Shell scenarios

The Energy Security Scenarios

Summary

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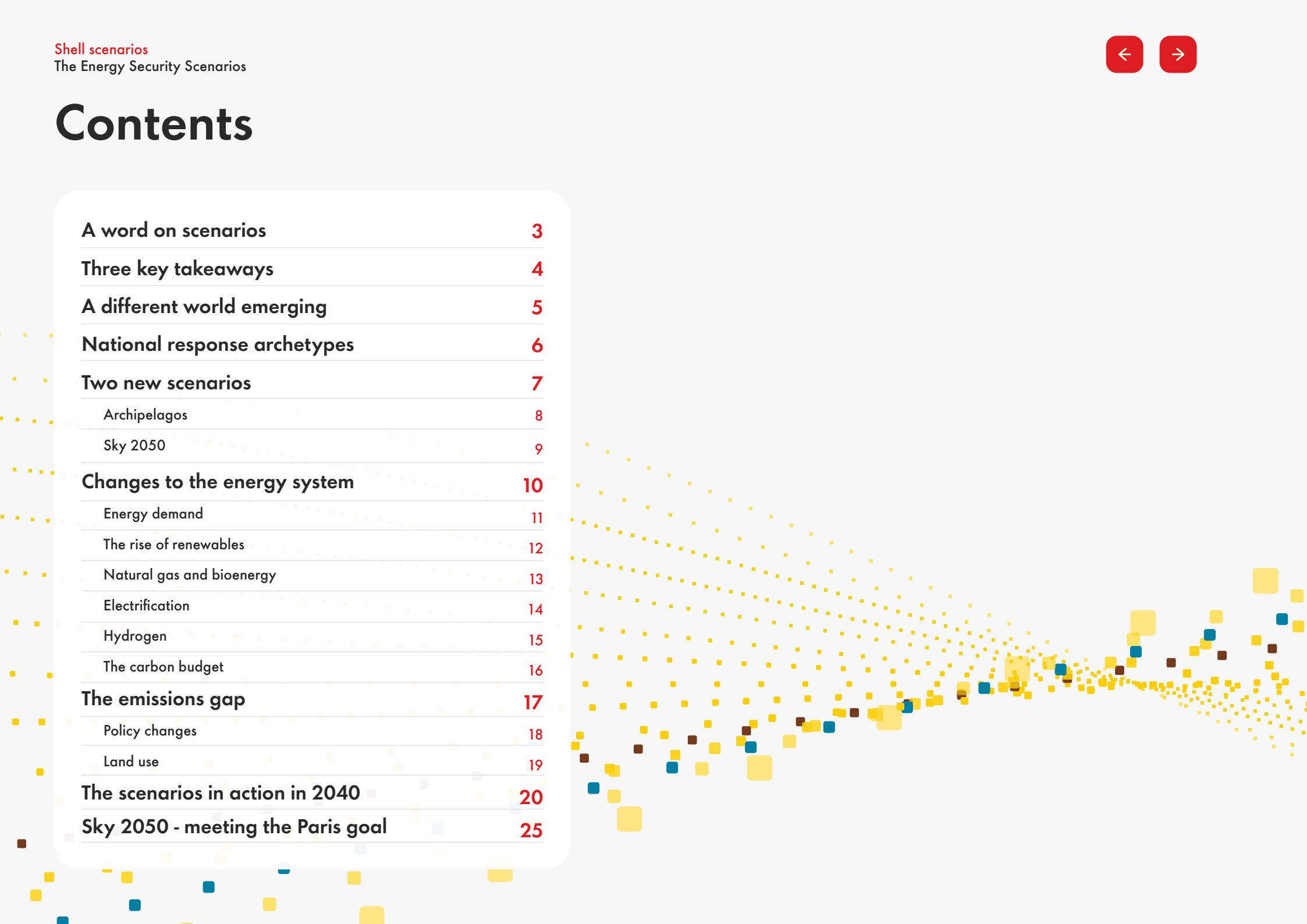


A word on scenarios

What we present here are scenarios. To get the most from them, it is important to know what these are and what they are not. Scenarios are an exploration of how the world could possibly evolve under different sets of assumptions. They are informed by data, constructed using models and contain insights from leading experts in the relevant fields.

The process of creating scenarios involves considering different versions of possible futures. Some of these may seem unlikely or even surprising, yet they could still be possible. Other scenarios explore the possible outcomes of choices the world already appears to be making.

This perspective offers the reader the chance to evaluate those choices. It is by exploring the assumptions behind such possible futures that readers can expand their world view and consider the options for significant change. An example of one such assumption, which comes from the **Sky 2050** scenario detailed in these pages, is that all sales worldwide of passenger vehicles with an internal combustion engine end by 2040. The biggest assumption in **Sky 2050** is that multiple changes of this scale and speed occur simultaneously across the energy system.

The value to Shell of producing scenarios is to help senior management think about the long-term challenges the business could face. In this way, the thinking in Shell's scenarios may influence the company's strategy – as one of many inputs – but that is as far as it goes: scenarios are not expressions of Shell's strategy, they are not Shell's business plan and they do not necessarily reflect the thinking or behaviour of the business.

Shell also publishes some of its scenario thinking to help governments, academia and business to think about the long-term challenges that they, and the world at large, could face.

As useful as scenarios are, however, they are not created by using a crystal ball. So, while scenarios may contain a great deal of valuable information and insight, they are absolutely not predictions or expectations of what will happen, or even what will probably happen. Nor are they statements of what should happen. In short, scenarios are possible worlds built from incomplete and uncertain information. That is true of all scenarios, not just those created by Shell. All scenarios probably hold truth, but all of them are likely to be wrong in one way or another.

Ultimately, for all readers, scenarios are intended as an aid to making better decisions. They stretch minds, broaden horizons and explore assumptions.

Three key takeaways

Society

With a security mindset dominant, the world is entering an accelerating but increasingly competitive transition. This is a world of stark regional differences and behaviours. Nations struggle to achieve security in all its aspects, including the economy, borders and climate.

Energy

The trend is away from fossil fuels and towards electricity generated by renewables and nuclear. The countries which, today, are the least developed in the world will, as the century progresses, come to dominate global energy demand. Finding ways for these countries to both develop and decarbonise is essential.

Climate

The accelerating energy transition means that the possible global temperature outcomes are narrowing. The Energy Security Scenarios cover a temperature range between 1.2°C and 2.2°C warmer than pre-industrial times by 2100, far lower than the genuine concerns just a decade ago that the range extended beyond 4°C. Both scenarios rely on using sinks to remove and store carbon dioxide, and the final temperature outcome rests to a large extent on the world's success in deploying such sinks.

A different world emerging

At COP26 in Glasgow, world leaders gathered and collectively promised to deliver on the stretch goal of the Paris Agreement and limit global warming to 1.5 °C. Yet, within months, the Russian invasion of Ukraine had caused political upheaval and pointed the global agenda towards energy security.

In the wake of COP27 in Sharm el-Sheikh, this publication seeks to explore where the world goes from this point, with a focus on the possible energy and climate outcomes. We start with the Shell scenarios from early 2021, namely **Waves**, **Islands** and **Sky 1.5**. Each of these was built to explore the consequences of different underlying societal priorities: creation of wealth, concern for security and a desire for improved health and well-being.

When Russia invaded Ukraine in February 2022, the fragile post-Cold War global order cracked apart. There had already been worries about a shortfall in the supply of fossil-fuel energy, but the invasion made it clear for all to see that 80% of society's energy still comes from oil, gas and coal. As nations respond, the world is collectively plunging into the security mindset that dominates our **Islands** scenario, but with distinctly different national responses.

With the world dominated by a security mindset, four different responses to the situation, or archetypes, are beginning to be visible. Countries appear to be behaving similarly, based on how vulnerable they are to energy supply failures and energy price volatility.

Four evolving energy transition archetypes, each with a different pace of decarbonisation.

National response archetypes

The archetypes are:

Green Dream, which can be observed in the European Union. The EU's wealth makes it relatively able to deal with energy price volatility, but its advanced economies and depleted energy reserves make it highly vulnerable to energy supply failures. These countries seek security by driving hard to reduce energy use, increase energy efficiency and massively boost renewable generation.

Innovation Wins, which can be seen in countries like the USA and major resource-holders such as the United Arab Emirates. These countries are often self-sufficient in energy so are not vulnerable to supply failures, but their political systems are particularly exposed to swings in the energy price. They do not feel so threatened in the short term, but invest heavily in innovation and infrastructure as longer-term solutions to their energy needs and the needs of their energy customers.

Great Wall of Change, which is mainly relevant to China. The size of China's economy, its large coal reserves and the scale of the investments it is making in its own energy supply and infrastructure insulate it from both supply and price concerns. China takes a cautious approach, aware of the need to move away from coal and carefully monitoring global energy market developments. It looks to use its manufacturing strength to build its position as a global low-carbon energy powerhouse.

Surfers. These are countries that do not typically produce significant amounts of energy, which makes them vulnerable to both energy supply disruption and price swings. They seek out partnerships with others and try to ride the opportunities created by the actions of other archetype countries. They subdivide into:

Emergent Surfers, like India, which quickly adopt new technologies.

Rising Surfers, which include the world's least developed economies. These nations are more focused on establishing basic foundations, such as expanding access to modern energy sources.

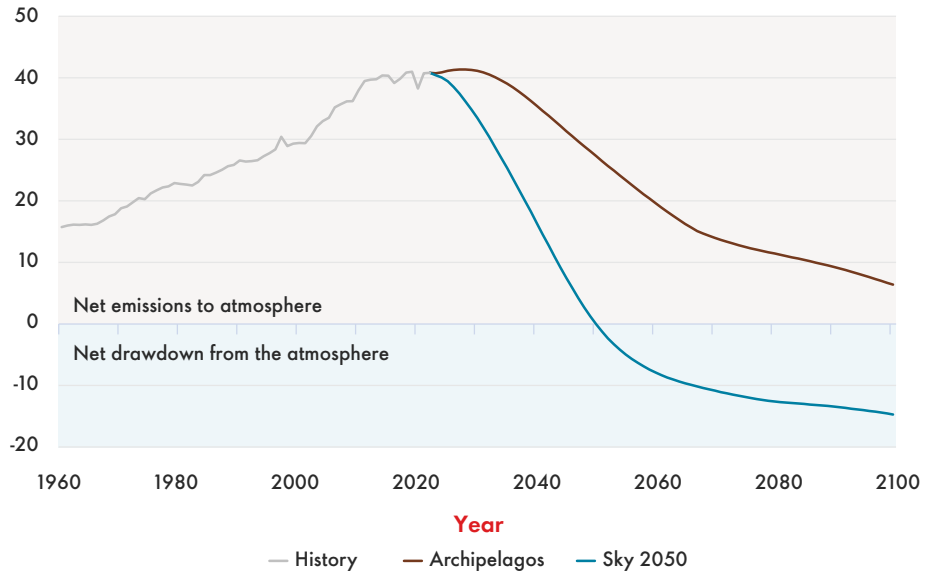
Two new scenarios

As the security mindset dominates, national interests take precedence within political agendas. These agendas are shaped by energy prices, supply concerns and growing climate pressures.

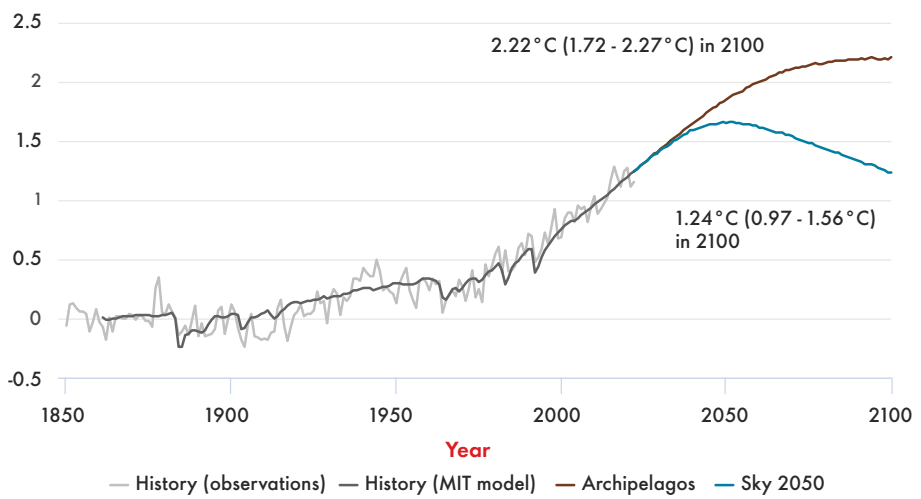
In this landscape, a tension becomes evident between what was promised to the world in Glasgow and what nations must do to calm immediate energy concerns.

Two scenarios emerge from the turmoil: **Archipelagos** and **Sky 2050**. The **Archipelagos** scenario seeks to follow a possible path from where the world was in 2022, while **Sky 2050** takes a normative approach that starts with a desired outcome and works backwards to explore how that outcome could be achieved. In the case of **Sky 2050**, the future it is aimed at is a world that achieves two key things: net-zero emissions by 2050 and global warming limited to 1.5°C by the end of the century.

Global anthropogenic CO_2 emissions from energy use, industrial processes and land use



Global mean surface temperature above 1850-1900 baseline: Sky 2050 and Archipelagos



Historical temperature data are taken from HadCRUT5 (November 2022). In these scenarios, we use global mean surface temperatures (ensemble medians) as modelled by the MIT Joint Program (December 2022). The figures in brackets refer to the 'very likely' range, defined as the 90% interval.

Two new scenarios: Archipelagos

In Archipelagos, the security mindset that is dominant today becomes entrenched worldwide. Global sentiment shifts away from managing emissions and towards energy security.

Despite this shift, the drive for energy security still includes the greater use of low-carbon technologies. These dynamics translate into global emissions peaking in the 2020s and falling from the mid-2030s. The energy transition accelerates compared to the 2021 **Islands** scenario, which set out a late and slow transition pathway.

Nationalism underpinned by renewed militarism grows, especially in those regions straddling two spheres of influence. The war over whether Ukraine belonged with Europe or with Russia turns out to be a template for any number of other disputed countries and territories. In many ways, the geopolitical order of the 2030s resembles the 19th-century world of power alliances more than the globalised post-Cold War settlement. As a result, global agreements, including pledges to support the UN Sustainable Development Goals and the Paris Agreement on climate change, fade in prominence.

Competition between nations spreads into many aspects of life, and results in multiple technology races – including in relation to new energy technologies. By 2040, a multi-polar trading world has developed with fierce competition over trade with India and some African and Latin American nations.

Rather than working together to address climate change, clusters of nations now scramble to secure energy supply and focus on building energy resilience to withstand future shocks. Emissions fall throughout the century, with net zero in sight, but still not achieved, by 2100.

The global average surface temperature is still rising in 2100, but is levelling off at around 2.2°C as emissions close in on net zero.

Two new scenarios: Sky 2050

In Sky 2050, long-term climate security is the primary anchor, with specific targets to reach net zero by 2050 and ultimately bring the global average surface temperature rise to 1.5 °C by 2100.

The war in Ukraine translates into gradual progress in the early 2020s, but that progress gains momentum towards the 2030s. This happens as the need to deliver low-carbon energy infrastructure takes on an urgency of its own, driven largely by security and price concerns. While progress is initially difficult to see, emissions start to fall from 2025 and, by 2040, the goal of net-zero emissions is clearly in sight. The energy system rapidly transforms.

At the outset, international institutions appear ineffectual in supporting the Paris Agreement and nations cling to archetype behaviours, driven by their vulnerability to energy supply failure or energy price volatility. Soon, however, citizens themselves start to push for change within their own countries and rapidly adopt new technologies to deliver environmental security. Politicians adopt climate-friendly policies to secure support, especially among the young. Quickly these policies become national priorities, and success in fulfilling their aims becomes a measure of national power.

What might have taken decades to negotiate now takes much less time as individual nations, cities and companies "just go for it!", with the world reaching net-zero emissions in 2050. Despite this achievement, there is a period in which the global average temperature rise is more than 1.5 °C warmer than pre-industrial levels. The world goes on to bring this back below 1.5 °C by 2075 and then to around 1.2 °C by the end of the century. The overshoot is an outcome some will consider unacceptable but, as our modelling implies, any discussion on how to prevent a breach of 1.5 °C would need to include action greater than the already substantial measures laid out in **Sky 2050**, which may not be technically feasible.

Changes to the energy system

The tension between the promises made at COP26 in Glasgow and the action needed to address immediate energy price and supply challenges is just the start. With security concerns dominating, as events unfold governments find themselves repeatedly drawn into the frame in pursuit of solutions. The pain caused by high energy prices demands quick, decisive action, while the pressure of a rising global surface temperature requires relentless action over many decades.

Both scenarios start with an immediate trade-off between solving short-term needs, by using fossil fuels, and meeting longer-term goals. In **Sky 2050**, that compromise adds greenhouse gas emissions and results in a greater overshoot of 1.5°C than might otherwise have been the case. In time, this larger overshoot is balanced out with greater action to remove emissions from the atmosphere. In **Archipelagos**, an even stronger use of fossil fuels to meet immediate energy needs results in higher short-term energy prices worldwide, with price rationing having a major effect in balancing global supply.

Sky 2050 brings society rapidly to net-zero emissions, but doing so requires major interventions from policymakers in the energy system. This includes action such as the forced retirement of fossil-fuel assets, punitive carbon prices, the rapid introduction and scaling up of early-stage technologies and significant energy conservation through efficiency and even economic austerity. Governments are forced to restrict societal choices, such as limiting the selling of internal combustion engine vehicles and limiting meat consumption. They also force through the construction of wind turbines and power lines in places where many citizens do not wish to see them, such as sites of natural beauty. Yet no government today has such a comprehensive mandate, and few, if any, appear willing to seek it at the polls.

Archipelagos sees higher fossil-fuel demand compared to **Sky 2050**, and meeting this demand requires investment. Yet activists, and an increasing number of investors, have little appetite for further oil and gas production. With such an impasse, governments are forced to step in to ensure money flows under threat of significant financial penalty. As investments are made, the prospect of a global temperature outcome well below 2°C vanishes, let alone hopes of 1.5°C. This leads to social unrest and the prospect of the early, and possibly forced, closure of fossil-fuel assets later in the century as solar, wind and hydrogen begin to dominate. Net-zero emissions comes late, and the process of getting there is painful, with society split and some investments ultimately failing.

Sky 2050 and **Archipelagos** see the growing tensions play out in different ways and, while both find a pathway forwards, both worlds face significant challenges.

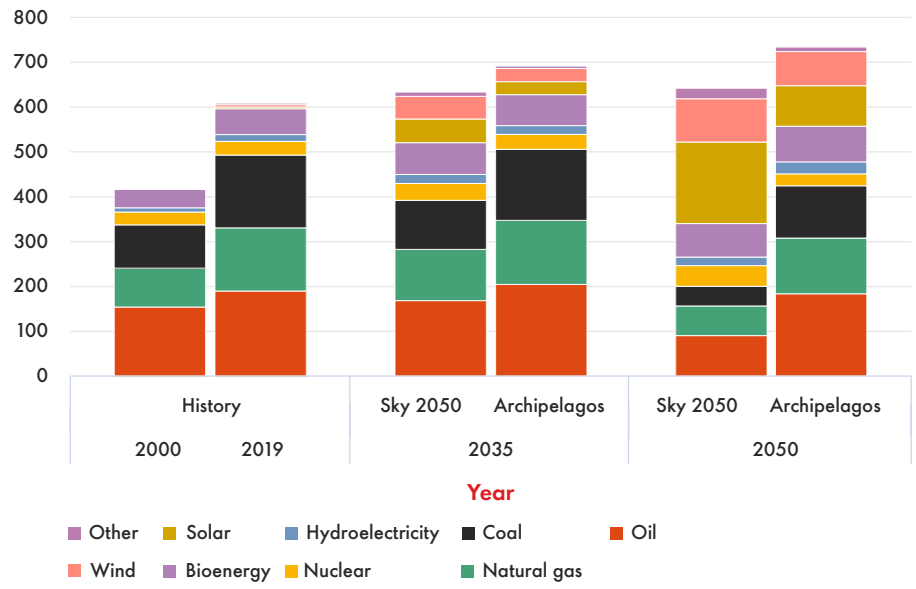
Energy demand

Globally, primary energy use rises throughout the century. Efficiency is key to limiting the growth in overall energy demand in Sky 2050, with electrification, retrofitting buildings and behaviour change all contributing.

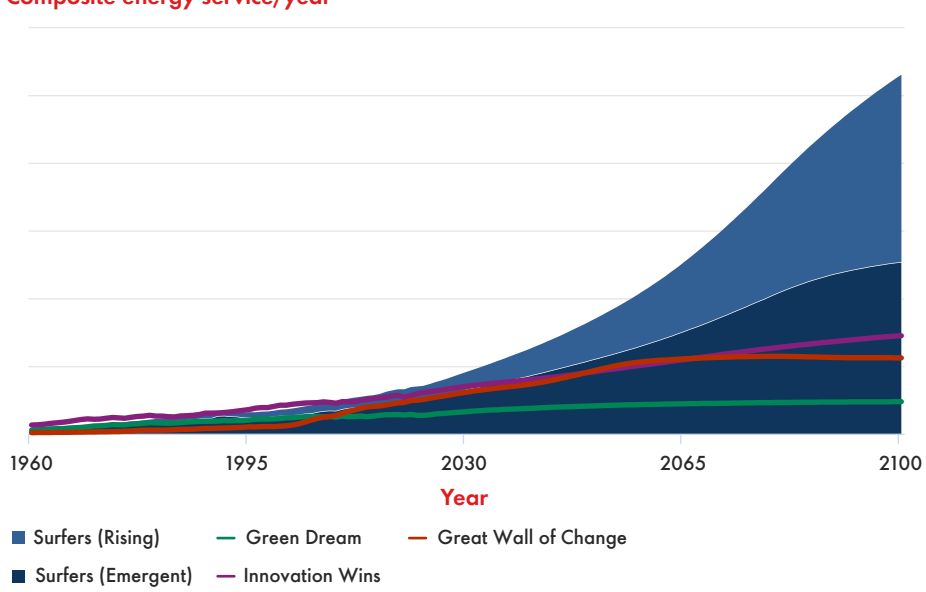
By 2050 nearly half of global energy demand comes from **Surfers**, with relatively little change elsewhere. By 2100, **Surfers** dominate global energy needs, with all demand growth coming in that group of countries.

The **Rising Surfers** see the fastest growth in energy demand. By the end of the century, the population has increased by 2.5 billion compared to 2020. Importantly, over the same time frame, access to energy services has become widespread. As a result, energy demand more than quadruples for this group by the end of the century.

Primary energy trends to 2050



The use of energy services by Surfers countries more than quadruples throughout the century



The rise of renewables

The energy system is at a renewable energy turning point.

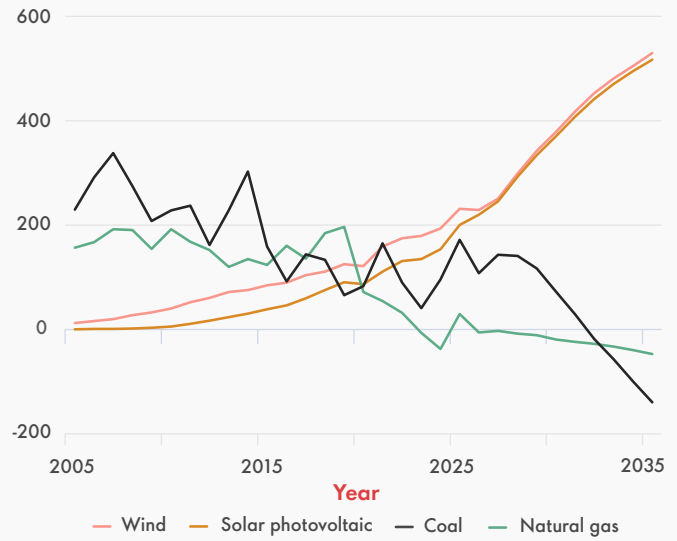
For solar photovoltaic alone, the world is already adding around 200-250 gigawatts (GW) of capacity each year, delivering some 250-300 terawatt-hours (TWh) of electricity. In **Archipelagos**, this grows to around 400 TWh in the early 2030s. This level of growth is greater than the additions of both coal and natural gas combined in the early 2020s.

Both coal and natural gas stop growing as sources of electricity in the 2030s, with no further net addition of generation from these energy sources.

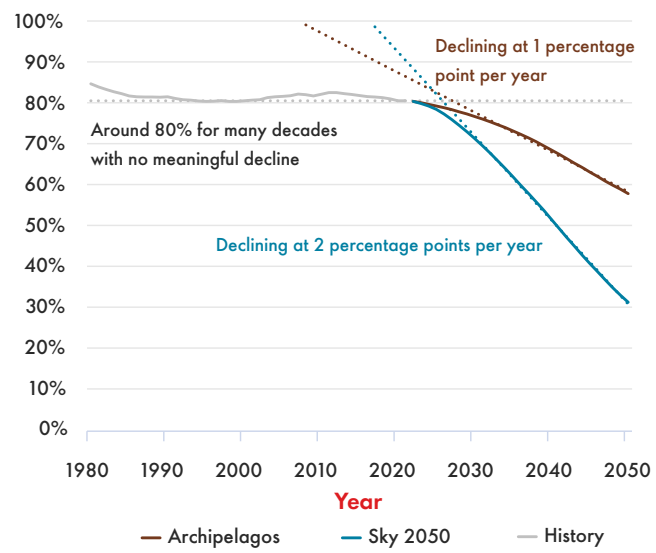
Fossil fuels lose market share. Over the past 60 years, the share of fossil fuels in primary energy has barely moved at around 80%, but this is about to change under both scenarios: by 2040, coal, oil and natural gas have all seen their market share peak. The declines that follow, in **Sky 2050**, are very pronounced.

The global primary energy mix shifts rapidly towards solar and wind, with nuclear also growing in the 2030s and 2040s. In **Archipelagos**, the early trends are similar, but then lag behind those seen in **Sky 2050** by 10-20 years.

Year-on-year change in electricity production, Archipelagos



Oil, coal and gas as a fraction of total primary energy



Natural gas and bioenergy

Natural gas demand starts to fall in the 2020s in Sky 2050. The need to rapidly cut emissions dictates a shift directly to solar, wind and nuclear, with any future natural gas use linked to carbon capture and storage (CCS). Despite this, natural gas continues to be used in the form of liquefied natural gas (LNG).

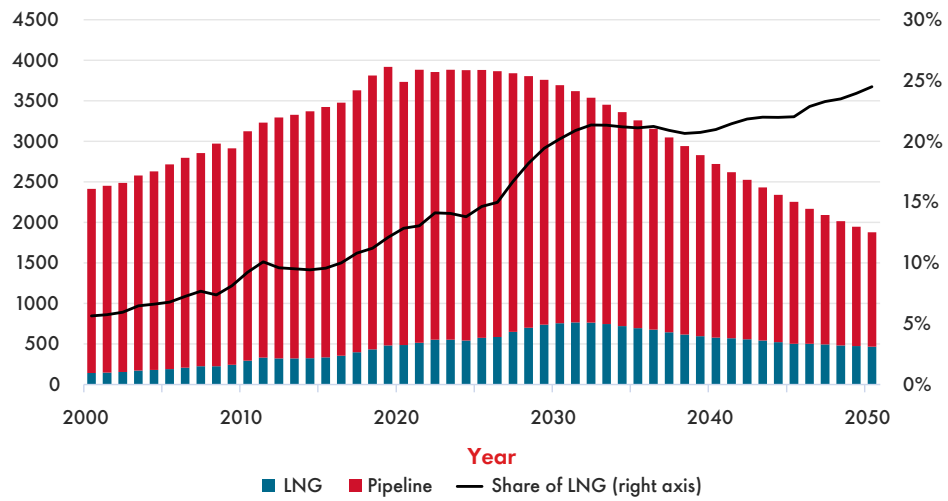
This is partly due to the fact it can be flexibly delivered to multiple locations and partly because of its role at industrial facilities, where natural gas continues to be used as both a fuel, with CCS, and to produce chemicals.

Both **Sky 2050** and **Archipelagos** rely on bioenergy. By 2050, the use of bioenergy in **Archipelagos** doubles, and nearly triples in **Sky 2050**. By the end of the century, in both scenarios, bioenergy use is around four times that of 2020. However, the underlying trends in the scenarios differ.

- In **Sky 2050**, there is dominant early growth of liquid fuels, mostly to replace oil in hard-to-decarbonise transport sectors – for example, as sustainable aviation fuel.
- In **Archipelagos**, growth is more in the commercial use of biomass in sectors such as power generation and industry.

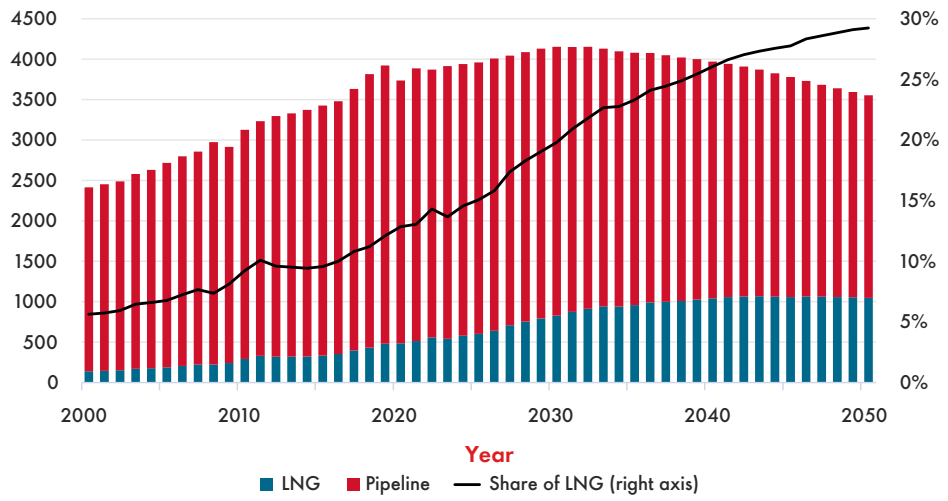
World natural gas production in Sky 2050

Billion cubic metres/year



World natural gas production in Archipelagos

Billion cubic metres/year



Electrification

Electrification is critical to achieving net-zero emissions. The major energy system shift in both scenarios is the rise of electricity in the final energy mix.

There is a major change in the role of electricity, starting early in the 2020s in **Sky 2050**, and by 2030 in **Archipelagos**.

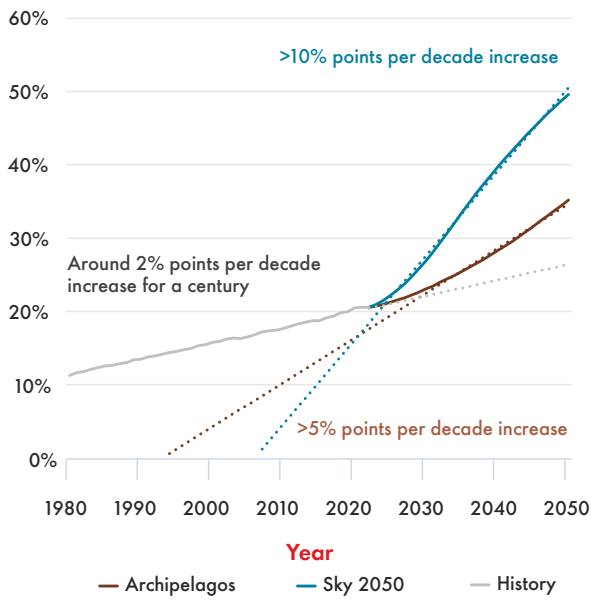
Both scenarios carry unprecedented change, with electricity growing at more than five percentage points of final energy market share each decade in **Archipelagos**. In **Sky 2050**, the increase is 10 percentage points every 10 years. This compares with a century-long historical trend closer to two percentage points per decade.

The electrification of passenger road transport kick-starts the shift, followed by residential and commercial electrification.

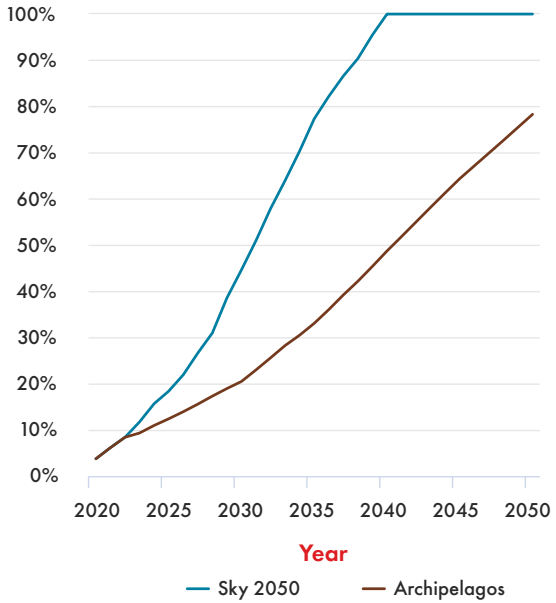
Electric vehicles are on the rise. In both scenarios the transition away from the internal combustion engine passenger vehicle moves at a rapid pace. **Sky 2050** shows a complete transition to battery-electric passenger vehicles in all countries by the mid-2050s. **Archipelagos** lags **Sky 2050** by up to 20 years, with a long tail of combustion engine use in **Rising Surfers** countries.

The electrification of the energy system will involve a substantial increase in the demand for certain minerals. Examples are copper, nickel, lithium and cobalt. These are needed for critical components within the emerging technologies underpinning the transformation. This could place significant pressure on the mining industry, where the current pace of growth would need to at least double to fulfil demand over the next 20 years.

Electricity as a percentage of total final energy



Electric vehicle share of new car sales

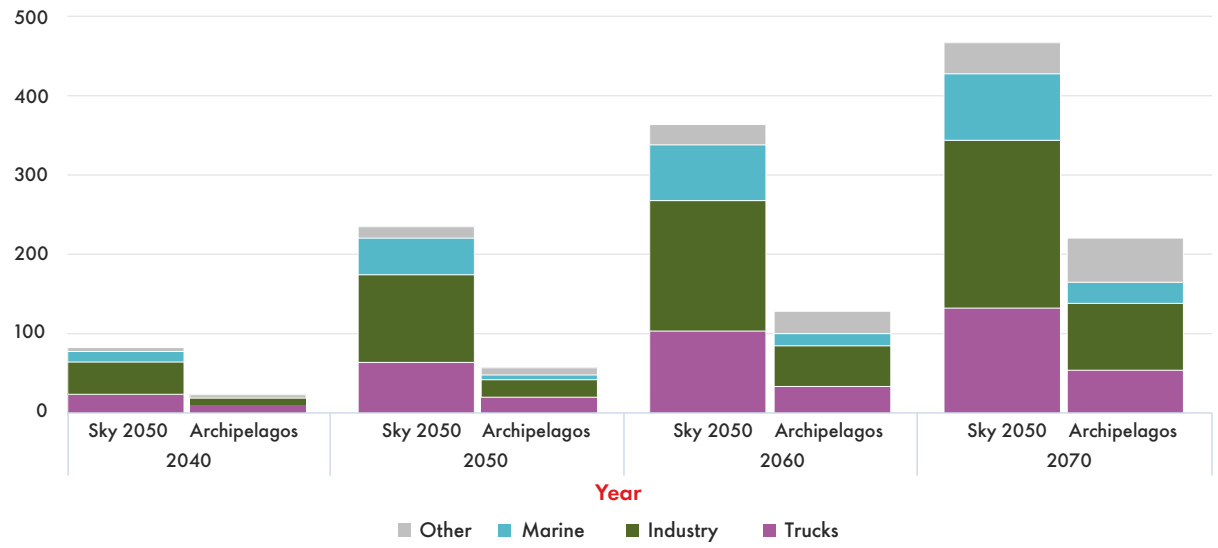


Hydrogen

Hydrogen becomes an important part of the energy system during the 2030s. It makes up 12% of final energy use in 2070 in Sky 2050, and more than 4% in Archipelagos.

- In **Sky 2050**, the 2030s see the arrival of container ships fuelled by hydrogen or hydrogen-based ammonia, but the emergence of this technology is a decade later in **Archipelagos**.
- In **Sky 2050**, the first passenger flights on hydrogen-fuelled planes take place in 2040.
- By 2050, around a third of the smelters in the world run on hydrogen in **Sky 2050**.
- In both **Sky 2050** and **Archipelagos**, hydrogen becomes the fuel of choice for long-distance heavy freight road transport. The first commercial hydrogen trucks appear on the road by the late 2020s.
- Hydrogen demand growth in **Sky 2050** is two exajoules (EJ) per year in the 2040s, five times the rate of **Archipelagos**. In **Archipelagos**, rapid growth does not emerge until after 2050. Achieving an annual growth rate of 2 EJ would require the equivalent of around 700 250-megawatt (MW) electrolysers every year, with enough renewable energy generation capacity to power them (250 MW is the size of the largest electrolyser due to be built in 2023).

Global hydrogen use by sector, Sky 2050 and Archipelagos



The carbon budget

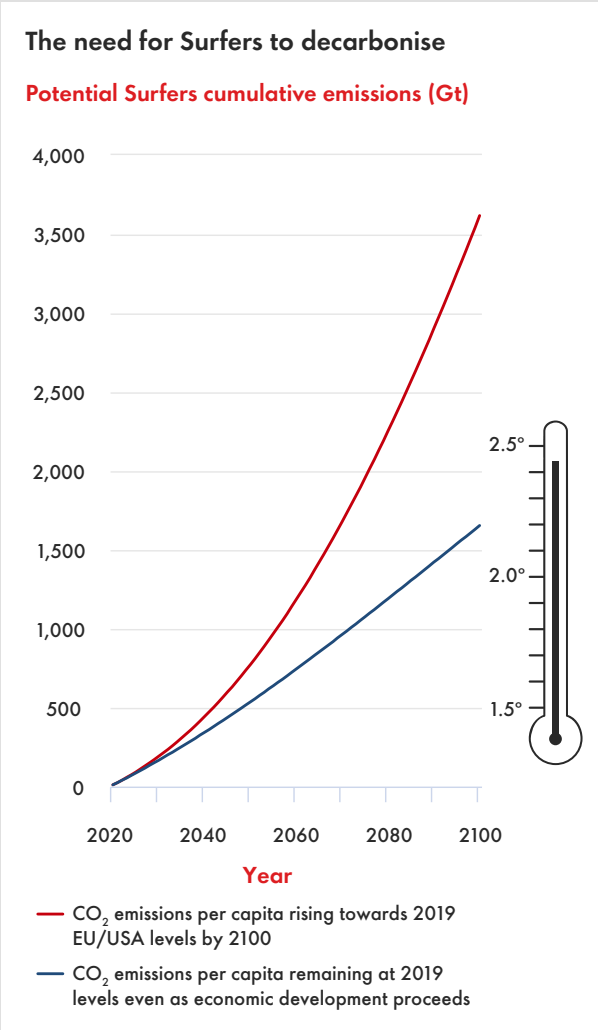
In 2021, the Intergovernmental Panel on Climate Change (IPCC) reported that if the world is to limit global warming to 1.5 °C, its carbon budget – the cumulative CO_2 emissions for a given temperature outcome – is 500 gigatonnes (Gt).

This is based on a starting point of January 1, 2020, and gives a 50% likelihood of limiting global warming to 1.5 °C. By the end of 2022, around 120 Gt of this budget had been used, leaving 380 Gt. Annual global emissions were more than 40 Gt of CO_2 in 2022, and are expected to be at around the same level in 2023. This means that managing overall emissions within the 380 Gt budget left at the start of 2023 is now a near-impossible task.

Overshoot seems almost inevitable even in a rapid transition. In agreeing to the Glasgow Climate Pact, countries pledged to reduce "global carbon dioxide emissions by 45% by 2030 relative to the 2010 level". But **Sky 2050**, which transforms as rapidly as is likely to be possible, does not come close to achieving this. **Sky 2050** sees a reduction of 12% in 2030, reaching 45% by 2038. In **Archipelagos**, CO_2 emissions peak in 2030 at 10% above 2010 levels, reaching a 45% reduction by 2060. **Sky 2050** achieves net-zero CO_2 emissions in 2050, but net-zero emissions is not reached in **Archipelagos** until the first half of the 22nd century.

If and when society exceeds its carbon budget of 380 Gt of cumulative emissions, it must balance the excess later in the century. It can do this by removing CO_2 from the atmosphere and storing it geologically. This is known as an overshoot pathway and **Sky 2050** is an overshoot scenario. Society needs to recognise the role of carbon capture, carbon removal from the atmosphere and carbon storage. The need to develop large-scale capacity is critical for managing atmospheric CO_2 levels and dealing with an overshoot of the carbon budget.

If the **Surfers** maintain their current modest per capita CO_2 footprint, their expected population growth alone could take the world beyond 1.5 °C by 2050, and to 2 °C warming by 2100. In any future that seeks to limit surface temperature warming, the **Surfers** will need to decarbonise from 2020 levels, even as they develop their economies.



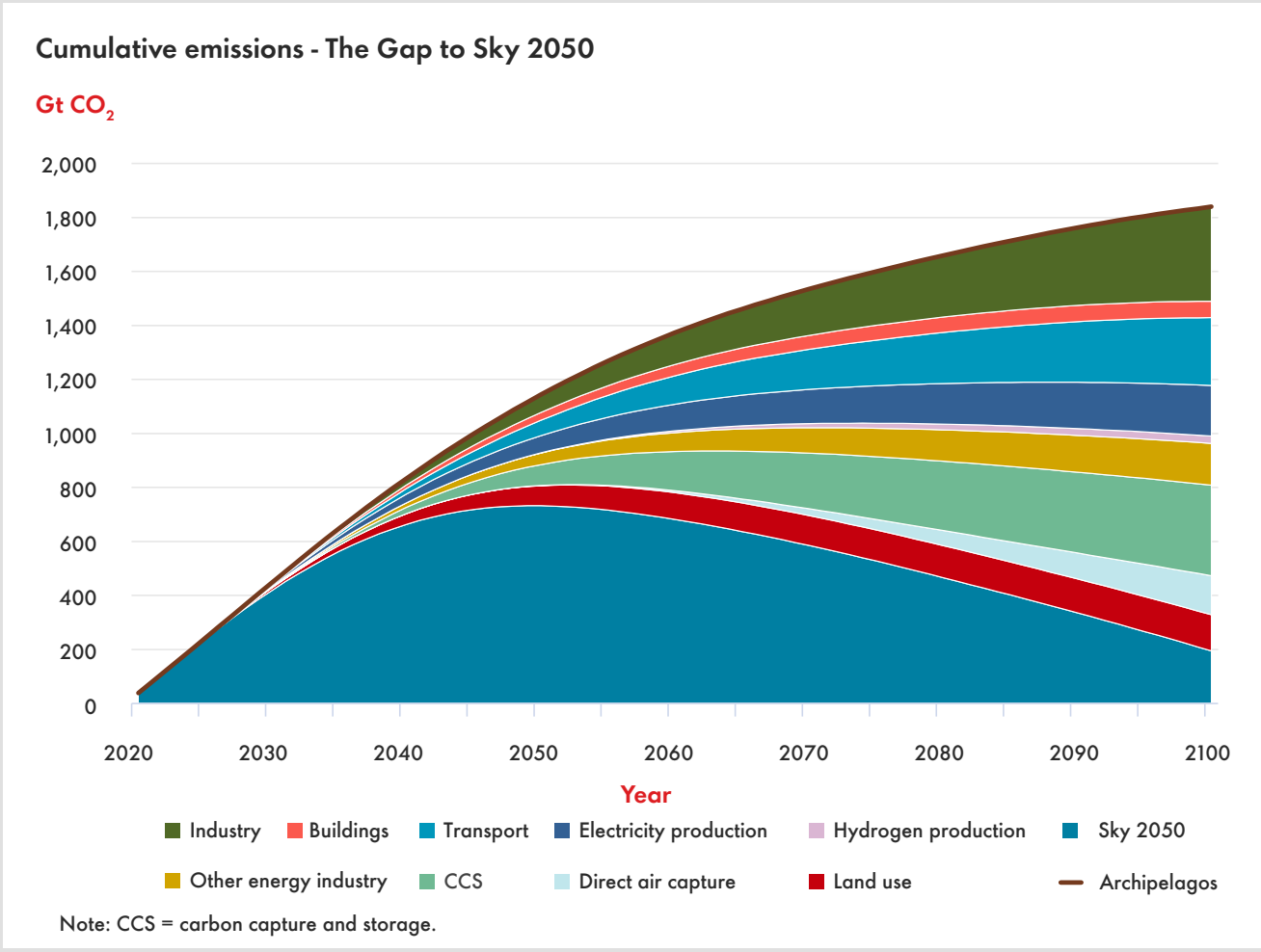
The emissions gap

By 2100, a world that has followed the Archipelagos pathway has emitted some 1.5 trillion tonnes of CO_2 more than a world that has followed the route outlined in Sky 2050. This emissions gap is equivalent to around 1°C of warming.

Although the gap is caused in many ways, the lack of facilities to store carbon in sinks in **Archipelagos** contributes to more than a third of the difference. In **Sky 2050**, land management, direct air capture and carbon capture and storage remove 600 billion tonnes more CO_2 by 2100.

The overall gap continues to widen until at least 2100, as a result of industry and transport emissions. Together the industry and transport sectors contribute 500 billion tonnes of additional emissions by the end of the century compared to **Sky 2050**. Within transport, in **Archipelagos**, aviation, shipping and road freight are still decarbonising late in the century, but emissions in all three are falling.

Industry needs to take decisive steps to reduce the emissions gap. For example, hydrogen reaches 1% of industrial final energy use in 2044 in **Archipelagos**, but **Sky 2050** gets to the same landmark 10 years earlier.



Policy changes

Shifting from an **Archipelagos** type world towards **Sky 2050** would require a concerted policy effort from governments.

This must start with the actions and ambition in the 2025 nationally determined contribution (NDC) submissions by countries as required by the Paris Agreement. In particular:

Green Dream and **Innovation Wins** countries must start to embrace large-scale development of negative emission technologies and practices.

China (**Great Wall of Change**) will need to target a reduction of up to 40% in emissions, from a mid-2020s peak, by 2035.

Most **Emergent Surfers** countries need to fully introduce absolute reduction targets in their NDCs and all **Surfers** countries must grasp the carbon storage opportunities offered by land management.

From the 2020s to 2040s, policies to encourage decarbonisation come in three waves:

- **2020s** – policies to accelerate the commercialisation of low-carbon technologies. This means scaling up demand at the same time as bringing down the cost of supply.
- **2030s** – policies to drive low-carbon choices. In particular, this means introducing carbon pricing mechanisms, as well as mandates in some sectors (such as ending the sale of internal combustion engine cars).
- **2040s** – policies to consolidate and amplify the low-carbon choices being made. One important step is to ensure that the lessons learned by early movers are passed on to accelerate the progress of others.

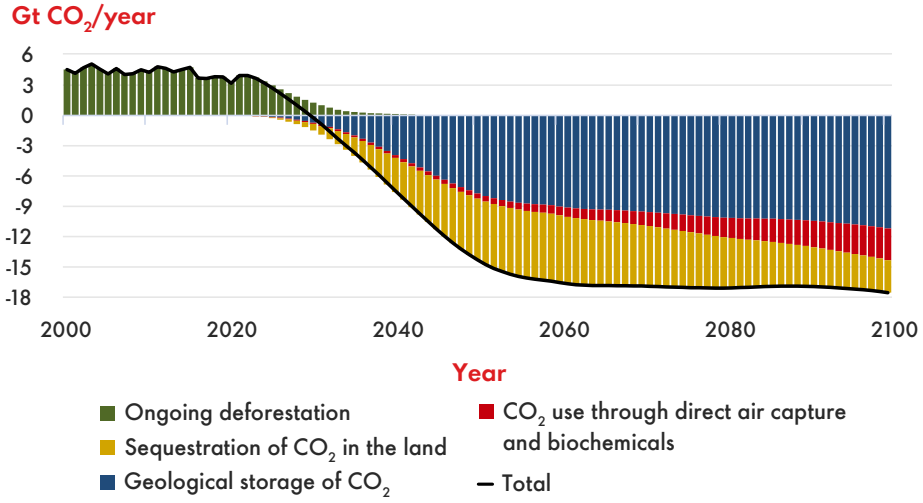
Land use

Delivering negative emissions requires a systematic and robust policy framework for carbon removal.

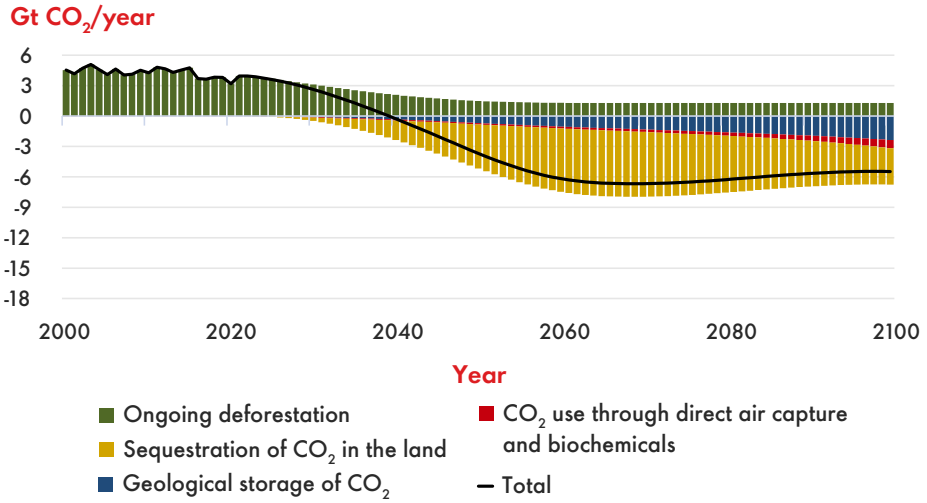
Global consensus on Article 6 of the Paris Agreement – which governs the trading of carbon credits between nations – and its implementation is essential for carbon removal. Carbon trading could be a win-win for global climate and economic development objectives. Countries like Indonesia and Brazil host some of the world's most important terrestrial and marine ecosystems for storing carbon.

By 2070, almost all land that humans interact with must be managed to maximise carbon storage. However, only a fraction of this land is changed from one type of use to another. Carbon management largely comes through improved farming practices and better management of forests, peatlands and wetlands. Reforestation is the major change of land use in both **Archipelagos** and **Sky 2050**. Both scenarios include the potential to reforest an area up to the size of Mexico: about 200 million hectares. Without a concerted effort to manage the land carbon stock, in addition to major energy system changes, the 1.5°C goal cannot be realised.

Land use change and development of sinks – Sky 2050



Land use change and development of sinks – Archipelagos



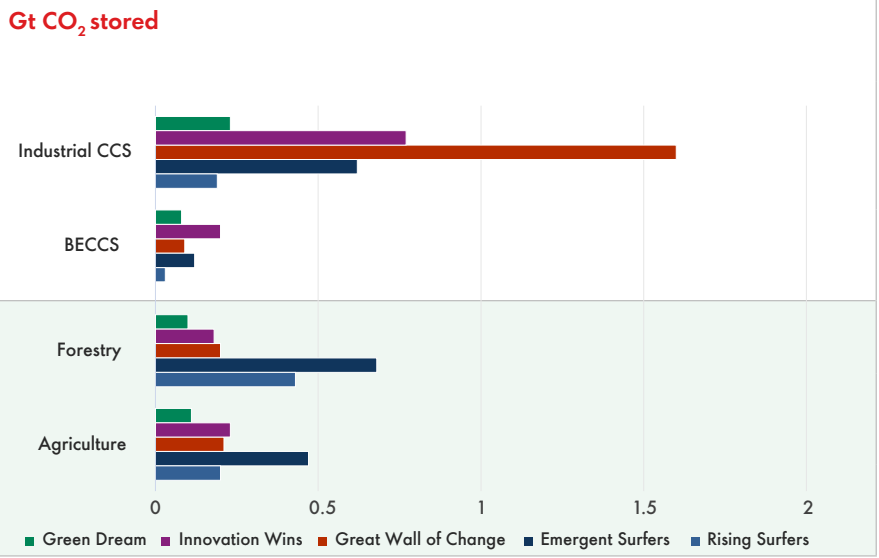
The scenarios in action in 2040

Achieving a global temperature rise of less than 1.5 °C requires extensive use of carbon sinks

By 2040 the world needs:

- carbon capture and storage (CCS) in industry at 2,000-3,000 facilities;
- large-scale deployment of direct air capture (DAC) underway;
- 500 bioenergy power plants with CCS (BECCS). Only one exists in 2023; and
- net reforestation well underway and land carbon management widely established.

Area of interest by 2040	Progress in 2023	Archipelagos	Sky 2050	Direct CO_2 management across the archetypes in 2040 under Sky 2050
Industrial use of CCS	45 million tonnes (Mt) operating	300 Mt	3,300 Mt	
Direct air capture with carbon storage (DACCS)	Small demonstration projects	Abandoned - no deployment until 2080	Begins large-scale deployment	
Bioenergy with carbon capture and storage (BECCS)	1 Mt (single facility)	40 Mt	520 Mt	
Land carbon uptake	4,000 Mt	Balanced	3,300 Mt	
Reforestation	Minimal	30 million hectares (Mha)	60 Mha	
All land under carbon management [1]	3 Mha	900 Mha (equivalent area of USA)	1,800 Mha	



[1] Includes a wide range of activities such as changes in agricultural practices, wetland protection.

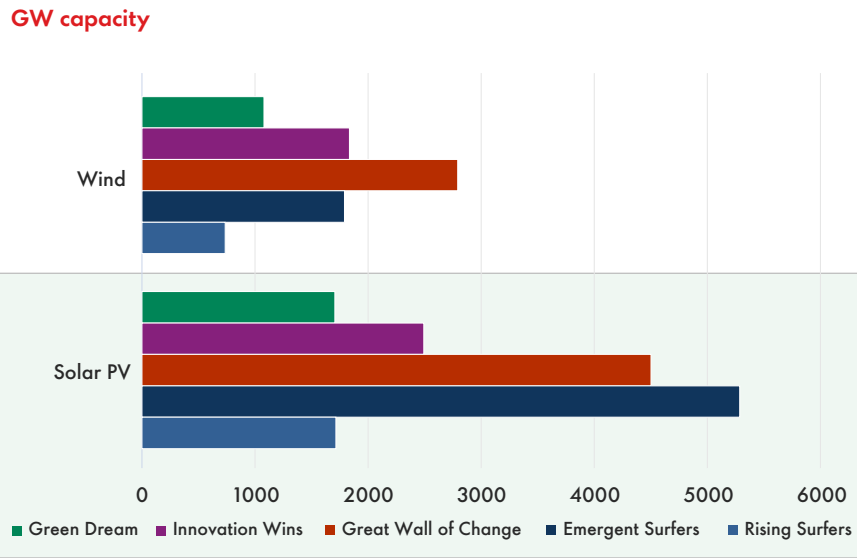
The scenarios in action in 2040

Electricity generation must rapidly shift to wind and solar generation

By 2040 the world needs to:

- quadruple the solar module manufacturing capacity of today;
- increase the deployment rate for wind power by almost tenfold; and
- create the capacity to store huge amounts of energy as solar and wind account for two-thirds of electricity generation.

Area of interest by 2040	Progress in 2023	Archipelagos	Sky 2050	Solar and wind deployment across the archetypes in 2040 under Sky 2050
Wind capacity	1,000 gigawatts (GW)	5,200 GW	8,000 GW	
Number of 10 megawatt-equivalent turbines installed	~10,000 turbines each year	~40,000 turbines each year	~90,000 turbines each year	
Solar photovoltaic capacity	1,100 GW	7,600 GW	15,600 GW	
Solar photovoltaic module production	200-250 GW per year	500 GW per year	950 GW per year	

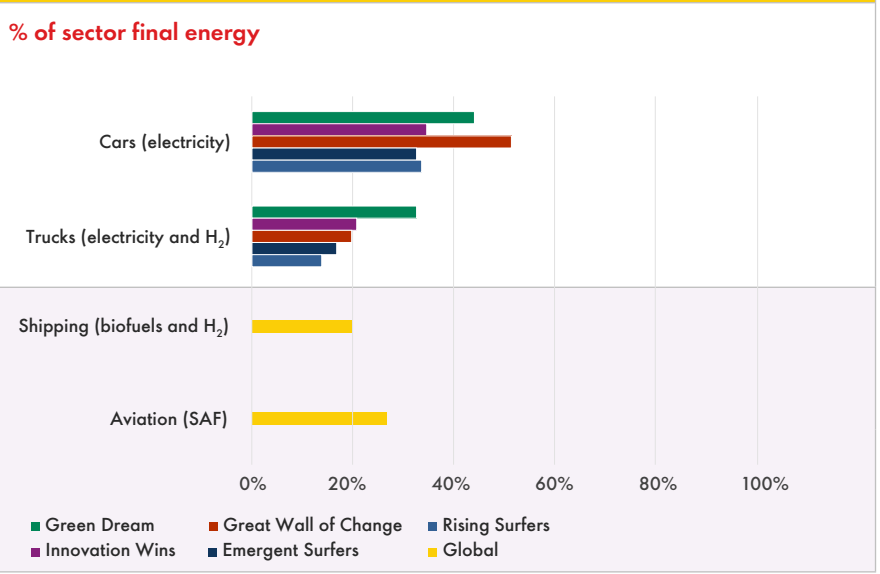


The scenarios in action in 2040

Ground transport must rapidly shift to electricity while shipping and aviation must move to alternative fuels

By 2040 the world needs to:

- transform sales of new passenger vehicle to 100% electric worldwide;
- have passengers taking flights on the first hydrogen-powered planes; and
- have a shipping sector that uses hydrogen as a mainstream fuel, with 10,000 ships in service.

Area of interest by 2040	Progress in 2023	Archipelagos	Sky 2050	Use of alternative fuels in transport in 2040 under Sky 2050
Passenger cars	Around 10% of new car sales are electric	50% of new cars are electric	100% of new cars are electric	
Vans and trucks	About 100,000 electric vans and trucks made per year	14% electric or hydrogen	30% electric or hydrogen	
Shipping	Alternative fuel projects announced	3% biofuel, first hydrogen ship[1]	10% biofuel, 10,000 hydrogen ships	
Aviation	limited blending of sustainable aviation fuel (SAF)	10% SAF globally	First hydrogen planes, 27% SAF globally	

[1] Hydrogen fuel cell, ammonia-based fuel or other hydrogen-based fuel.

The scenarios in action in 2040

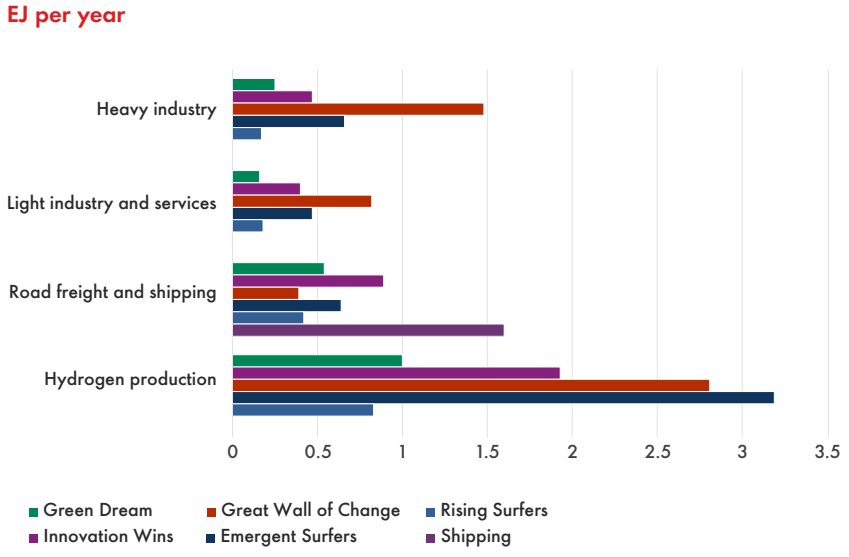
Hydrogen becomes an important fuel for industrial processes and heavy transport

By 2040 the world needs to:

- extensively deploy hydrogen-based industrial processes;
- deploy two 1 gigawatt electrolysers each week; and
- launch four new ships powered by hydrogen or hydrogen-based fuels, every day.

Area of interest by 2040	Progress in 2023	Archipelagos	Sky 2050
Heavy industry	Demonstration projects	100 million tonnes (Mt) production (equivalent)[1]	500 Mt iron production (equivalent)[2]
Light industry	Demonstration projects	1,500 large food processing plants using hydrogen	8,000 large food processing plants using hydrogen
Transport	Road freight pilots, no shipping or aviation	7 million hydrogen commercial vehicles on the road	18 million hydrogen commercial vehicles on the road
Hydrogen production	Primarily from natural gas	20 Mt, more than 75% from coal and natural gas	80 Mt, 75% from solar, wind and nuclear

Hydrogen use and production across the archetypes in 2040 under Sky 2050



[1] On the basis that all available industrial hydrogen is used to smelt iron ore [2] Global production is around 2 billion tonnes raw steel per year

The scenarios in action in 2040

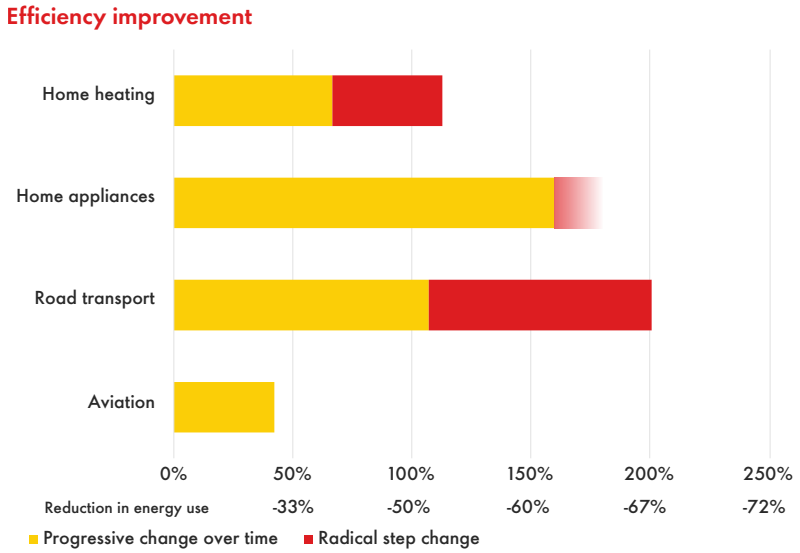
Advances in energy efficiency must be dramatic

By 2040 the world needs:

- rapid uptake of electricity in road transport to gain a step change in efficiency;
- widespread adoption of home insulation and electric heat pump technology;
- change in home appliances through smart technology and the adoption of best-in-class design; and
- continued progress in the aviation sector to further improve current airframes and engines.

Area of interest by 2040	Progress in 2023	Sky 2050 Progressive change	Sky 2050 Radical step change
Heating in buildings	Slow progress globally	Boiler design improvements and insulation	Electrification and heat pumps
Home appliances	Progress through consumer standards	Design changes and competition over time	Possibly through digitalisation
Road transport	Shift to electricity is the game-changer	Steady improvement in vehicle design	Switch to electricity
Aviation	Progress through design and cost management	Steady improvement in airframe and engine design	Not by mid-century

Energy efficiency improvements between 2019 and 2050 under Sky 2050

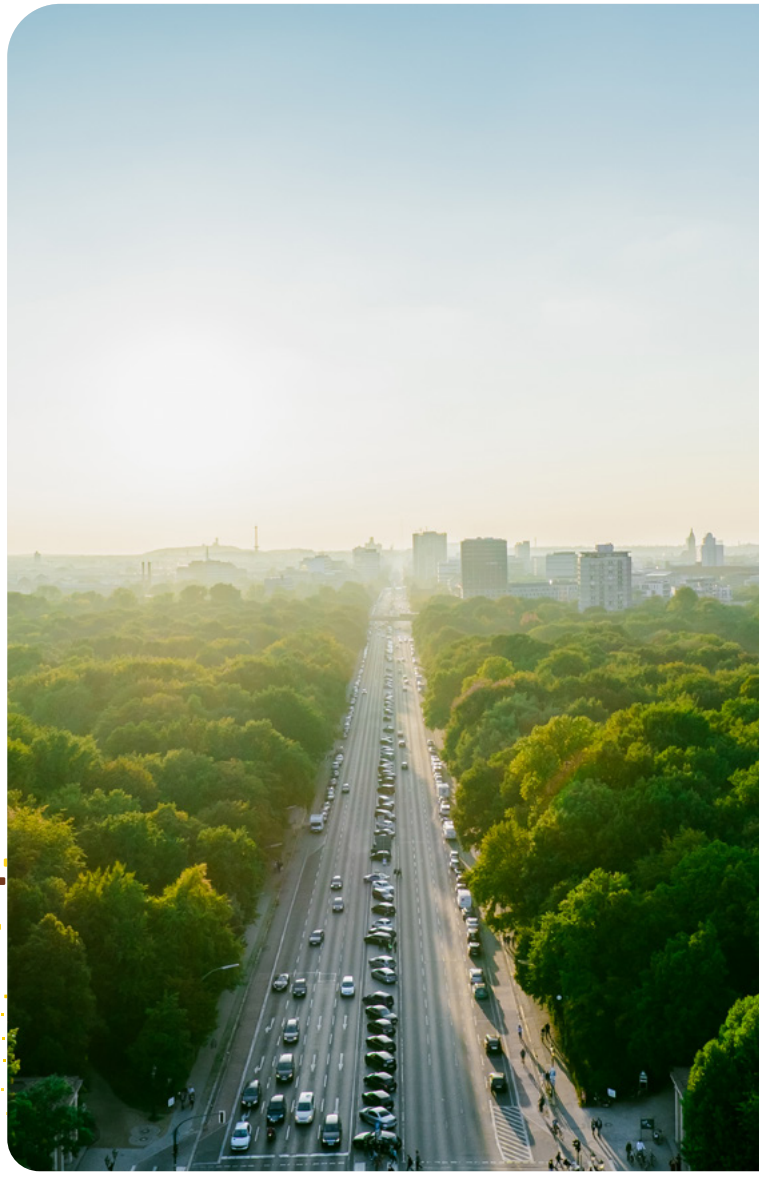


Sky 2050 – meeting the Paris goal

With a goal to limit warming to 1.5 °C by 2100, the Sky 2050 scenario offers a pathway towards net-zero emissions by 2050. But net-zero emissions does not mark the end of the transition.

Fossil-fuel use continues to decline, and major industries emerge based around the removal of CO_2 from the atmosphere. One involves direct air capture with carbon storage (DACCS). This strips CO_2 from the air and stores it permanently in geological formations. Another industry – bioenergy with carbon capture and storage (BECCS) – captures the CO_2 produced during bioenergy processes, also storing it underground.

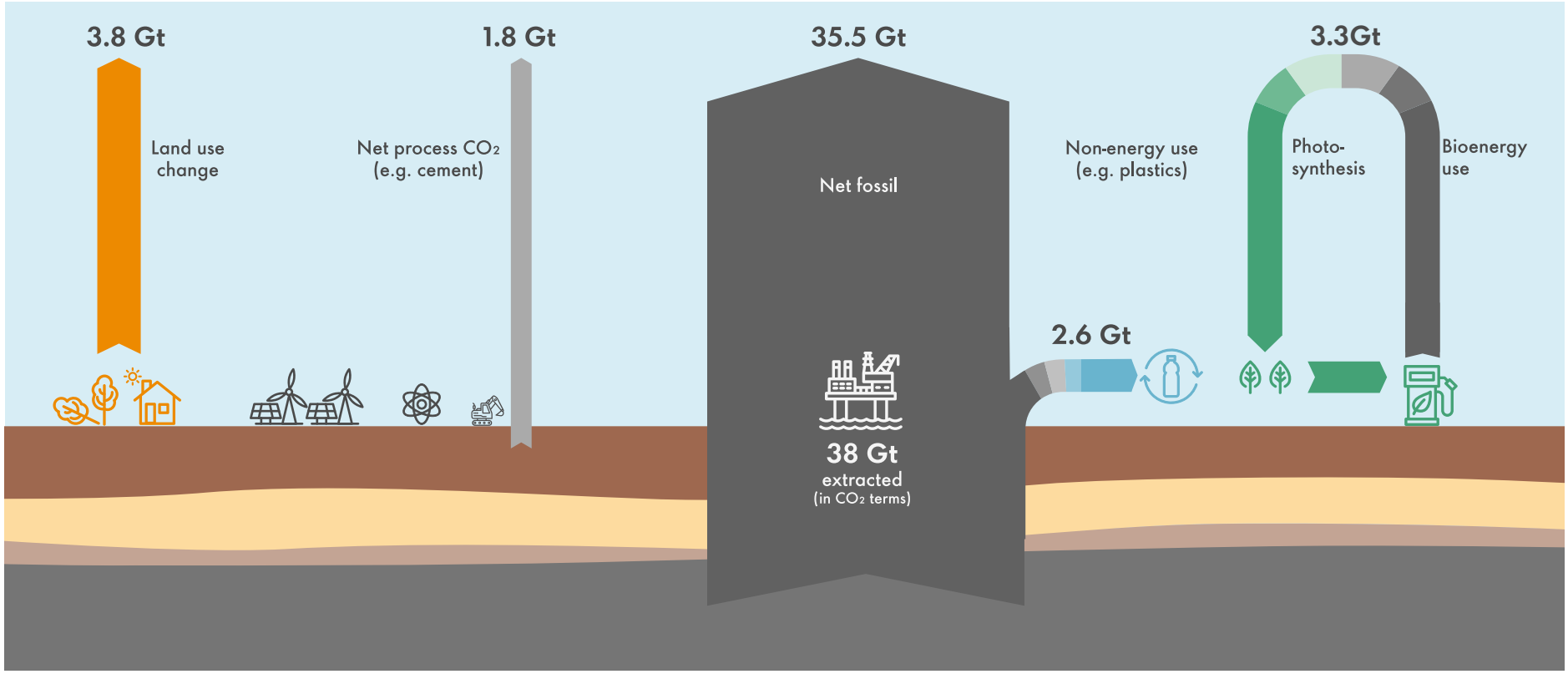
In **Sky 2050**, by 2100, DACCS has eclipsed other CO_2 capture and storage mechanisms within the economy. DACCS may even offer the world of the 22nd century the means to restore the global ecological balance to pre-industrial times and regain the environmental security that could come with it.



Sky 2050 – meeting the Paris goal

Sources and sinks of anthropogenic carbon (as CO_2) in 2019
Positive emissions of 41 Gt CO_2 per year

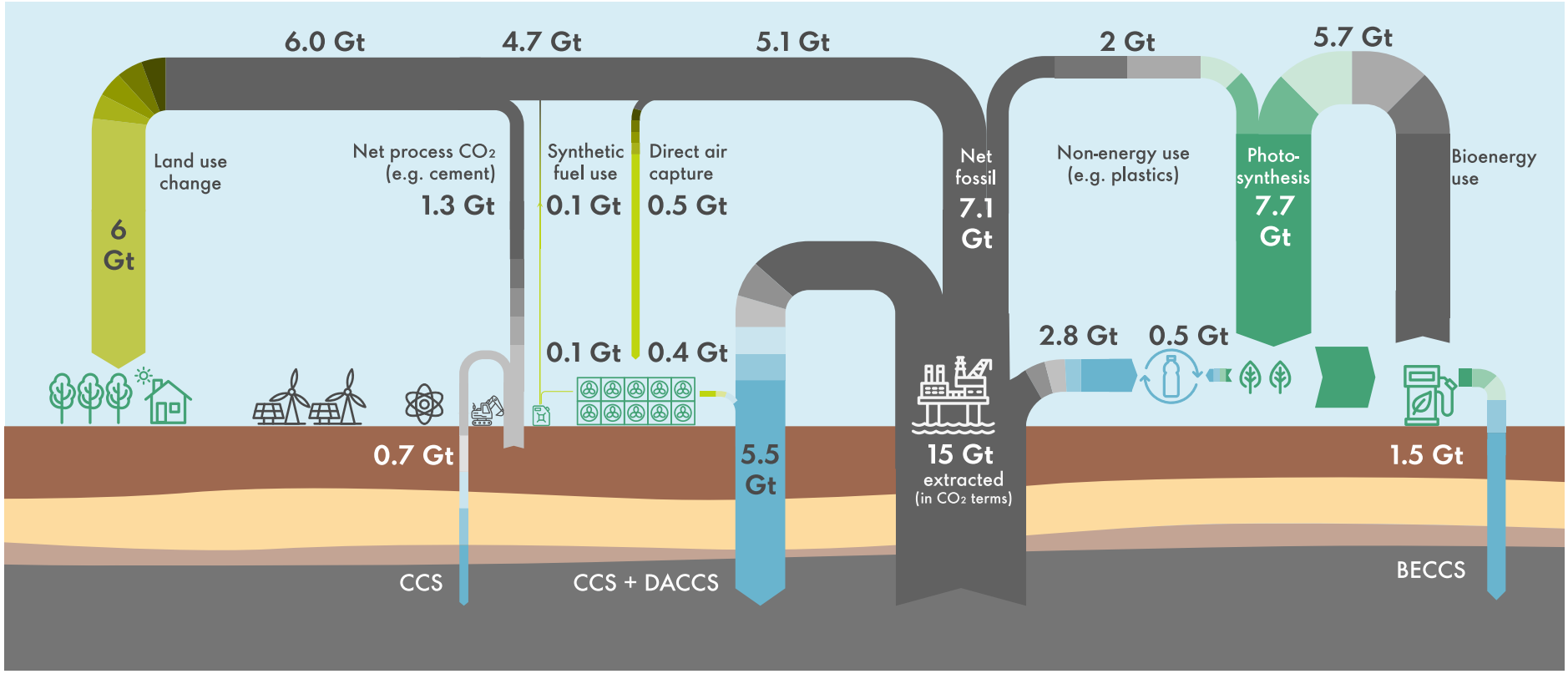
2019



Sky 2050 – meeting the Paris goal

Sources and sinks of anthropogenic carbon (as CO_2) in Sky 2050
Net-zero emissions in 2050

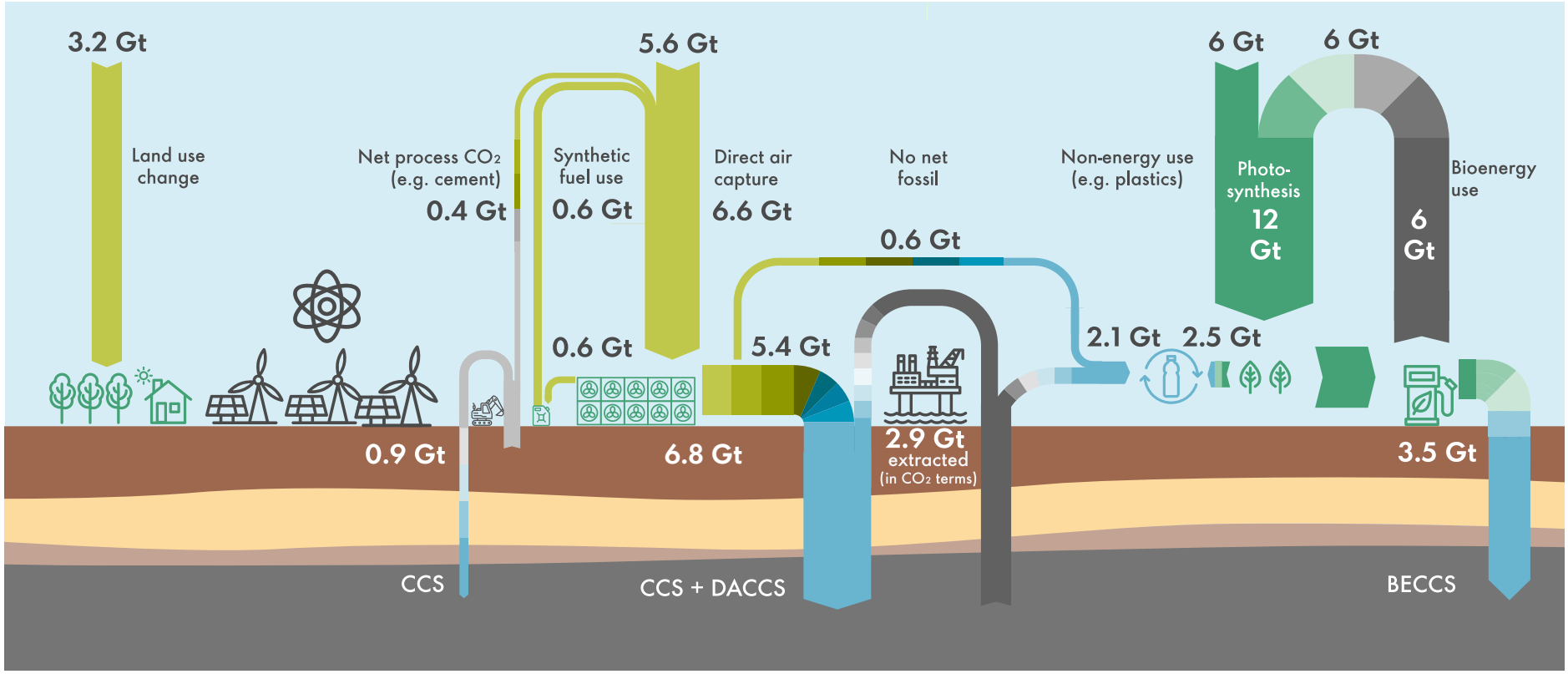
2050



Sky 2050 – meeting the Paris goal

Sources and sinks of anthropogenic carbon (as CO_2) in Sky 2050
Net-negative CO_2 emissions of 14.8 Gt CO_2 per year in 2100

2100



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