent budget that sees emissions down 57% from 2019 levels in 2030, and then 89% in 2040.
- Road transport emissions drop 11% by 2030 before this accelerates during the 2030s to reach 80% below 2019 levels in 2040. Residential and commercial buildings follow a more linear trajectory, down 16% below 2019 levels by 2030 and 58% by 2040. Harder-to-abate sectors such as aviation, steel and cement go slowest, capping emissions growth this decade before a linear decline to zero mid-century.

Figure 2: Total carbon budget for the energy sector



Source: BloombergNEF

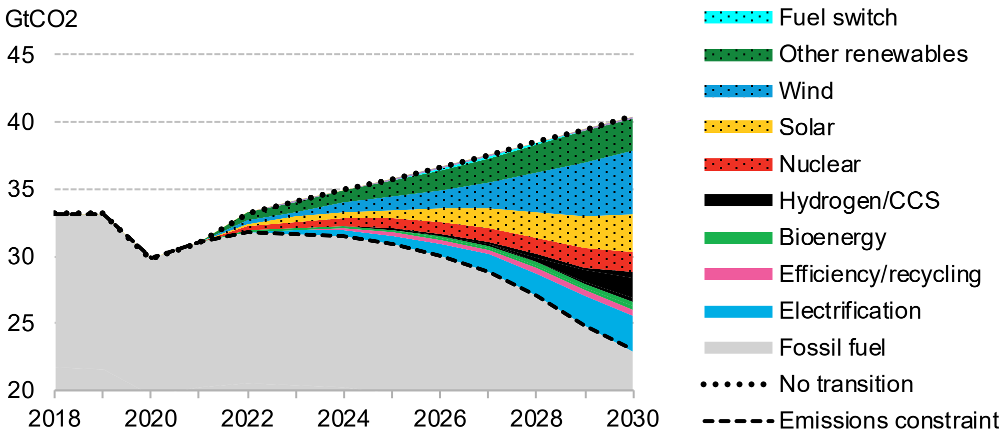
Getting on track to 2030

- The years between now and 2030 are critical in the race to net zero. For the world to get on track, there will need to be an immediate, unprecedented acceleration in deployment of existing technologies, such as renewable energy and electric vehicles. In parallel, new technologies need to be commercially demonstrated and scaled up, in order to be ready for massive deployment before the decade is out.
- More than three quarters of the abatement effort in this period falls to the power sector and the faster deployment of wind and solar PV. Another 14% is achieved via greater use of electricity in transport, building heat and to provide lower-temperature heat in industry. Greater recycling in steel, aluminum and plastics accounts for 2%, and growth of bioenergy for sustainable aviation fuel and shipping another 2%.
- Getting on track for the power sector, means adding up to 505GW of new wind, 455GW of new solar and 245GWh new battery storage on average every year to 2030 under our *Green Scenario*. This is over 5.2-times the amount of wind capacity added in 2020, 3.2-times the amount of solar and 26-times the amount of battery storage. By 2030, that adds up to a total of 5.8TW of installed wind, 5.3TW of installed PV, and 2.5TWh of batteries. These totals are up eightfold, ninefold and 176-fold from 2020 levels, respectively. At the same time, around 125GW of coal-fired capacity needs to retire on average each year so that by 2030 coal-fired power is 67-72% below 2019 levels. Capital flows need to accelerate markedly too. New investment in wind and solar capacity has been flat at around $300 billion per year for several years. This figure needs to rise to between $763 billion to $1.8 trillion per year between 2021 and 2030 depending on scenario, to get on track for net zero.
- Getting on track for transport means adding an average of 35 million electric vehicles each year so that by 2030 there are 355 million EVs in 2030 and emissions from the road segment are 11% below 2019 levels. At the same time, sustainable aviation fuels need to increase to

18% of total jet fuel use by 2030, and greater emphasis needs to be placed on operational efficiency in shipping as well as increasing biofuels use to 4% of fuel consumption.

- Getting on track for buildings means adding an average of 18 million new heat pumps each year to 2030, or 186 million by the end of the decade, while also continuing to improve building efficiency.
- Getting on track for industry means increasing the amount of aluminum that is recycled by 67% from 2020 levels. For steel the required improvement in recycling is 44% more by 2030 compared with 2020 levels. And for plastics, recycling needs to rise 149% from 2020 levels by 2030. This scrap is then feedstock for lower-energy and lower-emissions secondary production, which accounts for 43% of total steel, 37% of aluminum and 22% of plastics production in 2030. Getting on track also means increasing electricity to 50% of energy use in lower-temperature processes this decade.
- Hydrogen, CCS and new nuclear technologies do not play a meaningful abatement role in the 2020s, but getting them to scale is a critical task for this decade. In our *Green Scenario*, 1.9TW of electrolyzers need to get deployed by 2030 to kickstart the hydrogen sector. In our *Gray Scenario,* 936Mt of carbon capture and storage is in place by 2030. In our *Red Scenario,* the first small modular nuclear reactors are online by 2027, and 390MW are deployed by 2030. Without hitting these milestones, it will be difficult to achieve the rates of deployment needed in the respective scenarios in the 2030s and 2040s.

Figure 3: Total energy emissions and abatement to 2030, by source, all scenarios



Source: BloombergNEF

Getting to net-zero in 2050

- The central feature of each scenario is the switch to electricity in the end-use economy. This reduces direct emissions in transport, buildings and industry, and despite increasing electricity demand and emissions upstream in the power sector, electricity generation is generally cleaner than downstream fossil-fuel use, resulting in a net reduction. At the same time, ongoing deployment of zero-carbon power improves this equation over time.
- All scenarios include increased recycling for steel, aluminum and chemicals, as well as faster consumer uptake of rooftop PV systems and small batteries. We include carbon removal alongside CCS to offset residual emissions in this process, and a small amount of removal in

the next decade for sectors where we don't see viable abatement options, such as in cement production.

- In our *Green Scenario*, clean electricity accounts for 61% of total abatement to 2050. Greater electricity use in the form of electric vehicles, heat pumps, and lower-temperature industrial processes adds another 18%. Hydrogen in the end-use economy accounts for a further 14% of total abatement. This includes high-temperature heat in industrial processes such as steel making, chemicals and cement; aviation, shipping, some road and rail, and hydrogen used in boilers for space and water heating. Combining hydrogen in power generation and the end-use economy, it makes up almost a quarter, or 23%, of total emissions reduction.
- Abatement in the *Gray Scenario* is again dominated by clean power, which accounts for 61% of total emissions reductions to 2050. This time carbon capture and storage (CCS) allows coal and gas to continue to play a significant role. Combining CCS in power generation and the end-use economy, it makes up 18% of total emissions reduction to net-zero in this scenario. Bioenergy in the end-use economy plays a larger role in this scenario, particularly in aviation and shipping, accounting for 6% of total abatement. Increased recycling and secondary manufacturing in industry accounts for a further 3%, and a small amount of blue hydrogen in industry and transport, at 4%.
- Abatement in the *Red Scenario* looks similar to abatement in the *Green Scenario*, apart from a change in the power sector, where a nuclear renaissance reduces the volume of renewables, and its higher capacity factor and limited flexibility negates the need for hydrogen-fired generation to meet seasonal demand, but increases the use of batteries. Clean electricity accounts for 61% of total abatement to 2050. Of this, wind power makes up 41%, solar 20%, nuclear 26% and other zero-emissions power, including hydro, some 13%.

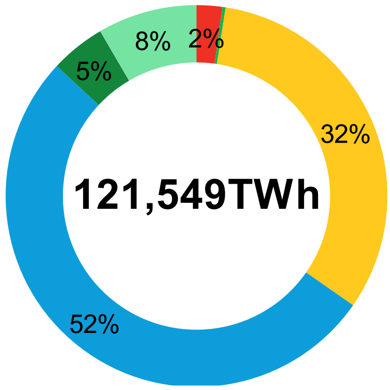
Power

- Either Wind or solar PV is the cheapest form of new-build electricity generation in almost all major markets, covering two-thirds of world population, some 77% of global GDP, and 91% of all electricity generation. Furthermore, it is now cheaper to build new renewables from scratch than operate existing coal and gas plants in a growing number of countries, including China, India and much of Europe.
- With the most cost-effective zero-carbon solutions and large, established supply chains, clean power is an obvious pathway to decarbonization for the energy sector. In each of our scenarios, the growth of electricity use in industry, transport and buildings pushes up its share of total final energy to just below 50% in 2050, from 19% today.
- Emissions reduction in the power sector is driven predominantly by new wind and solar, which make up between 59% and 65% of abatement across our scenarios. The dominance of low-cost renewables leaves relatively little space for hydrogen, CCS and small modular nuclear reactors in power generation. These technologies account for a further 14% to 26% of power-sector emissions reductions over the next three decades. By 2030, zero-carbon sources provide at least three quarters of electricity in each of our scenarios, and by 2035 they account for 90% or more.
- While it took two decades to deploy the first one thousand gigawatts of wind and solar PV, getting to zero emissions in our *Green Scenario* requires an average of around 1,400 gigawatts of renewables added every year for the next three decades. Fossil-fuel power generation is overtaken by zero-carbon sources in 2025. In our *Gray Scenario* variable renewables reach 62% of generation in 2050 and in our *Green Scenario* they reach 84%. This figure is lowest in our *Red Scenario* as nuclear is also cheap to run, and once it is

generating it can't be turned off as easily, and in our *Gray Scenario* where coal-fired power with CCS and combined-cycle gas with CCS run at higher capacity factors.

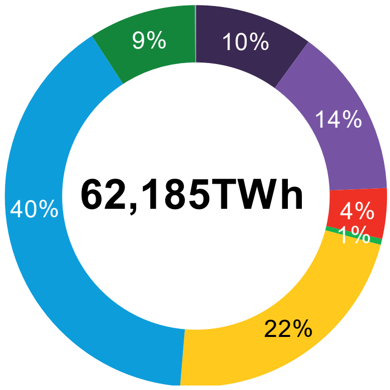
- In each scenario, utility-scale solar PV sees the most deployment, with between 7.3TW installed by 2050 in our *Gray Scenario*, and 16.5TW in the *Green Scenario*. Onshore wind is a close second, with between 5.6TW deployed by 2050 in the *Gray Scenario* and 15.4TW in the *Green Scenario*. And offshore wind reaches between 1.4TW and 9.8TW, again the higher in the *Green Scenario* and lower in the *Gray Scenario*. An additional 0.9-3.4TW of batteries help supply and demand amid this rapid growth in renewables.
- In our *Green Scenario* we see new hydrogen-fired, combined-cycle and open-cycle turbines emerging from the late 2020s, reaching 5.5TW in 2050. This is roughly the same size as all the coal, gas, nuclear and hydro power stations running in the world today put together. Our *Gray Scenario* has around 7.8TW of coal- and gas-fired power in combination with CCS in 2050.

Figure 4: Electricity generation by technology in the *Green Scenario*, 2050



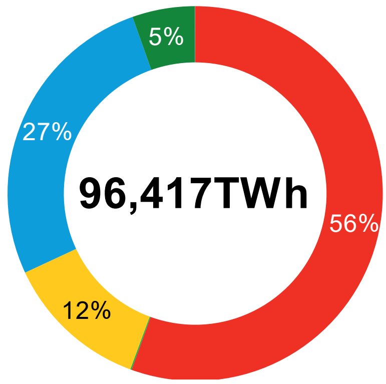
Source: BloombergNEF Note: includes both power for end-use economy and hydrogen manufacturing.

Figure 5: Electricity generation by technology in the *Gray Scenario*, 2050



Source: BloombergNEF

Figure 6: Electricity generation by technology in the *Red Scenario*, 2050



Source: BloombergNEF Note: includes both power for end-use economy and hydrogen manufacturing.

Other, Wind, Solar, Other renewables, Bioenergy, Nuclear, Hydrogen, Oil with CCS, Gas with CCS, Coal with CCS, Oil, Gas, Coal

- By 2050 there is just over 7TW of nuclear capacity in our *Red Scenario*. This is around 19-times the nuclear power capacity installed globally today. Just under half that number is used to generate around 19,000TWh of electricity in the end-use economy. The other 3,572GW of nuclear capacity is used to power electrolyzers and produce hydrogen in this scenario.
- There is a brief period in the years to 2030 when gas grows in all our scenarios to help support the rapid expansion of renewables and displace existing coal generation. However, this 'gas boom' is short-lived and gives way to hydrogen and small modular nuclear reactors, as well as coal- and gas-fired power in combination with CCS, once they become available in the 2030s.
- The rapid decarbonization needed to meet the carbon budget hurts unabated coal and gas assets. In each of our scenarios, unabated coal generation is down 67%-72% by 2030 and as much as 70% of the almost 2TW of coal installed today goes offline. In our *Green Scenario* and *Red Scenario*, coal capacity continues to fall thereafter and is phased out completely by

2050. In our *Gray Scenario*, carbon capture and storage ushers in a renaissance for coal-fired power. By 2050, there is 1.7TW of coal-fired power with CCS in the *Gray Scenario* – almost as much as all global coal capacity combined today.

Transport

- Electric vehicles (EVs) offer a commercially available, economically viable route to deep decarbonization for road transport. In all scenarios there is a significant growth in EV sales. By 2030, there are 355 million passenger electric vehicles on the road. This is double the EV fleet size in our *Economic Transition Scenario* as described in the *Electric Vehicle Outlook 2021*, and an 11-fold increase in annual vehicle sales from 2020. By 2040, there are roughly 1.4 billion EVs on the road. By 2050, some 90-95% of all vehicles are electric.
- Electricity use in aviation, shipping and rail is much smaller. In aviation, we assume that only light aircraft on commuter routes become electric. These routes make up just 5% of total aviation fuel consumption. Electric shipping is confined to domestic and short-haul general cargo vessels, ferries, cruises and other light vessels. In rail, there is good potential for electrification of freight that currently runs on diesel. However, rail accounts for just 1.6% of energy use in transport, so the impact is relatively small.
- In our *Green Scenario* and *Red Scenario*, ammonia derived from hydrogen becomes the dominant solution in shipping for new vessels post-2030, and hydrogen-fueled planes emerge for short- to medium-haul flights between 500 kilometers and 4,500km. We also assume some small uptake of hydrogen-fueled trains.
- In aviation, sustainable aviation fuel (SAF) is the only solution for long-haul flights over 4,500 kilometers, and SAF production needs to triple by 2030, reaching 18% of total aviation fuel demand in that year. By 2050, the share of SAF grows to 95% of jet fuel demand in the *Gray Scenario*, and 39% in the *Green* and *Red Scenarios*.
- In shipping, efficiency improvements make up two-thirds of emissions reductions to 2030 in each of our three scenarios, and 2050 it accounts for around 45% of abatement in the sector. In the *Green* and *Red Scenarios* biofuels and ammonia derived from zero-carbon hydrogen each make up 18%-35% of emissions reductions. In the *Gray Scenario* biofuels play a bigger role, growing to 46% of final energy in 2050, compared with 4% in 2030. On-board CCS allows oil to continue to supply around 17% of final energy in shipping by mid-century.
- While demand for mobility increases to 2050, final energy demand from transport peaks around 119,000PJ in 2025, before declining significantly to 2050 in each of our scenarios. This is due to both the mass shift to more energy-efficient electric vehicles, as well as greater efficiency in shipping and aviation. By 2050 final energy use is down by up to 44% from 2019 levels and dominated by electricity and either hydrogen or biofuels, depending on scenario.

Buildings

- One route to decarbonize building energy is to switch from direct combustion of fossil fuels to electricity. Electricity consumption in buildings is already relatively high, with appliances, air conditioners and electric heating systems accounting for just under a quarter of final energy in residential buildings today, and more than 50% of energy in commercial buildings.
- The deployment of efficient heat pumps, direct electric heaters and clean cooking systems running on electricity provide 74% of building emissions abatement to 2050 in our *Green* and *Red Scenarios*, and almost three quarters in our *Gray Scenario*. Improved building efficiency, both from new construction and higher renovation rates, provides 10% of emissions reductions in 2050.

- In each of our scenarios, around 186 million households install heat pump systems by 2030, increasing to 1.4 billion households by 2050. The transition for commercial buildings moves much faster as businesses and building owners are quicker to set net-zero targets and deploy capital.
- In the *Green* and *Red Scenarios*, hydrogen plays a relatively large role, with hydrogen-fired boilers responsible for around 40% of the abatement in the sector over the outlook. In the *Gray Scenario*, there is a larger role for district heating, which provides around 6% of total buildings-sector abatement.
- Electricity provides the largest share of final energy to the sector, growing from 32% today to 37%-38% by 2030, and then 62%-68% in 2050, depending on scenario. Bioenergy use declines across the board, down from 24% of final energy today, to 19%-20% in 2050. Hydrogen grows and makes up 12% of final energy use in buildings in our *Green Scenario* and *Red Scenario*, and district heating makes up 5% in the *Gray Scenario*.

Industry

- Industry, supplying raw materials for manufacturing and construction and finished goods to consumers, is not only a major economic sector but also an important consumer of energy. The sector used around 122,800PJ of energy in 2019, or some 30% of total final energy consumption. Processes for raw material production often require very high temperatures. This makes them highly energy-intensive and dependent on the burning of fossil fuels. Decarbonizing these high-heat processes is a challenge, especially in the short-to-medium term.
- Greater recycling in steel, aluminum and plastics accounts for 10% of the abatement effort required in industry to reduce emissions to zero in each of our scenarios. This is because secondary production is much more energy-efficient and therefore less carbon-intensive than primary production.
- Switching from fossil fuels to electricity is the single most effective way to reduce emissions in industry. This is an available, low-carbon option in many industrial sectors where low-temperature heat is required, particularly in petrochemicals and aluminum recycling. Other lower-temperature processes, such as those in food and tobacco, and in pulp and paper, can also be electrified. Switching to electricity makes up 41% to 46% of total abatement, depending on the scenario.
- Retrofitting plants with carbon capture technology and storing the CO_2, or switching to furnaces, boilers and other processes that burn hydrogen instead of fossil fuels, is key to decarbonization of high-temperature processes. Hydrogen-based heat replaces around 43% of fossil fuel use in industry to 2050 in our *Red* and *Green Scenarios*, and CCS achieves 46% of all industrial abatement in our *Gray Scenario*.
- In **steel**, greater recycling accounts for two-thirds of emission savings to 2030, with secondary production, which relies solely on electricity, reaching 45% of steel production worldwide, up from 27% today. There is also a slow shift to hydrogen for primary steel in our *Green* and *Red Scenarios* from 2025, but it accelerates from 2030, to make up 92% of emissions reductions and 77% of final energy in the sector. In the *Gray Scenario*, CCS makes up 59% of emissions reductions, and coal use rises 1% per year and supplies 67% of final energy – similar to levels today.
- In **aluminum**, final energy consumption in all three scenarios remains dominated by electricity use in primary smelting. Most of the emissions are in alumina production. Greater recycling and a switch to electricity in secondary production and alumnia refining make up

around 81% of emissions reductions to 2030. Between 2030 and 2050, hydrogen and electrification account for the largest share of emissions reductions in our *Green* and *Red Scenarios*. In the *Gray Scenario*, around 58% of emissions are removed by CCS, roughly a third by electricity, and the rest by recycling.

- There are relatively few options for decarbonizing **cement** over the next 10 years, and in our *Green Scenario* and *Red Scenario.* Fossil fuels continue to dominate energy use in the cement sector all the way to 2030, despite some increase in the use of bioenergy. In these early years carbon removals are likely needed for the sector to get on track. From 2030, hydrogen for heat production in rotary kilns becomes widespread, accounting for almost 70% of total abatement to 2050. Electric rotary kilns make up 20%, and bioenergy in conventional kilns 11%. In the *Gray Scenario*, CCS begins from 2025 and ramps up significantly post-2030. Overall, CCS is responsible for 84% of all abatement in the cement sector by 2050 in this scenario.
- For **petrochemicals**, around three-quarters of the abatement effort needed to get on track for net-zero emissions in the years to 2030 is met by greater recycling. By 2050, we assume 56% of all plastics are produced using recycled materials, up from 12% in 2020. From 2030 to 2050, the role of electric crackers grows, ultimately reducing emissions by 62% in our *Green Scenario* and *Red Scenario*. Hydrogen-fired heaters contribute 11%. Greater use of electricity is also the primary action to reduce emissions in our *Gray Scenario*, reducing emissions around 62% from 2030 to 2050. Carbon capture and storage provides another 11% of the emissions reductions, and carbon removals roughly 1.4%.

Final energy consumption

- Final energy consumption declines in each of our scenarios as a combination of demand-side energy efficiency, more recycling, a shift away from oil products, and greater use of electricity means less energy is needed even as demand for mobility, heating and manufacturing grows with population and wealth.
- In each of our scenarios, a shift to electricity in the end-use economy plays a central role in the transition, increasing to around 49% of final energy consumption by 2050. This shift is most prominent in road transport, where electric vehicles come to dominate, and in buildings, where conventional oil- and gas-fired heating systems are replaced with electric ones. There is also a switch to electricity in low-temperature industrial processes. This ‘electrification’ increases overall electricity demand by around 47% above the background trajectory in each of our scenarios.
- The consumption of coal, gas and oil products in final energy declines dramatically in each of our scenarios. Totaling around 68% of final energy today, fossil fuels drop to 30% in our *Gray Scenario* by 2050, and just 13% in our *Green* and *Red Scenarios*, where they are used only as chemical feedstock.
- In our *Gray Scenario*, coal and gas maintain a share of 10% and 9% of final energy in 2050. This is because carbon capture and storage technology allows coal and gas to continue to be used for heat production in industry. In contrast, oil products drop to 10% of final energy in this scenario from 42% today, as oil in road transport and shipping benefit little from CCS.

Figure 7: Hydrogen demand, *Green Scenario*

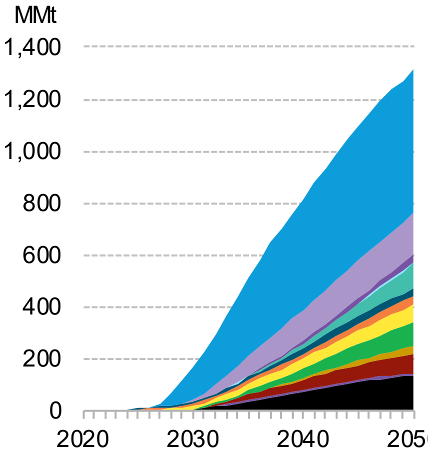


Figure 8: Hydrogen demand, *Red Scenario*

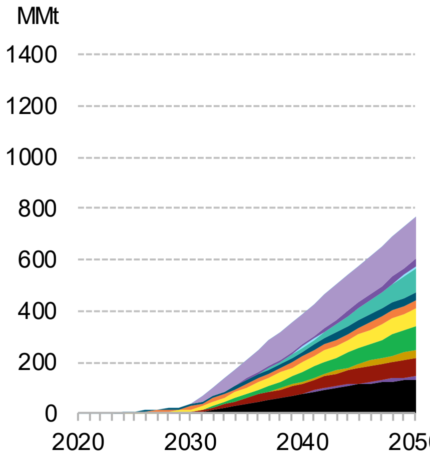
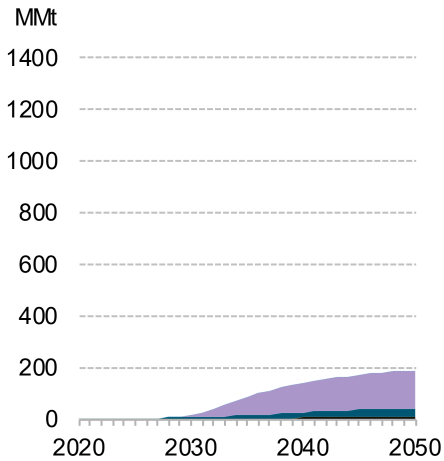


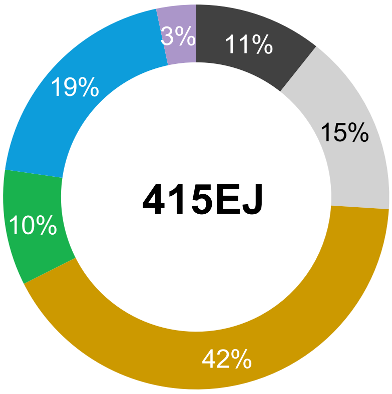
Figure 9: Hydrogen demand, *Gray Scenario*



Source: BloombergNEF. Note: Existing hydrogen market of 67MMt assumed to be supplied via current dedicated production, and 48MMt as a by-product of industrial processes.

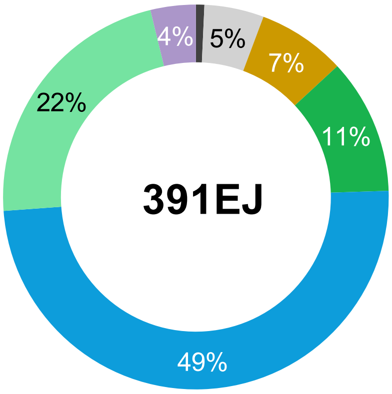
- Hydrogen emerges as part of the final energy mix in each of our scenarios. It plays a minor role in our *Gray Scenario,* with just 190Mt of demand in 2050, and a major role in our *Green Scenario*, where demand reaches 1,318Mt and around 22% of total final energy consumption, up from less than 0.002% today.
- The single biggest use of hydrogen in our *Green Scenario* is the power sector, with 553Mt, or 42% of demand, in 2050. Hydrogen consumption in the end-use economy is 766Mt in both the *Green Scenario* and *Red Scenario*. Of the end-use sectors, hydrogen is used most in industry, at 341Mt in 2050, some 40% of which goes to steel production. A further 161Mt is used in the transport sector, largely in aviation, which accounts for 95Mt, or 59%. There is another 30Mt of hydrogen for medium and heavy commercial vehicles. The use of hydrogen in buildings is smaller, standing at 102Mt in 2050 – two-thirds of which goes to residential buildings.
- As electrolyzer technology improves, we assume that the electricity required to produce one ton of hydrogen falls from 53MWh today to 45MWh in 2050. That means hydrogen manufacturing in our *Green* and *Red Scenarios* requires between 34,396TWh and 59,264TWh of electricity generation. To put these figures in context, making hydrogen in our *Green Scenario* needs around 1.9 times more electricity than is produced worldwide today. To make the hydrogen for our *Red Scenario* requires 1.5 times as much.
- Overall electricity use, including power used to make hydrogen, increases 3.7 times from 2019 levels in our *Red Scenario* to 96,417TWh in 2050. This figure is even higher in our *Green Scenario*, where electricity demand increases 4.6 times from 2019 levels to 121,549TWh in 2050. Taken together, about 71% of total final energy in our *Green Scenario* comes directly or indirectly from electricity by mid-century.

Figure 10: Total final energy, 2019



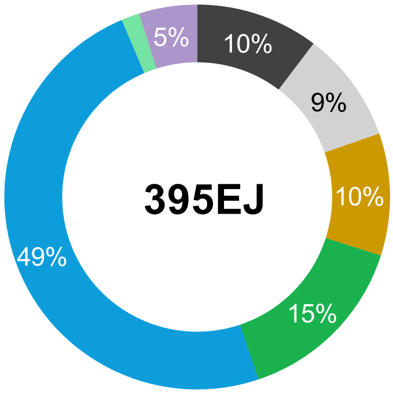
Source: BloombergNEF

Figure 11: Total final energy, 2050
Green Scenario* and *Red Scenario



Source: BloombergNEF

Figure 12: Total final energy, 2050
Gray Scenario



Source: BloombergNEF

Primary energy supply

- Each of our net-zero scenarios describes major transformations in the primary energy supply. In our *Green Scenario*, wind, PV, hydro and other renewables make up 28% of primary energy in 2030, some 62% in 2040 and 85% in 2050. This is up from just 12% today, or just 1.3% if we count just wind and solar. At the same time, fossil fuels drop at around 7% per year from 2019 to make up 10% of supply in 2050.
- In the *Red Scenario*, nuclear fuel grows to dominate primary energy supply, making up 66% in 2050. This outsized role reflects the low conversion efficiency of nuclear fuel to nuclear power and nuclear power to hydrogen. In the *Gray Scenario*, where widespread use of post-combustion carbon capture and storage means coal and gas in particular can continue to be used, fossil fuels decline 2% a year but still make up 52% of primary energy in 2050.
- Fossil fuels currently account for around 83% of total primary energy. This figure includes all the energy losses as fossil fuels are transformed into electricity, or refined, and then used to supply the end-use economy. Today, around 53% of primary energy is lost in transformation before it can do anything useful. In each scenario, peak demand for fossil fuels is brought forward, with oil and coal never again reaching pre-pandemic highs.
- The speed and timing of decline across oil, gas and coal differs among the three fuels, and by scenario. Oil is alone in seeing significant, long-term decline in all three scenarios, whereas coal and gas have a lifeline in CCS in the *Gray Scenario*. Policymakers must manage these declines carefully, considering multiple strategic goals and needs, for example, to transition capital flows away from these sectors and minimize stranded assets; to achieve a just transition for workers and communities, and to preserve economic sectors of national importance where possible.

Figure 13: Total primary energy
Green Scenario

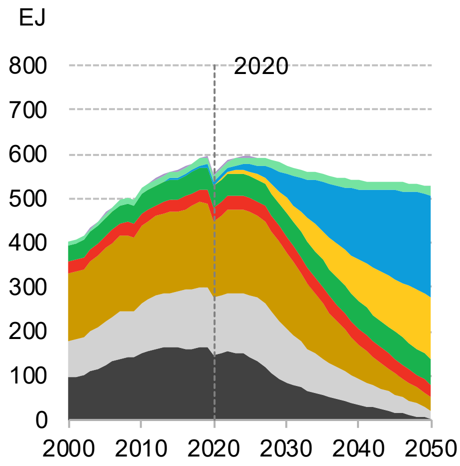


Figure 14: Total primary energy
Gray Scenario

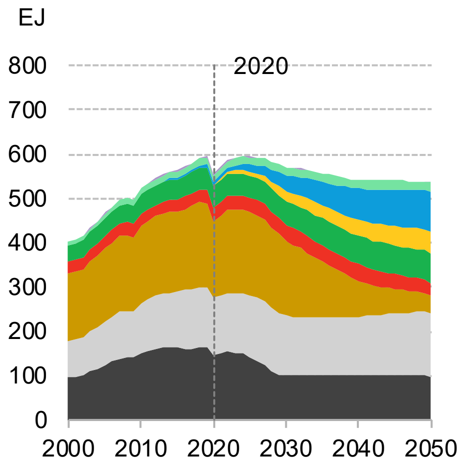
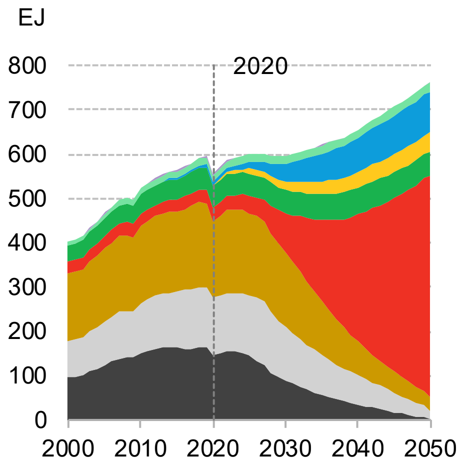


Figure 15: Total primary energy
Red Scenario



Other | Other renewables | Wind | Solar | Bioenergy | Nuclear | Oil | Gas | Coal

Source: BloombergNEF

- Coal declines quickly and early in our *Green* and *Red Scenarios*, down 5% year on year to as little as 3,807Mt in 2030 – that's as much as 45% below 2019 levels. It then continues to fall all the way to 110Mt in 2050 as decarbonization ramps up in heavy industry. The use of CCS in our *Gray Scenario* significantly slows coal's decline from around 2027, as the technology supports ongoing demand growth in power generation and high-temperature industries like steel and cement.
- Oil is hit hard in all three scenarios. Demand recovers post-pandemic but it doesn't again reach pre-crisis levels. By 2030, demand is at 85-87 million barrels per day (mbd), depending on the scenario, from around 97mbd in 2019. By 2050, the switch to electric vehicles, sustainable aviation fuel and hydrogen reduces oil demand in our *Green* and *Red Scenarios* to just 15mbd of feedstock. Even in our *Gray Scenario*, oil declines as it is mostly used in the transport sector where CCS can offer little support. In this scenario demand falls to 21mbd in 2050
- Gas continues to see some modest growth this decade, rising up to 1% per year to a peak in 2026 or 2027, depending on the scenario. This is mainly driven by coal-to-gas fuel switching in the power sector. In our *Green Scenario* and *Red Scenario*, total gas demand declines to 518 billion cubic meters in 2050, as hydrogen and other zero-carbon fuels displace gas in buildings, industry and electricity generation. In the *Gray Scenario*, the use of CCS in power and industry allows gas demand to recover from a low of about 3,400bcm in 2034, to 3,754bcm, or 4.2% above 2019 levels, by 2050.
- Overall, our scenarios describe strong decoupling of energy and emissions from economic growth. Final energy consumption relative to GDP falls 62% between 2019 and 2050. This translates into 3.1% year-on-year decline in the energy intensity of GDP. Between 2000 and 2018, final energy intensity only fell 1.3% per annum on average. Primary energy intensity of GDP falls even more strongly, down 65% between 2019 and 2050 in our *Green Scenario*, 64% in our *Gray Scenario* and 49% in our *Red Scenario*.

Investment required

- Large investments in energy infrastructure are needed for the energy transition, with capital flowing away from fossil fuels and toward clean power and other climate solutions. Despite uncertainty around overall cost of each pathway, we estimate required investment in energy supply and infrastructure of between $92 trillion and $173 trillion over the next three decades. To achieve this, annual investment will need to more than double, from around $1.7 trillion per year today, to somewhere between $3.1 trillion and $5.8 trillion per year on average over the next three decades.
- For the *Green Scenario*, around 53% of all investment goes to the production, storage and transport of hydrogen. Power generation, storage and the grid take another 37%, and fossil fuels the remaining 10%. In contrast, the *Red Scenario* requires 55% of investment flows to the power sector, 35 percentage points of which goes to power generation – both renewables and nuclear. Hydrogen makes up to 34% and fossil fuels 11%. Again, in the *Gray Scenario* investment in power generation, energy storage and the grid makes up the bulk of investment, at 55%, fossil fuels account for 20% and CCS some 15%. The final 8% goes to hydrogen.

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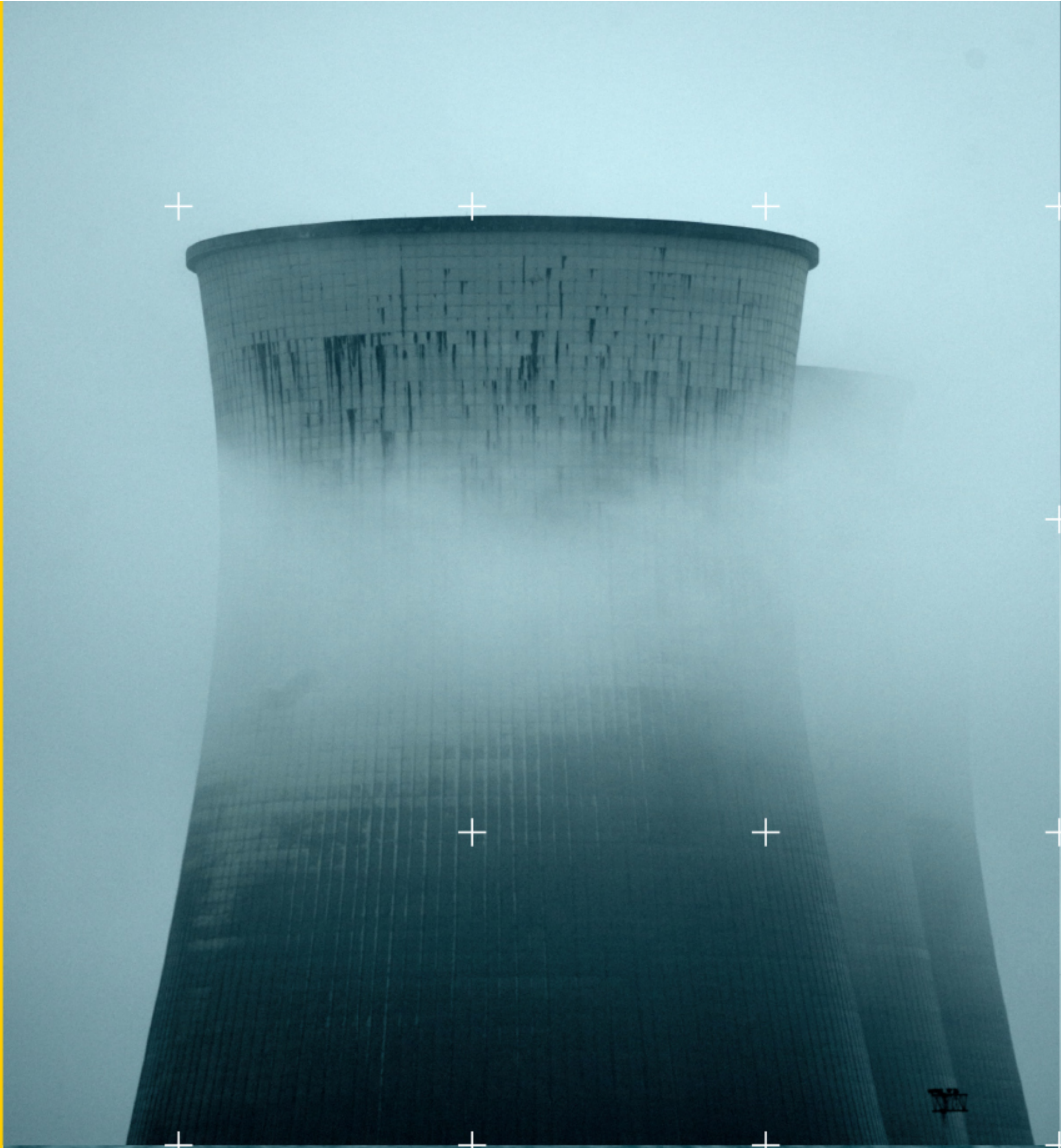

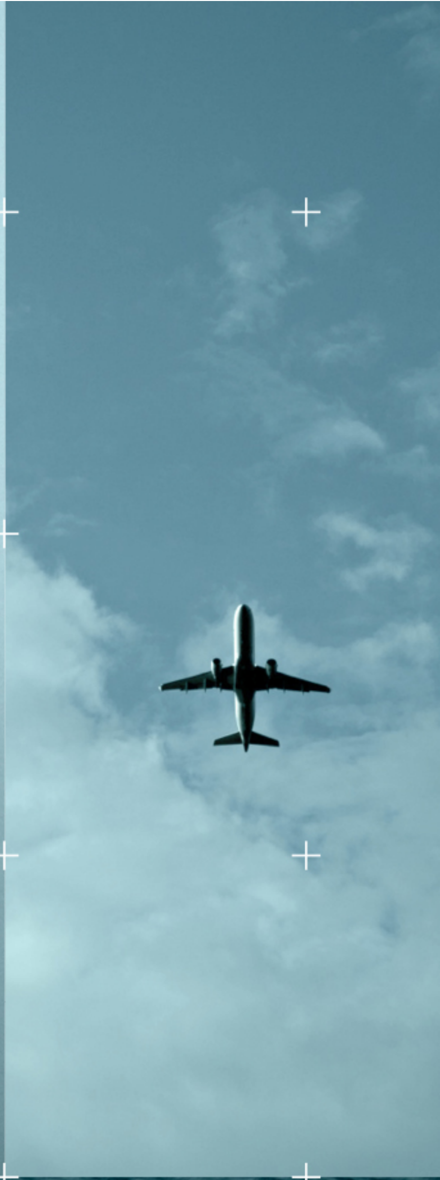


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