Shell Scenarios

The 2026 Energy Security Scenarios

Challenges to the transition

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Contents

A changing world

When Shell published The Energy Security Scenarios in March 2023, with its Archipelagos and Horizon storylines, the focus of the world was on high energy prices, with the cost of electricity at record levels in much of Europe. At the time, the ink was barely dry on the November 2021 Glasgow Climate Pact.

Throughout 2024 and at the start of 2025 when we added the **Surge** scenario, a cautious optimism was sweeping through global economies as artificial intelligence (AI) technologies heralded a much sought after spurt in global growth. As 2026 unfolds, new threats, including some led by AI concerns, unresolved conflicts and heightened trade tensions have put the world on edge. The world is also edging closer to 1.5°C of warming with global CO_2 emissions yet to start falling. These developments require a rethink of both how global growth might develop and how the energy transition could unfold. This will be presented in a revision of the **Archipelagos** scenario.

Surge remains important, given that AI technologies maintain their ability to surprise and transform society. As in recent years, the inclusion of the normative **Horizon** scenario illustrates a possible pathway to bring the world in line with the goal of the Paris Agreement.

Energy choices and security

National security concerns, cost to the consumer, domestic trade considerations and long-term climate agreements all play a role in energy choices.

Historically, most economies have developed on the back of coal because of its low cost, wide availability and broad range of use, from generating electricity to smelting ores and providing a simple source of domestic heating. The last major economy to develop largely on coal was China, which now consumes more coal than the rest of the world put together. Coal was the clear choice in the late 20th century, but now China is deploying new energy technologies, faster than the rest of the world put together. Rapid electrification of transport and industry in China is enabling the country to reduce its current dependency on oil and gas.

An alternative 21st-century choice is also playing out in India, where the initial global concern centred on it repeating the Chinese coal-use boom of the 2000s and 2010s. But new choices have emerged due to cost reductions in solar photovoltaic and electric vehicles, added to environmental concerns related to clean air in the cities.

In Europe, a broad lack of domestic fossil energy, the energy security wake-up following the Russian invasion of Ukraine and a social push for climate leadership has led the region to set very ambitious targets for almost complete energy system decarbonisation by 2040: just 15 years to eliminate 2.5 billion tonnes of CO_2 emissions per year.

In contrast to Europe, the USA continues to expand its domestic oil and gas production, becoming the largest producer globally and the world's largest liquefied natural gas exporter. Yet as wind and solar electricity generation are under challenge, the country may be on the verge of commercialising nuclear fusion, which could profoundly change the energy system.

A major question for the 21st century lies with the energy system development for 1.5 billion people in Africa, which is likely to rise to nearly 4 billion by late century. The region has significant fossil resources, but if these were to be developed along 20th-century country lines, it would push the world above 3°C of warming.

At Shell, scenario analysis plays a key role in creating context and growing understanding around energy system, technology, geopolitical and social trends. Scenarios are an exploration of how the world could possibly evolve under different sets of assumptions.

The process of creating scenarios involves considering different possible futures, some of which may seem unlikely or even surprising. The value to Shell of producing scenarios is to help people think about the long-term challenges and to challenge assumptions about the way in which the external world could develop. 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 scenarios are informed by data, constructed using models, and contain insights from leading experts in relevant fields.

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.

Ultimately, for all readers, scenarios are intended as an aid to making better decisions. They stretch minds, broaden horizons and explore assumptions. We hope this set of revised scenarios does exactly that.

Artificial intelligence, technology and the evolution of the energy system

The influence of AI and new technologies is felt in many areas, but over the next 30 years it could bring significant change to the energy system.

- Production of modules (such as solar photovoltaic panels, batteries and heat pumps) for the energy system could accelerate as AI improves manufacturing and delivers ever more complex assembly line production of components.
- Autonomous systems are appearing in vehicles. When electric vehicles (EV) begin to operate autonomously on a larger scale within a managed traffic environment, system efficiencies could be considerable, sparking a more rapid uptake of EVs.
- A managed EV system allows the battery storage inherent in the vehicles to contribute to electricity grid storage and flexibility requirements, hastening the journey to a renewable-only electricity system.
- As quantum advantage emerges (the point at which a quantum computing system solves problems outside the reach of classical algorithms), advances in materials science, electrochemistry, biotechnology and nuclear engineering could accelerate electrification and energy storage, introduce new fuel processes and bring small modular nuclear reactors into widespread use.
- Large energy infrastructure projects could be accelerated as new AI tools are applied to project management.
- AI and the supporting data systems will require large-scale uninterruptible power supplies, with overall electricity demand increasing as a result, even as other efficiency gains are made.
- AI can support improved electricity system management, in terms of balancing long-distance intermittent renewable supply, enabling battery storage, and managing demand through smart responses in homes and factories.

Technology timelines

Historically, the energy system has been through multiple waves of change. Typically, there is a span of 15–25 years between the first appearance of a technology and it becoming established, then another 15–25 years for it to be adopted system wide. But that timeline is being challenged. Timelines for the adoption of information technology are half those for new energy systems. As AI technologies become incorporated into the energy system, faster change may result. As technology companies adopt large-scale modular production of energy system components, such as solar photovoltaic and batteries, there are clear signs of change, but will more widespread disruption follow?

2005–2010 ◀◀ Looking back 15 years	2025	Looking forward 15 years ▶▶ 2040–2045

Data-driven systems

The new technology of yesterday ...

- Lifestyle productivity: Apple iPhone introduced (2007)
- Mature search engine algorithms (Google) and first video uploaded to YouTube (2005)

... is the mainstream technology today

- More smartphones than people
- 14 billion Google searches per day and 30,000 hours of video added to YouTube per hour

... and leads to global transformation

- Increased consumption and productivity
- Virtual services, autonomous systems and pervasive AI

Energy-driven systems

The new technology of yesterday ...

- Electric cars: Tesla Roadster
- Solar: 17 GW installed with subsidies
- First commercial grid-scale battery, 20 MW

... is now established in the energy system (1–5%)

- 21 million EVs and PHEVs each year (1/4 of production)
- 650+ GW of solar PV installed per year
- 80 GW (180 GWh) of grid-scale batteries in use

... and is becoming mainstream (>20–30%)

- All new vehicles are electric
- 1,000+ GW of solar installation per year
- 3 TW (30 TWh) of grid-scale batteries

The new technology today ...

- Generative AI, ChatGPT and large language models
- First DAC demonstration facilities
- Industrial electric processes and electric furnaces
- Modular production of energy system infrastructure

... will create new AI-driven foundations

- Vehicle autonomy and autonomous traffic management
- Virtual aggregation of modular energy system components
- Mass assembly line production of modular components
- DAC module production scales up

Acronyms:

MW – megawatts
GW – gigawatts
GWh – gigawatt-hours
TW – terawatts
TWh – terawatt-hours
EV – electric vehicles
PHEV – plug-in hybrid electric vehicle
DAC – direct air capture
PV – photovoltaic

Key scenarios observations

This section sets out key geopolitical, technological and societal input observations which were specifically formulated to stretch thinking and underpin this set of Scenarios narratives and the Scenarios energy demand, energy mix and carbon management observations below.

Geopolitics, technology, society

- Political and societal tension is evident today as countries strive to deliver a new era of economic growth, ensure national security and trade competitiveness, and address rising CO_2 emissions.
- Economic growth over the coming two decades is uncertain, with both the prospect of a weak outlook on the back of global security tensions and the possibility of renewed strength through labour productivity gains driven by AI. The outcome is somewhat binary by nature. Regional growth patterns vary considerably across scenarios.
- The world is approaching 1.5 °C of warming above pre-industrial levels (based on a long-term moving average change).
- A global realignment of influence is underway as nations seek commercial and technological advantage through trade, innovation, energy security and controlled migration pathways.
- AI technologies herald societal change. Many emerging technologies are changing the energy landscape, including electric transport, electric appliances such as heat pumps, electrification in industry, and the rapid growth of data centres throughout the world.
- Over the next 25 years, about a third of the world's growing population (i.e. 3 billion people) will embrace higher income lifestyles, such as buying their first car or taking their first flight. Demand for energy services (the physical benefit, utility or good derived from using energy) will continue to increase as the global population grows and living standards rise.
- Construction of the energy system is shifting from large bespoke projects built in the field to modular units produced on assembly lines. This will accelerate the uptake of solar photovoltaic, wind turbines, grid batteries, heat pumps, hydrogen electrolysers, potentially small modular nuclear reactors and CO_2 direct air capture units in the future.
- The less developed countries are growing their energy use, but do not follow the historic energy development pathways seen in developed Asia, China, Europe and the USA. Renewable sources (including biomass) dominate electricity generation, electric vehicles are preferred and industry trends more towards electricity than thermal combustion for heat.

Energy demand

- The scenarios in this report highlight that primary energy demand in 2050 could be nearly a quarter higher than that in 2025 depending on economic growth rates, energy efficiency gains and the pace of electrification.
- Demand for oil is likely to grow by 3–5 million barrels per day into the early 2030s, with a long but slow decline after that as petroleum fuels remain affordable and convenient for transport, particularly in long-distance road haulage, aviation and marine. The use of petrochemicals is likely to continue into the 22nd century.
- Total demand for natural gas could grow by nearly 10% into the 2040s, reaching about 4,500 billion cubic metres (bcm) per year, of which up to 700 million tonnes per year (or 952 bcm) is liquefied natural gas (LNG). Natural gas is used in balancing intermittent renewable electricity supply. It has an important role in helping the world move away from coal.
- Global investment in oil and gas is currently about $550 billion per year, which will be required for many decades as the annual rate of field depletion is about 5–6% for oil and 7% for gas, which is considerably higher than the expected annual decline in demand of 1–2%. However, only the most competitive resources in terms of cost, risk and carbon intensity will attract capital.

The energy mix

- Coal has proved hard to dislodge in the global energy system, but peak coal use before 2030 is common across the scenarios. However, continued, albeit declining, use of coal beyond 2100 is possible, with consumption still at one third of peak levels at that time.

- Following current trends, new technologies could halve the carbon intensity of the energy system by 2050. Biofuels, carbon capture and storage (CCS) and natural and engineered carbon removals will lower or offset emissions of fossil fuels. Renewable and nuclear power in combination with electrification will help decarbonise many energy services.
- Biofuels make up about 3% of the global liquid fuel market. Volumes are expected to at least double by 2050, particularly if advanced conversion technologies progress.
- Electrification increases in all sectors. In the second half of the century, electricity largely dominates the energy system, but with oil proving resilient for petrochemicals, aviation and marine applications. Natural gas remains an important industrial fuel.
- Road transport of all types shifts to battery electric powered propulsion, but some demand for liquid fuels in heavy trucks could persist until the early 2100s. Regional variation in battery electric adoption could be significant.
- Although the broad use of hydrogen as an energy carrier would be a positive development for mid-century net zero CO_2 emissions, this is looking unlikely. Hydrogen in heavy transport is losing favour because of battery electric technologies and lack of infrastructure investment, leaving industrial applications as the more plausible use case. New global demand for hydrogen as final energy appears limited to less than 60 million tonnes per year by 2050.
- The rapid growth of renewable power continues. In the three scenarios, solar photovoltaic with battery storage in lower-latitude countries and wind in northern latitudes satisfies at least two thirds of electricity demand by the 2060s. By then, natural gas and LNG has shifted from base load to a back-up fuel in power generation or is supporting uninterruptible demand in energy-intensive industries and data centres.
- New nuclear power technologies bring growth to the sector after decades of stagnation. Although the replacement of ageing facilities hampers net capacity expansion until the 2040s, the sector flourishes on the back of small modular reactor development and potentially thorium technology.

Carbon management

- In all scenarios, CCS becomes a multibillion tonnes of CO_2 per year industry during the century, with significant upward potential from the lowest case outcome. Growth at scale in both natural and engineered carbon removal is crucial for reaching net zero emissions before 2100.
- Without a concerted effort to manage the land carbon stock, in addition to major energy system changes, achieving the Paris Agreement goal to hold the increase in the global average temperature rise to well below 2 °C may not be possible. All the scenarios envisage greater effort to manage the land, for reasons of carbon management but also, crucially, to reverse the global decline in biodiversity.
- By 2100, and with a focus on carbon removal technologies and practices, the world could achieve less than 1.5 °C of warming. But plausible scenarios show an overshoot of this goal by the mid-2030s.
- There is sufficient momentum in the energy transition to suggest a pre-2035 peak in fossil fuel use and a decline thereafter. These scenarios point to the world achieving net zero CO_2 emissions, but the timing is highly uncertain and an extended use of some fossil fuels into the next century is quite plausible.
- With two distinct and plausible scenarios exploring varied paces of energy transition in a security focused world, but seeing rising pressure from climate change, the temperature range in **Surge** and **Archipelagos** in 2100 is an increase of between 2.0 and 2.5 °C.

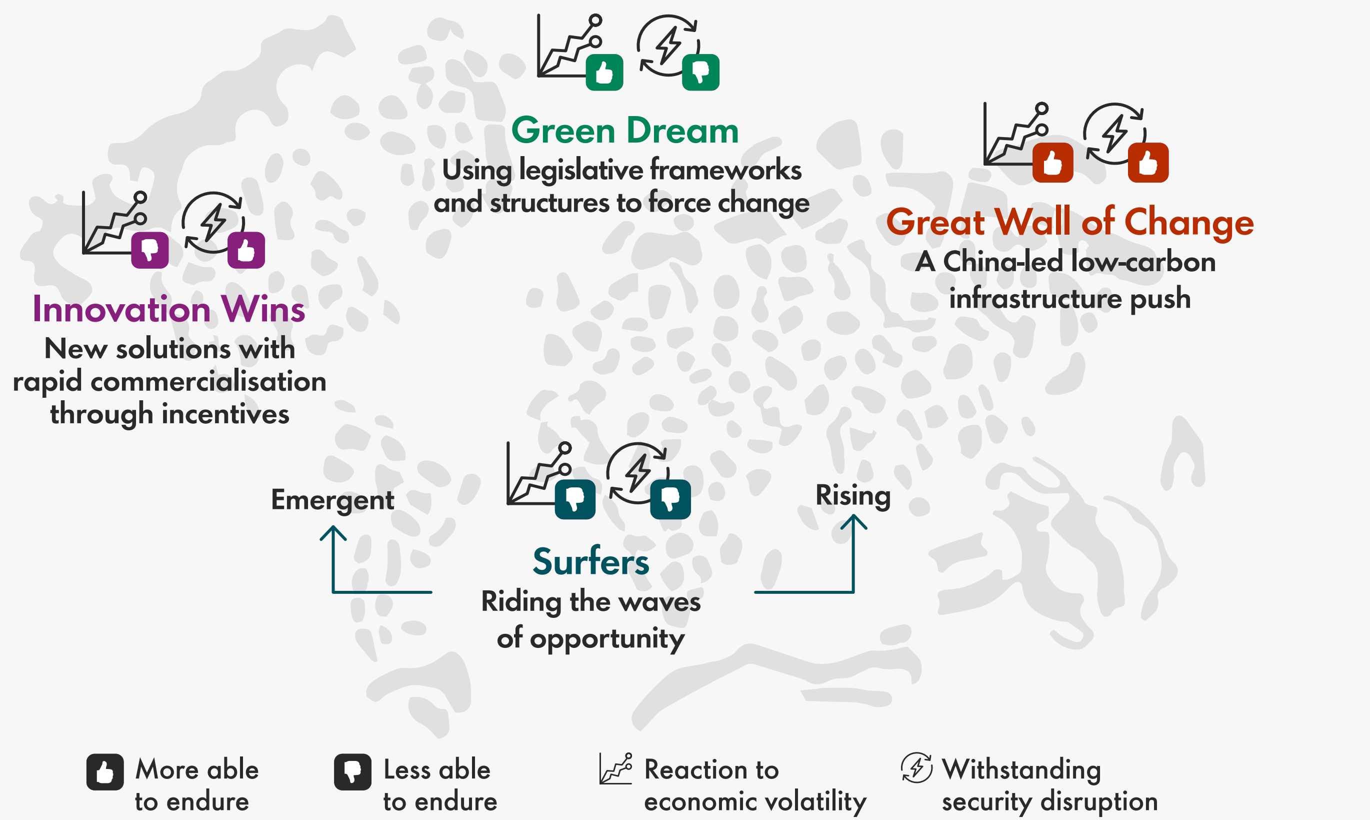
National response archetypes

The world is far from homogeneous in how countries respond to security issues, but the underlying response types are similar across a range of scenarios. In **The Energy Security Scenarios** in 2023, we made use of an archetype response framework that we have continued to use in this 2026 revision. Four different archetype responses to security, climate, economic growth and technology pressures are visible, based on how vulnerable countries are to security failures and how they manage economic volatility.

Innovation Wins, which can be seen in countries like the USA and major resourceholders such as Middle East nations. These countries are often self-sufficient in energy and other resources so are not vulnerable to supply failures, but their political systems are particularly exposed to economic volatility, such as swings in energy prices and inflation. They do not feel so threatened in the short term but invest heavily in innovation and infrastructure as longer-term solutions to their needs. These are highly competitive countries determined to protect their economic positions.

Green Dream, which can be observed in the European Union. The EU's wealth makes it relatively able to deal with economic volatility, but its import-dependent energy system is vulnerable to disruption, such as after the Russian invasion of Ukraine. These countries may seek security through legislative means. In the energy sector, this has resulted in reduced energy use, increased energy efficiency and an ongoing attempt to shift quickly and entirely to renewable energy. For digital technology, protectionism through legal channels and heightened regulation has emerged, which could leave the region without a major technology sector.

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



Great Wall of Change applies mainly to China. The size of China's economy and the scale of the investments it is making in its own energy supply, through both its manufacturing capability and infrastructure build-out rate, provides resilience against both global economic volatility and security threats. It looks to use its manufacturing strength to build its position as a leading nation and low-carbon-energy powerhouse.

Surfers are countries that may face numerous economic and development challenges, which makes them vulnerable to both economic volatility and supply security. But they are quick to adopt new technologies when affordable, and they seek partnerships with others and try to ride the opportunities created by the actions of other archetype country groups. They subdivide into:

Emergent Surfers, like India, which are adept at political positioning and eager to leapfrog traditional development pathways.

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 and providing the basic requirements for a good life.

Three security scenarios

As the security mindset dominates and the global competitive landscape becomes more intense, national interests are taking precedence within political agendas. The world is entering a period of apparent polycrisis, characterised by a seemingly intractable and tangled web of problems that are not just simultaneous but also mutually reinforcing. The concerns are multiple: insipid economic growth, balancing trade with other countries, AI technologies that provide additional advantage to already advanced economies, growing militarism from traditional adversaries, and increasing climate pressures. The latter are seen through the lens of extreme weather events and legal actions around the world.

Three scenarios emerge from the pressures facing nations: **Archipelagos**, **Surge** and **Horizon**.

The **Archipelagos** scenario sees a world that reacts to the pressures of regional conflicts, increasing migration across multiple borders and uneven global trade patterns. Concerns mount over trade, reliable allies, a new superpower, resource availability, populist leaders and the environment. In a world of uncertain and confusing signals, these concerns lead to both domestic prioritisation of key resources and new global alignments. Countries act as if global conflict is imminent, yet the scenario has no such outcome.

In this 2026 revision to **Archipelagos**, the global security concerns have intensified, with even more focus on domestic energy production and a distancing from traditional trading partners by the likes of China and India. New collaborations emerge and energy markets become increasingly transactional as the world becomes more opportunistic in its approach to securing energy supplies.

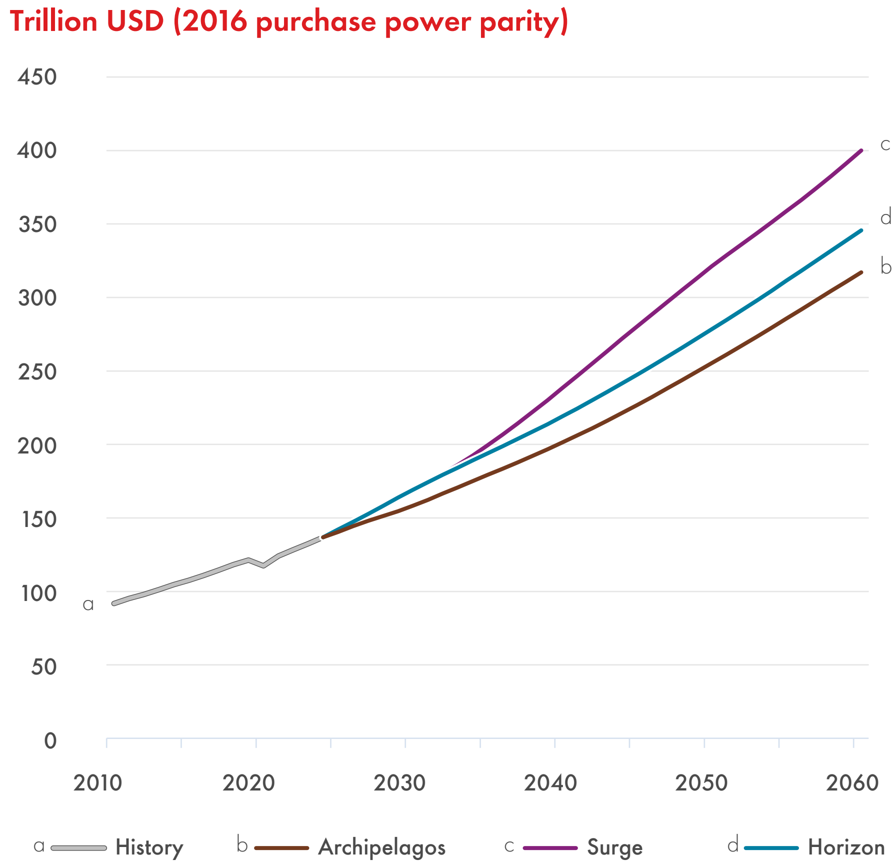
In **Surge**, an era of robust economic growth is ushered in by AI technologies that are welcomed and not overly challenged, with economic growth and AI infrastructure driving up energy demand. The geopolitical landscape offers a spur for change as China and the USA compete for AI dominance.

Horizon is illustrative of a rapid acceleration of the energy transition and introduction of carbon management practices to sharply reduce emissions, both of which are in response to a comprehensive policy framework with strong societal and political support. Importantly, **Horizon** takes a normative approach aimed at 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.

Each scenario features a unique global growth trajectory.

- In **Archipelagos**, trade tensions and global decoupling result in a low-growth scenario, with the world economy smaller by approximately 8% in 2050 than in **Horizon**. The reduction in annual growth is more profound in the coming decade to 2035 than in the period 2035 to 2050.
- **Surge** is built on the highest growth assumptions, with a boost in productivity emerging from deeper use of AI technologies in global supply chains. New goods and services also emerge, further boosting growth.
- **Horizon** is a normative middle case, with global economic growth between 2.5% and 3% for the balance of the 2020s and just below 2% through to 2100.

Gross domestic product in the three scenarios



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Economic growth in a fragmenting world

Global economic growth over recent decades has benefitted from globalisation and greater integration of economic and financial systems, enabling goods and services to be produced at lower cost and traded across national and regional boundaries. But the world shifted course since the 2008 global financial crisis, with rising trade disputes and a growing number of conflicts, sanctions and capital controls. This trend towards geo-economic fragmentation has intensified in the aftermath of the global pandemic in 2020 and Russia's full-scale invasion of Ukraine in 2022.

Since 2010, cross-border flows of goods have levelled off and there has been a surge in import tariffs and trade restrictions. Cross-border direct investments and capital flows have also been declining. China's renminbi and other emerging market currencies are increasingly used in global commodities, trade and financial markets (albeit from a low base, with traditional Western currencies like the US dollar continuing to dominate). As countries reshore supply chains for national security or geopolitical reasons, the pattern of trade and capital flows has been shifting, increasingly occurring within geopolitical alliances, rather than between geographically close countries.

In a world of political fragmentation and decoupling between nations, economic efficiency losses can mount, leading to lower overall growth. Depending on the severity of the decoupling, the International Monetary Fund (IMF) has estimated that geo-economic fragmentation could reduce global GDP by 0.2–7% by 2050 and GDP in individual countries by as much as 8–12% over the same period. The Organisation for Economic Cooperation and Development has estimated that reshoring of supply chains could reduce global GDP by 5%.

In the **Archipelagos** scenario, the different archetype groups experience different economic benefits or headwinds from the general fragmentation and decoupling that is inherent to the story.

- The **Innovation Wins** economies are about 5% smaller in 2050 than in **Horizon**. This follows the IMF low-case scenario of amplifying trade tensions and decoupling this decade, with the USA making good use of its large internal market and reshoring to see the economy returning to trend growth in the 2030s. This means some re-industrialisation in the USA and its consequent impact on energy use. However, geo-economic fragmentation dents US economic dynamism, limiting the growth potential in the 2030s and beyond.
- The **Great Wall of Change**, which is primarily China, also sees a similar fall in growth of about 5% in GDP by 2050 relative to **Horizon**. Globalisation has been a key pillar supporting China's economic growth. Accelerating global fragmentation and disorderly decoupling from the USA, coming on top of a weak domestic economy, act as a drag on China's economic growth this decade. Growth returns to its long-term trend in the 2030s, with China moving to a structurally lower economic growth path as its economy matures. Although the shorter-term dip in growth is not as sharp in China as in the **Innovation Wins** countries, the dip persists longer.
- The **Green Dream** countries, primarily within Europe, experience a 7% loss in GDP through to 2050 due to a combination of negative factors. A problematic decade through to the mid-2030s ensues, with security vulnerabilities to Russia, economic vulnerabilities from US isolationism, and political instability and vulnerabilities in Africa. Higher defence and infrastructure spending cannot offset the drag from an ageing population, structurally low productivity, and high energy prices and tension. The more trade-open economies, like the UK and Germany, face lower economic growth. As the **Green Dream** countries continue to pursue rapid decarbonisation into the 2030s and other countries lag, competitiveness concerns mount and, ultimately, goals are not achieved. New energy infrastructure projects generate insufficient returns to support the growth ambitions of the region.
- The **Emergent Surfers** can be seen as winners in a fragmenting world. Their human capital, high skill base in technology and engineering, and opportunity-based mindset enable them to benefit as global trade resets in the 2030s. While these economies face lower immediate growth prospects as trade tensions and accelerating geo-economic fragmentation degrade their trade-dependent economies, they ultimately benefit from the opportunities created by the subsequent resetting of global trade and manufacturing patterns. They develop a competitive advantage in higher-value and low-carbon industries, which boosts economic productivity and growth from 2030 onwards. These are countries with a focus on their commercial future and tend to be more transactional in their approach to diplomacy, leading to an economy that is 5% bigger by 2050 than in the **Horizon** scenario.
- The benefits that flow to the **Emergent Surfers** are not experienced by the **Rising Surfers**. Their progression up the economic development ladder is disrupted by global tensions, requiring realignment away from historical allies and the creation of new collaborations with new conditions. Geo-economic fragmentation means that these countries lose some of the benefits of trade and face slower technology spillovers and knowledge diffusion. These countries still see solid growth, but by 2050 the overall reduction in GDP compared to expectations has reached 9%.

Artificial intelligence and economic growth

The trend towards greater automation in blue-collar manufacturing has been well established for more than 200 years, delivering productivity improvements through higher production rates, optimised production processes, greater materials efficiency and improved product quality. In more recent decades, digitalisation has enabled greater automation of white-collar business processes and, in this century, it has transformed consumer purchasing.

Adoption of AI is expected to boost global productivity (GDP per worker), with the benefit likely to outweigh the economic cost of labour displacement. These benefits could be important at a time when global population growth is estimated to have passed its peak, with population declines imminent in some large economies.

Previous technological revolutions have boosted growth to varying degrees; for example, the different phases of the revolution in information and communications technology in the 1990s and 2000s raised US annual productivity growth by between 0.5 and 1.5 percentage points. The impact of these past technological revolutions has varied across countries, sectors and time.

Estimates of the productivity gain from AI range widely but are systematically lower for emerging and developing economies than advanced economies. The USA is likely to gain the most, with its deep capital markets, high R&D spend, an ability to attract skilled migrants, flexible labour markets, and an entrepreneurial and innovative culture. Countries like China, Sweden and South Korea benefit from their well-developed and widely accessible digital infrastructure. An International Monetary Fund analysis determined that around 40% of global employment is exposed to AI, by replacing some jobs and complementing others. This ranges from 60% in advanced economies to 40% in emerging markets and 26% in low-income countries.

The impact of AI may result in a period of rising income disparity and an increasing digital divide between countries. At first, countries with the necessary infrastructure, skills and market access thrive, such as the USA, China, Singapore and the UK. Inequality between countries initially widens. While the USA leads and enjoys the most pronounced growth, China continues its role as the principal global manufacturer of energy system infrastructure.

The rest of the world does catch up, but not all at once. The **Surfers** benefit from access to markets and data, and a different energy system architecture emerges in many countries compared with existing legacy systems. There is still robust industrial growth in the **Surfers** countries, but this is largely on the back of population growth and a shift from the current limited demand for energy services.

While the **Innovation Wins** countries reap the biggest rewards, those lagging will see a material change in their economies over time. A middle-income group emerges that aspires to greater wealth, travel and the acquisition of material possessions, although not to the extent seen in Europe and the USA in the 20th century.

Three distinct storylines in a period of apparent polycrisis

The scenarios explore the challenges the world faces as countries deal with aggressive neighbours and adversaries, face mounting trade issues and grapple with migration, while still attempting to reap the benefits of global technology developments like AI and manage rising greenhouse gas emissions.

Horizon

A normative scenario illustrates how long-term environmental security is delivered as the world reaches net zero emissions by 2050, while aiming for 1.5°C.

Archipelagos

Security through realignment is pursued as self-interest and security concerns become deeply rooted in the national psyche. Economic growth suffers and, while global conflict doesn't emerge, nations act as if it will.

Surge

Economic security emerges through growth and productivity improvements, with AI technologies reshaping society and driving rapid change in the energy system.

Archipelagos

In **Archipelagos**, the underlying driver within the scenario is a global realignment of influence. China, the **Great Wall of Change**, has become the world's major producer of industrial equipment, largest refiner of minerals and biggest manufacturer of domestic goods and cars, and it is positioning itself as a technology leader, long the hallmark of the USA. By the late 2020s, the wealthy developed countries are facing heightened commercial competition, erosion of their hegemony and aggressive military expansionism at a time when the coffers are empty following the global pandemic.

The shift in balance fractures the post-war pattern of US and European power, with the **Emergent Surfers** following the money. The **Rising Surfers**, looking for new allies after a decline in support from the likes of the USA, look towards China for electricity infrastructure, particularly solar photovoltaic and battery storage mini-grid systems.

Beijing doubles down on its industrial strategy, transforming from the world's factory into the world's innovation hub. By the early 2030s, it leads the globe in quantum computing, AI, green energy and next-generation semiconductors. Chinese firms become household names worldwide, often outpacing American technology giants in both innovation and affordability. China leads not by replacing the USA as global hegemon, but by reshaping the terms of trade, technology and diplomacy. It acts as a selective integrator, setting standards in supply chains, digital platforms and new energy infrastructure – but without universal norms or a strong global security role.

A growing push-back by the USA, EU and their immediate allies means the 2030s are defined by messiness, not mastery. Trade is volatile, trust is low, alliances are fluid and climate adaptation overshadows mitigation.

Although China is ascendant, it is not triumphant. Trading partners are wary of overexposure to Beijing's influence. The USA is diminished, but not irrelevant. In the space left behind, middle powers such as India, Vietnam, Brazil, Indonesia and Turkey scramble for advantage, navigating a fractured, unpredictable global order. This is also a world of **Emergent Surfers**, progressive nations that ride multiple currents rather than anchor to one and succeed in an increasingly transactional economic environment.

They exploit commodity volatility, hedge between digital platforms and weaponise their own labour, logistics or location advantages. For some, this pays off. For others, especially those with weak institutions or divisive politics, it leads to drift or dependency.

By the late 2030s, India is following in the steps of China, albeit 15 years behind. While it never reaches the scale of Chinese manufacturing production, it surpasses that country in terms of white-collar services.

As Beijing's star rises, Moscow watches on. Russia envisions itself as an indispensable partner to China's rise, gaining global leverage by proximity given its vast natural resources of oil, gas and minerals, which it sees as critical assets in this new order. Although Chinese companies invest heavily in Russian logistics and infrastructure, enabling Russian oil and gas to flow East and away from Europe and the Mediterranean, Beijing is also recalibrating.

Through the late 2030s and into the 2040s, Beijing withdraws quietly but systematically from its Russian interdependence. As China's renewable energy and battery storage technology surpasses anything the West or Russia can offer, the country's dependence on Russian oil and gas begins to fade. By the mid-2040s the pipeline flow has reduced significantly.

However, China remains dependent on Russia for Arctic access and its secure Arctic ports. The region becomes strategically important, and nations compete for dominance given the opening of trans-polar trade routes, which tend to hug the Arctic coastal regions.

This scenario features a world which builds strongly on the behaviours seen in the four archetypes. A highly competitive world emerges, but it is increasingly transactional and opportunistic. Growth suffers as a result, with the geopolitical focus shifting away from the post-war transatlantic pillars of the USA and Europe. The energy transition continues, but with little focus on net zero emissions in 2050; only truly competitive or strategically beneficial energy technologies do well. Carbon capture, advanced biofuels, synthetic fuels and immature low-carbon industrial processes all experience setbacks. But technologies built around solar, wind and battery storage flourish.

Changes ahead in China

In **Archipelagos**, China seeks to be free of G7 influence on oil and gas markets, and become an increasingly important supplier of modular components for the global energy system.

A key determinant in implementing this strategy is the pace of electrification in the economy. The fraction of electricity in final energy in China is already more than 30%, and the system shifts rapidly to 50% by the mid-2040s, well ahead of the USA which already lags China in electrification. The USA only reaches current Chinese levels of electrification in 2050.

China shifts rapidly to electric vehicles and quickly electrifies its industrial base. The electrification of transport isn't limited to passenger cars; by the 2070s, the road freight sector is also entirely electric. By contrast, in **Archipelagos**, half the energy used for trucks in the USA in 2075 is still from oil.

To support the electrification trend, China grows its domestic use of solar and wind power nearly seven-fold in 40 years and expands its nuclear fleet four-fold in the same period. By the early 2060s, coal-fired electricity generation has ended and, by the early 2070s, all fossil generation has ceased.

With its built-environment infrastructure base largely established by mid-century and its population in decline, Chinese industrial capacity starts to fall, with less production of basic raw materials like cement and steel.

The USA enters a phase of retrenchment. Mounting debt, political polarisation and volatility limit its capacity to project power. Yet it retains dominance in military deterrence, digital security, biotechnology and space. Rather than policing the world, it becomes a fortress innovator, focused on defending the open web and protecting supply chains with strategic allies. With tariffs in place, US consumer demand softens but does not collapse. The USA's withdrawal from global consumerism is not replaced by any single power – rather, the global economy fragments into regional blocs, with middle-income consumers in India, Indonesia and Nigeria driving the next wave of selective growth. Again, the **Surfers** rise, helping drive global commerce.

The EU remains globally engaged but no longer shapes the global rules. It maintains economic weight in high-value exports, standards-setting and regulation, but struggles to scale influence beyond its region.

The **Green Dream** ethos remains entrenched, but Brussels finds it has limited enforcement capacity. Member States diverge and ignore or delay targets. Nevertheless, the bloc holds together, more out of mutual vulnerability than shared ambition.

With US hegemony waning, and China unwilling or lacking interest in global leadership, geopolitics becomes more fragmented and multipolar. Regional blocs and middle powers, with greater relative influence, become critical actors in the global system. They shape local political dynamics, intensify regionalised economic integration and become pivotal players in local security issues. These regional players also shape energy markets, shifting alliances to ensure both reliable energy flows and the success of their transitions. Most importantly, they act autonomously and transactionally – not as satellites or clients of any superpower.

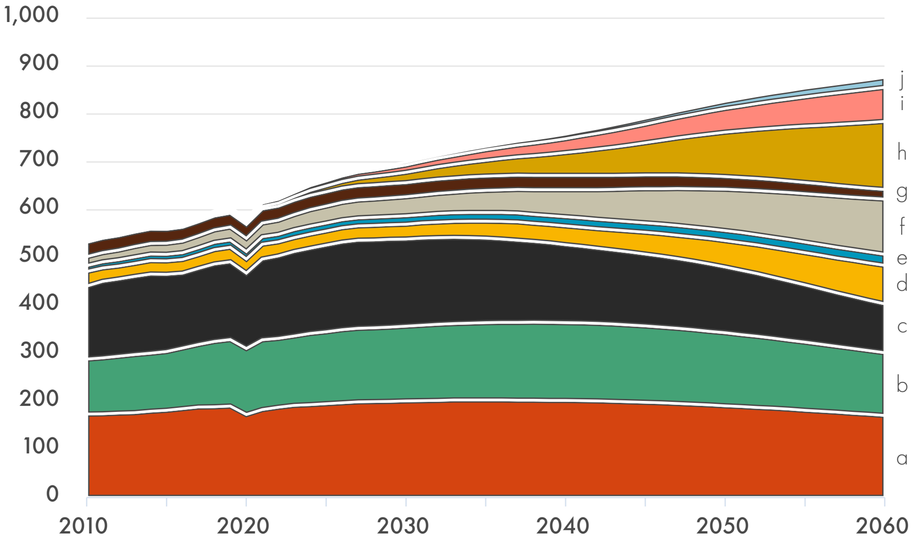
India emerges as a political and digital counterweight to China, not by mirroring its scale but by offering an alternative path: democratic, decentralised and semi-aligned.

This is not a world of collapse. It is a world of perpetual instability, competition and transactional functionality. No single power dominates. Middle powers shape the future more than great ones. Growth persists, but co-ordination erodes.

Archipelagos is a story of adaptation without alignment, innovation without integration and resilience without trust. A world that works, but only just.

Development of primary energy in **Archipelagos**

Primary energy, EJ per year



a Oil
b Natural gas
c Coal
d Nuclear
e Hydroelectricity
f Commercial bioenergy
g Traditional bioenergy
h Solar
i Wind
j Other renewables

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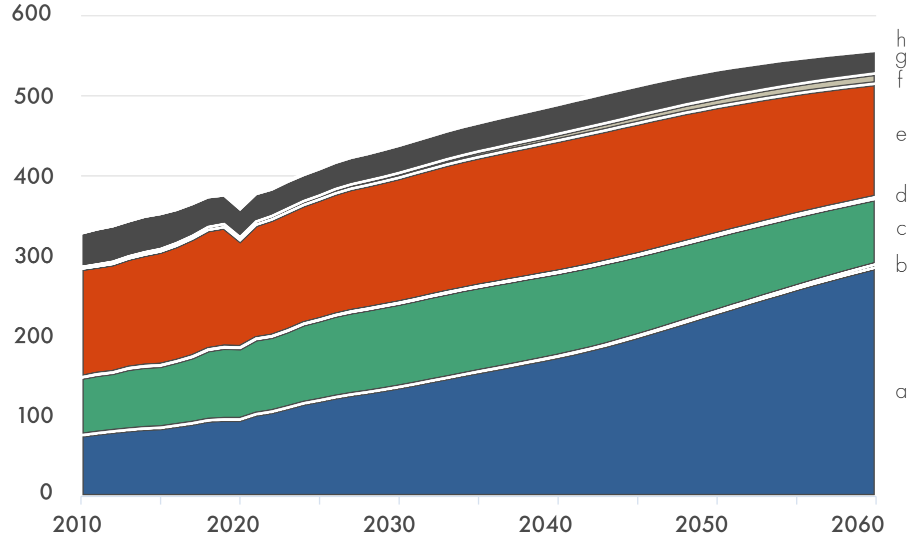
Development of final energy in **Archipelagos**

Final energy, EJ per year



a Electricity
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c Gaseous fossil fuels
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g Solid fossil fuels
h Solid biofuels

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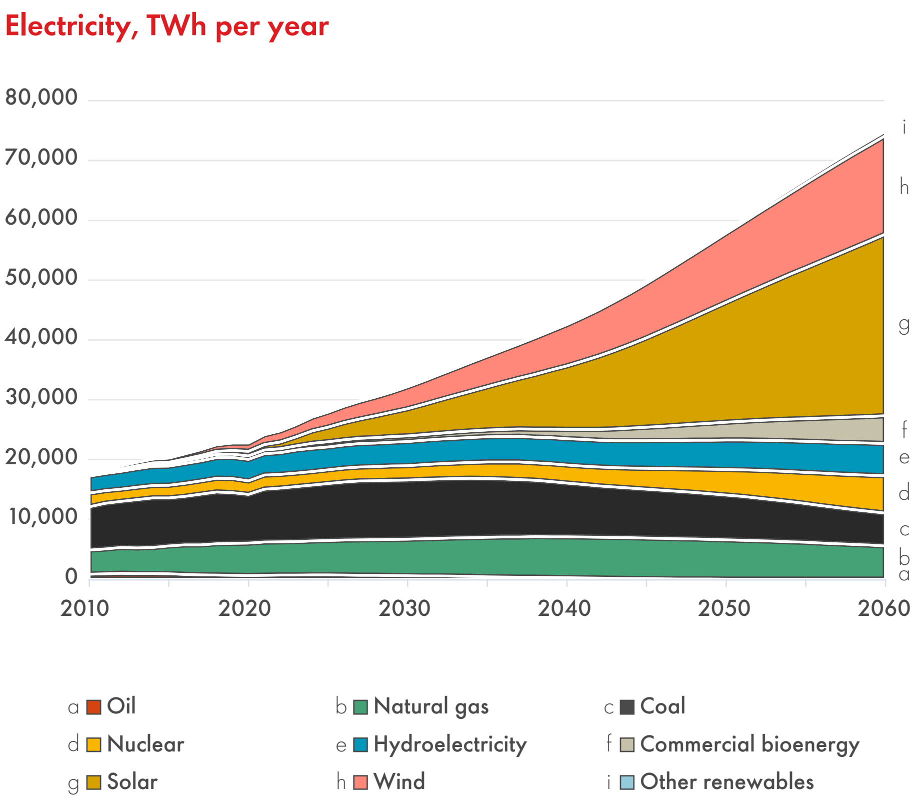
Growing global electricity demand in **Archipelagos**



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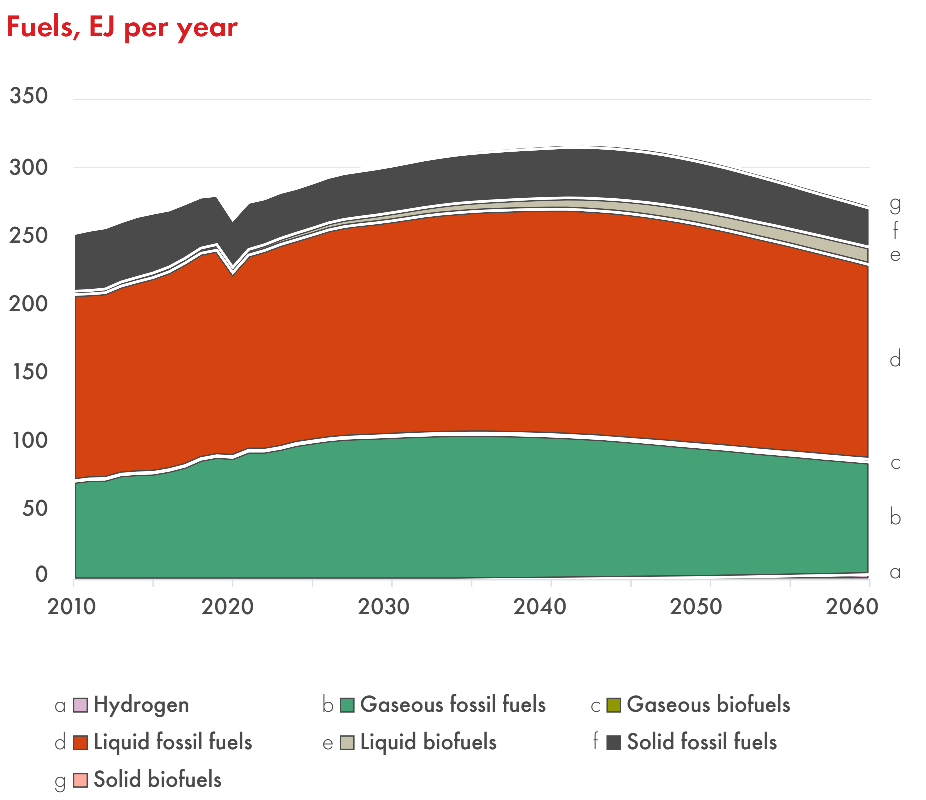
Development of the molecular fuel mix in **Archipelagos**



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Surge

In **Surge**, AI technologies take root and usher in a period of stronger economic growth. Governments yield to related hardware and data security issues as the economic benefits of AI meet their more immediate needs, but they are confronted with higher energy demand and a society that transforms more rapidly than legislative responses can keep pace with.

AI technologies that are emerging today become core foundation elements of global information technology infrastructure throughout the 2030s, with rapid innovation in the sector leading to disruptive change. The energy system shifts more rapidly towards production of components as modules which are then assembled "Lego-style" in the field, as is currently the case with solar photovoltaic. This marks a shift away from large one-off bespoke projects.

The trend towards modular construction expands rapidly for solar photovoltaic, power grid batteries, hydrogen electrolysers, heat pumps and, in the 2040s, direct air capture units that remove CO_2 from the atmosphere. Smaller industrial electric furnaces are similarly built, as are the various units required for electricity distribution and larger 3D printers for medium-sized manufacturers. Production on this scale brings significant cost reductions.

The trend leads to a more dispersed, electricity-based energy system in which AI integrates the deployed modules, although fossil fuel use persists in many industrial applications because of cost competitiveness. While electricity systems maintain regional coherence, decisions on power dispatching and demand management become more decentralised and distributed. Many local smart solutions emerge, better integrating electricity into local energy use.

Solar photovoltaic manufacturing easily exceeds 1 terawatt of panel production annually by 2030, nearly doubling from some 600 gigawatts in 2025. The revolution in battery production for transport extends to modular grid battery units. This leads to the rapid deployment of combined solar photovoltaic and battery arrays.

In the 2040s, the small modular nuclear reactor comes of age, with rapid production of 25–200 megawatt units. These become popular for facilities such as large data centres, industrial electric furnaces and even ships. A new era of commercial marine propulsion begins to emerge. Modular components for energy production and manufacturing in combination with AI give rise to the emergence of new manufacturing and production in many less developed economies, which provides growth and opportunity.

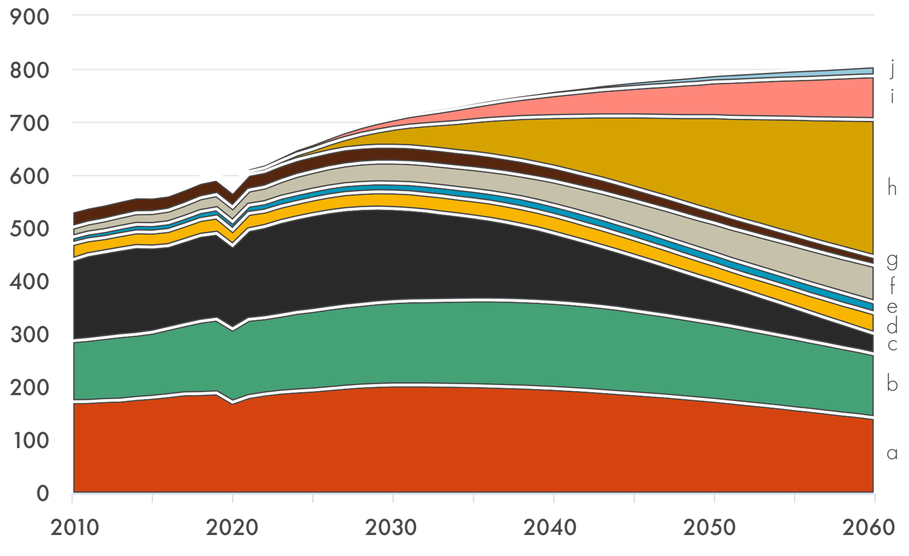
Various enterprises flourish throughout Africa as towns and even villages secure investment for local manufacturing, which in turn improves local and national governance.

The trend marks a new start for many countries, with the rapid emergence of a middle-income population in some locations, supported by the new opportunities and refreshed governance structures. While industries such as cement production, mining and smelting remain important and grow as infrastructure is built, the development of a large heavy industry sector, as seen in China in the 1990s and 2000s, is not repeated on the same scale. But services and light industry flourish.

Given its heavy industry base, China continues its role as the principal global manufacturer of energy system infrastructure. While India, Europe and the USA attempt to match the scale, China remains dominant in modular system production and the processing of minerals and chemicals required for such production.

Development of primary energy in **Surge**

Primary energy, EJ per year



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f Commercial bioenergy
g Traditional bioenergy
h Solar
i Wind
j Other renewables

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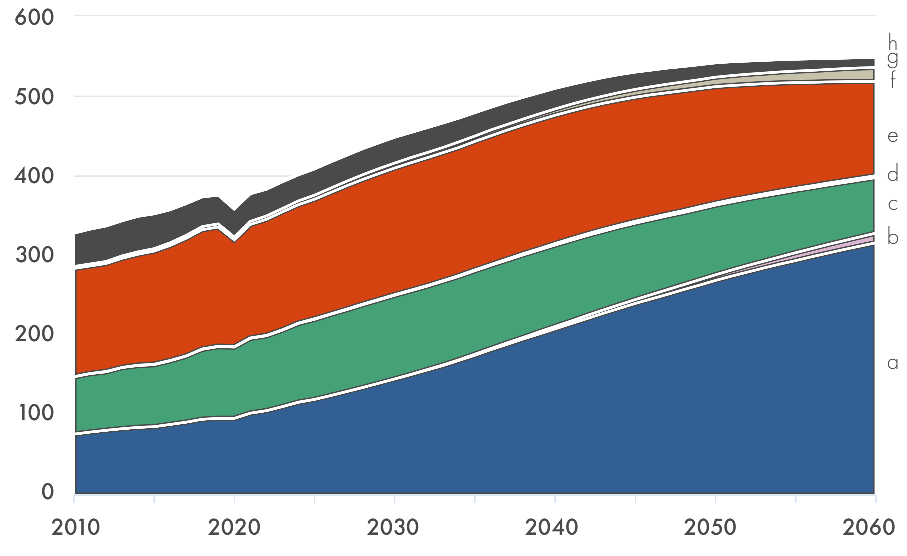
Development of final energy in **Surge**

Final energy, EJ per year

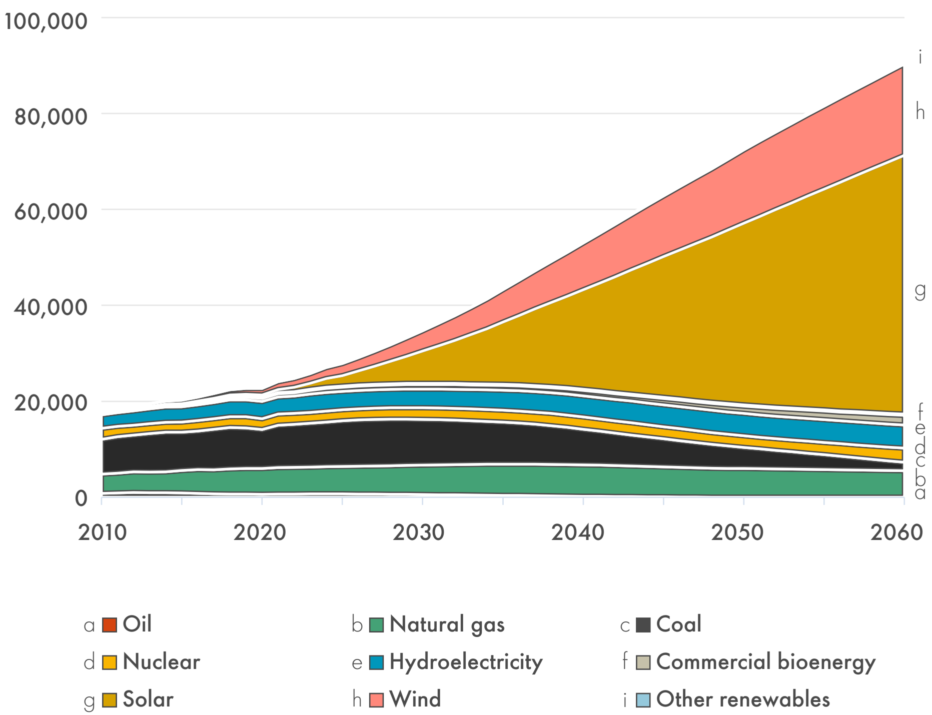


a Electricity
b Hydrogen
c Gaseous fossil fuels
d Gaseous biofuels
e Liquid fossil fuels
f Liquid biofuels
g Solid fossil fuels
h Solid biofuels

See the accessibility description

Growing global electricity demand in **Surge**

Electricity, TWh per year



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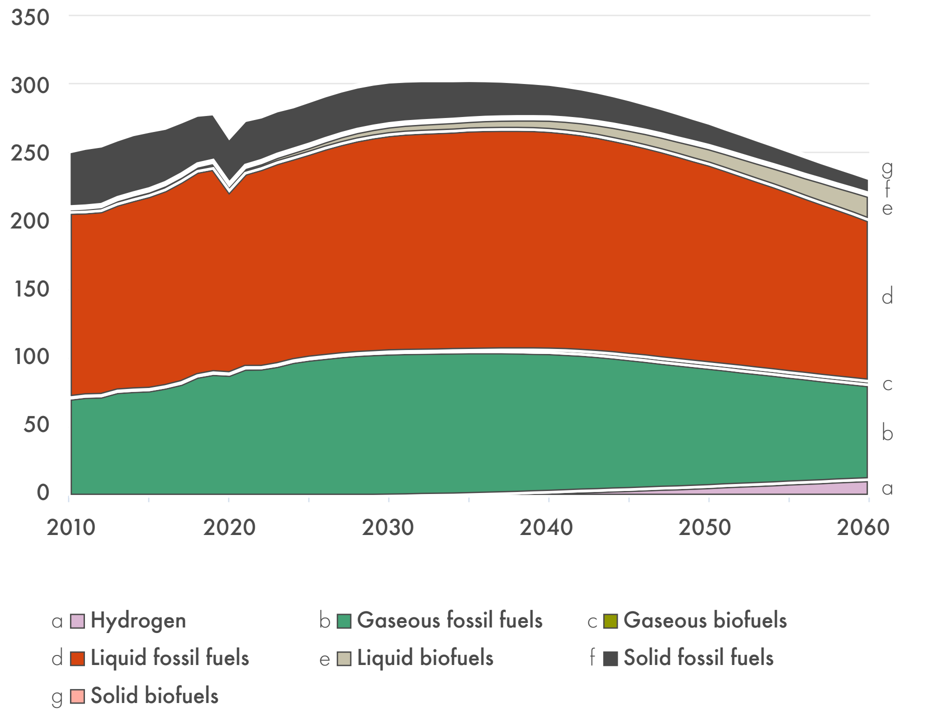
Development of the molecular fuel mix in **Surge**

Fuels, EJ per year



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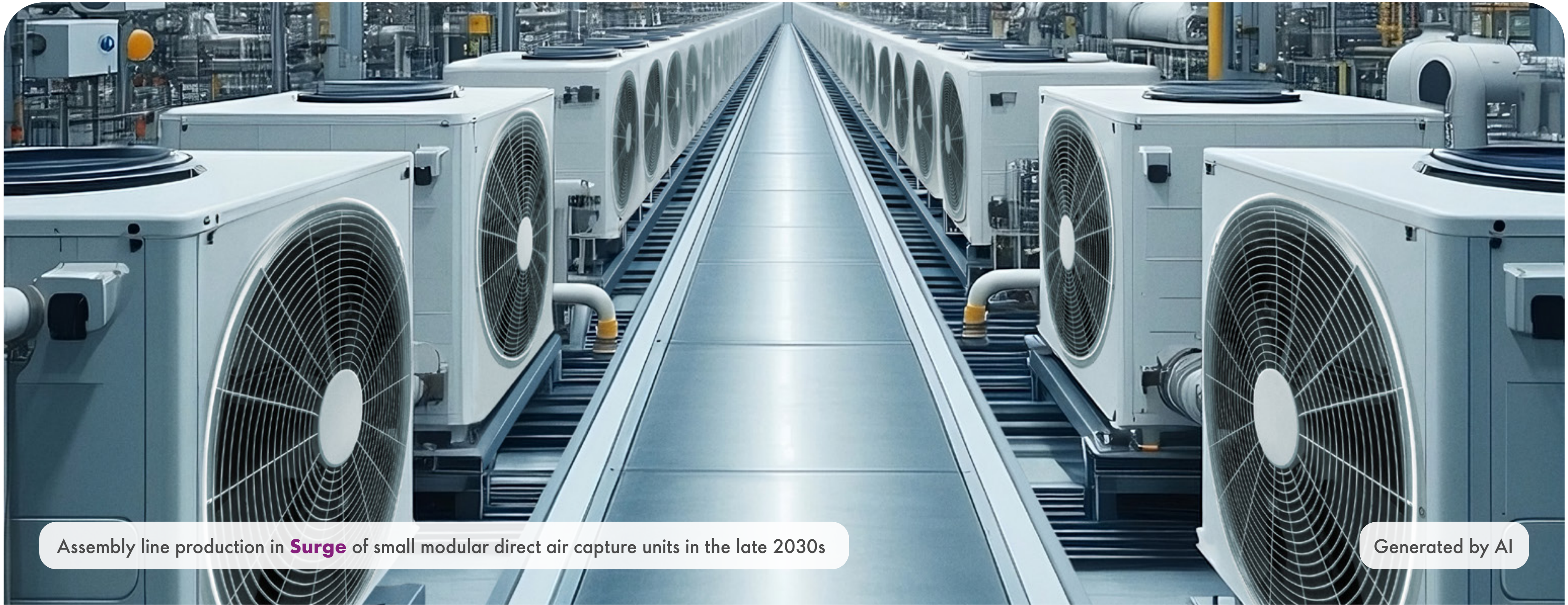
In **Surge**, a new technocratic era emerges, with AI benefitting in the 2030s from quantum advantage (the point at which a quantum computing system solves problems outside the reach of classical algorithms). This delivers advances in basic sciences, accelerating change in the energy system and shifting energy production and management to new entrants from the technology sector.

New conducting materials help usher in faster electrification through cost reduction and the lessening of material constraints.

Advanced biofuels rapidly replace jet fuel in aviation, and electrochemistry developments push battery performance to new heights. Global technology companies favour renewables and, later, nuclear energy. Out of necessity, they become leaders in carbon management because of their huge demand for electricity and energy services.

Direct air capture becomes a winning technology with total deployment removing 1 gigatonne of CO_2 per year by the mid-2050s. The accelerated shift to electricity and the rapid deployment of modular energy infrastructure reduces global CO_2 emissions from the early 2030s, increasingly so in the 2040s. However, net zero CO_2 emissions is not achieved by 2050 in **Surge**. By 2060, CO_2 emissions have fallen by nearly 75% from their 2027 peak, with net zero CO_2 emissions finally achieved in 2080. By 2100, the global surface temperature rise in **Surge** compared with the period 1850–1900 is about 2.0°C.



Assembly line production in **Surge** of small modular direct air capture units in the late 2030s

Generated by AI

Horizon

Horizon is a normative scenario, in that specific targets are incorporated to reach net zero CO_2 emissions by 2050 and deliver a global average surface temperature rise below 1.5°C by 2100.

There are visible signs of a rapid energy transition in 2025, but progress is far from uniform across all sectors. Solar photovoltaic is now heading towards 1 terawatt of new capacity each year before 2030, and this stands out as the main success story of the progress required to deliver the targets underpinning **Horizon**.

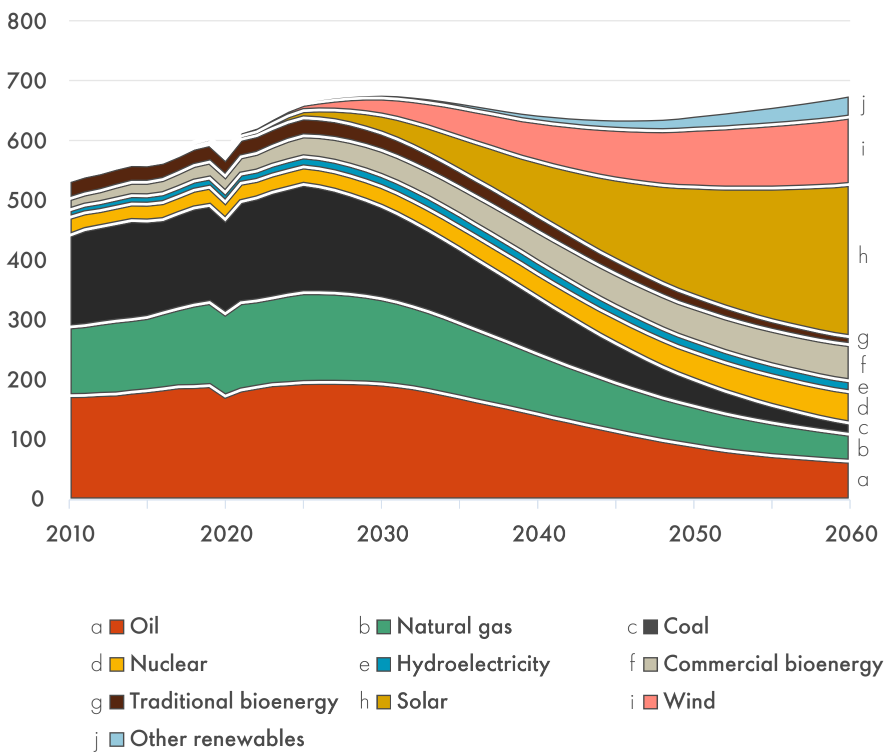
As seen in the early 2020s, delivering large emission reductions in support of the Paris Agreement has not happened. Rather, nations cling to archetype behaviours, driven by energy price and supply concerns. But change must happen in the immediate future for emissions to fall fast enough to reach net zero by 2050. In **Horizon**, citizens themselves start to push for change within their own countries and rapidly adopt new technologies to deliver environmental security. Politicians follow and 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. A comprehensive policy framework emerges, and nationally determined contributions submitted under the Paris Agreement are reported to be on track for net zero in 2050 by the UN Environment Programme in its 2030 annual report.

This happens as the need to deliver low-carbon energy infrastructure takes on an urgency of its own, as energy security and price concerns continue. The energy system rapidly transforms. Following a much-delayed agreement on Article 6 of the Paris Agreement, a carbon removals industry is quickly established based on natural removals and carbon capture and storage. After 2040, systems that remove CO_2 from the atmosphere (direct air carbon capture and storage, or DACCS) become commercially viable.

Horizon features a period in which the global average temperature is more than 1.5°C warmer than pre-industrial levels, given the proximity to that goal in 2025. The world goes on to bring this below 1.5°C again later in the century. The **Horizon** story implies that actions to prevent any overshoot of 1.5°C would need to be even greater than the already substantial measures laid out in the scenario and therefore may not be technically feasible without further substantial interventions by governments.

Development of primary energy in Horizon

Primary energy, EJ per year



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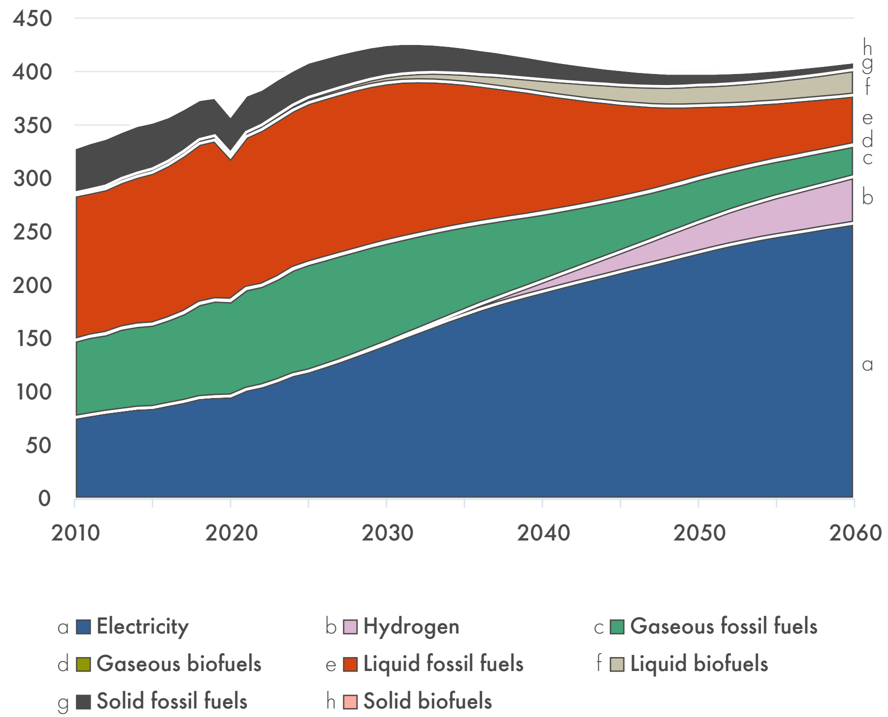
Development of final energy in Horizon

Final energy, EJ per year



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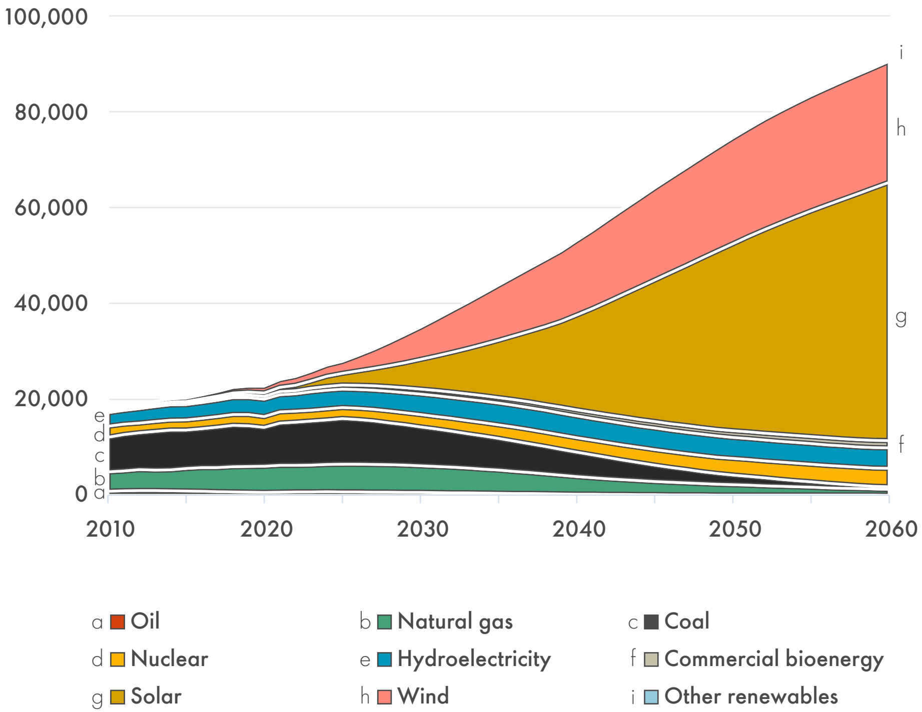
Growing global electricity demand in **Horizon**

Electricity, TWh per year



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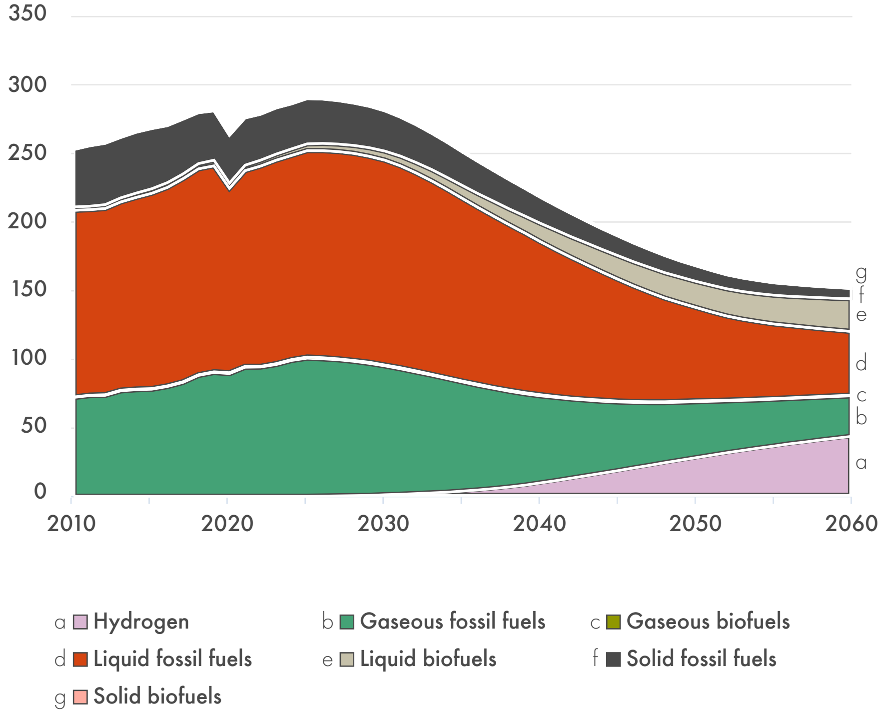
Development of the molecular fuel mix in **Horizon**

Fuels, EJ per year



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Changes to the energy system

The three scenarios recognise the current global dependency on oil, gas and coal for energy needs, at nearly 80% of primary energy use. A point of inflection is currently emerging as renewable energy technologies reach scale, with fossil fuels losing market share over time. A second point of inflection is also developing, notably an acceleration in the uptake of electricity in final energy use and therefore a declining market share for liquid and gaseous fuels.

These two points of inflection are largely the result of two technologies, solar photovoltaic and battery storage. Both are emerging at increasing scale and falling cost because of assembly line production of deployable units.

Solar photovoltaic has been a feature of the energy system for 40 years, but in the last decade deployment has grown rapidly to become a meaningful disruptor. With new capacity of about 600 GW per year, some 500+ TWh of electricity production is being added annually to the grid, or about 2% of total global generation. Wind generation is adding to this, but it has been far surpassed by solar.

Large batteries are disrupting the transport system and supporting the deployment of solar photovoltaic through grid electricity storage to manage intermittency. According to the IEA, specific planned projects are likely to take global production capacity to about 6.5 TWh by 2030. If this capacity is fully utilised and split between grid and transport applications, it would be sufficient to produce some 35 million electric vehicles (about half of global production) and enough grid storage capacity to supply the entire night-time load of Japan and Australia combined.

Looking forward, disruption continues in the electricity and transport systems in all three scenarios. This will be far from homogeneous given national politics and preferences, but it will continue at pace. Incremental change from 2026 is scenario dependent, with future deployment highly dependent on global trade, politics and economic growth prospects.

However, the energy transition and journey to net zero emissions require more than just electricity generation and the supply of electric vehicles. Industrial sectors, aviation, marine and building heating all need to change. These sectors account for nearly half of global emissions and are considered harder to abate. Progress has been modest, with the introduction of new processes and fuels still limited. For example, sustainable aviation fuels make up less than 1% of total fuel demand in the aviation sector. Similarly, there is no operational facility smelting iron ore with hydrogen, but several projects are in development. Nevertheless, there are hundreds of facilities globally burning coal for smelting.

The nature of the hard-to-abate sectors transition going forwards is highly uncertain, as is the focus on emissions management. It is quite possible to arrive in 2050 with an all-electric global car fleet and still find that anthropogenic CO_2 emissions have hardly fallen compared to 2025.

In **Archipelagos**, priorities shift towards domestic resources and opportunism in trade, both of which tend to favour fossil fuel use, with coal demand proving to be resilient into the 2030s. Given the weaker global economy, increased military spending and critical mineral supply mired in trade disputes, the energy transition loses some pace. Technology pathways such as direct air capture become nearer-term casualties, and growth in carbon capture and storage, other than for certain industries, is non-existent. **Archipelagos** sees the highest fossil fuel use in 2050, even with lower overall energy service demand, and supplying the fossil fuels requires new investment.

As those investments are made, the prospect of a global temperature outcome well below 2°C (versus 1850–1900) vanishes. Even 2.5°C may be a challenge. This leads to some civil unrest and an eventual focus on adaptation, but only after a string of weather events forces governments to respond. Net zero emissions becomes a 22nd-century goal, with society split and some investments ultimately failing. However, global CO_2 emissions do begin a slow trend downwards from the mid-2030s.

In **Surge**, the private sector takes the lead on energy and economic growth as AI technologies reshape the global economy. **Surge** sees both higher oil and gas demand in the shorter term and higher energy demand overall as economic growth picks up. This means that **Surge** offers relative resilience for oil and gas production, not because of slower development or uptake of new energy technologies, but simply because of more buoyant economic growth driving overall energy demand. Although new energy infrastructure appears rapidly, demand is such that existing energy production and systems are retained for longer.

With GDP in **Surge** rising faster than in **Horizon** and **Archipelagos**, final energy demand by 2050 is more than 800 exajoules (EJ), compared with 655 EJ in 2024. Energy demand comes from both the expansion of AI itself (data centres, data transmission, learning systems and generative AI) and, more importantly, AI-induced economic growth and electrification. In **Surge**, AI-related energy demand reaches 5,000 TWh or 20 EJ for IT infrastructure in 2050. That is five times the current energy use of information technology infrastructure and 8% of **Surge** electricity demand in 2050.

The private sector plays a large role in shaping the energy system through modular component production of energy infrastructure, rapid conversion of manufacturing to electrification and a late but important trend in managing CO_2 emissions.

Energy system design and implementation increasingly shifts away from early 21st century incumbent energy companies towards the global technology behemoths. Net zero emissions are achieved in 2080, and the world can limit warming to 2°C in 2100.

In **Horizon**, the near-term resilience of fossil fuels increases greenhouse gas emissions and results in an overshoot of the 1.5°C goal. In time, this overshoot is balanced with greater action to remove CO_2 from the atmosphere, and by 2100 the global average surface temperature rise is below 1.5°C.

After 2030, **Horizon** brings society rapidly to net zero emissions, and the scenario sets out the major interventions in the energy system required from policymakers to achieve that outcome. This includes the early retirement of some higher carbon intensity fossil-fuel assets, high carbon prices, the rapid introduction and scaling up of early-stage technologies, and significant energy conservation through efficiency and even energy austerity.

Governments are forced to limit societal choices, such as restricting the selling of internal combustion engine vehicles and dissuading excessive 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. A major effort to capture and store carbon dioxide is a feature of **Horizon**, including both nature-based and technical solutions.

Critical minerals and the energy transition

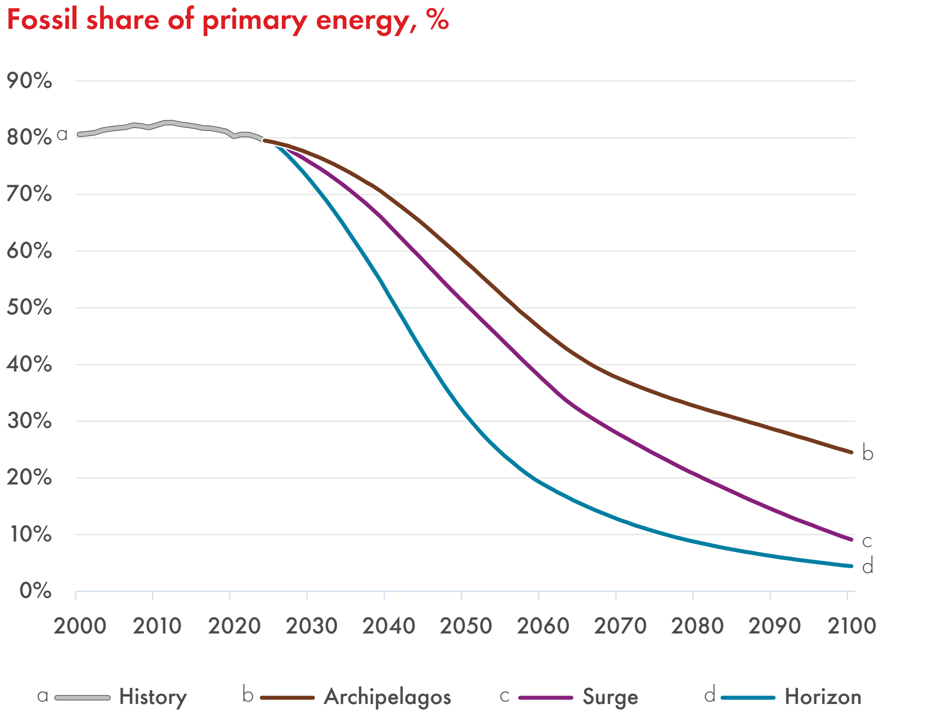
The future energy system will bring increased dependency on critical minerals, such as lithium, nickel, cobalt, graphite, neodymium and copper. These minerals become more important in a world with increasing electrification. The world has sufficient reserves, but geopolitics can disrupt supply.

In **Archipelagos**, the story of critical minerals becomes one of strategic competition, national hoarding and reshoring. China's dominance remains substantial, but it becomes contested, hedged against and diversified, rather than fully replaced. Initially, China maintains a strong grip on refining and processing minerals, using its dominance to tie mineral access to trade and security agreements.

Throughout the 2030s, the USA, the EU, Japan, South Korea and Australia build refining capacity with a focus on minerals for batteries. Africa, Latin America and Southeast Asia play a more active role. For example, Indonesia leverages its nickel deposits for technology transfer and refining partnerships, and the Democratic Republic of the Congo experiments with resource-backed development agreements. The circular economy becomes a strategic pillar of mineral independence. Europe and Japan lead in battery recycling and rare-earth reclamation from electronic waste. Similarly, the USA launches federal mandates for electric-vehicle end-of-life recovery. Resource recovery becomes as politically important as new mining, given the security issues and environmental challenges facing new mines. More countries nationalise or heavily regulate their mineral assets. During the 2030s, mineral diplomacy becomes reminiscent of 1970s oil politics. As nations react with trade barriers, tariffs and restrictions, the ensuing mineral supply headwinds slow down the energy transition.

Research and development accelerates in mineral-light technologies, including sodium-ion batteries (less reliant on cobalt and lithium), solid-state storage with less rare-earth content and magnet technology using iron nitride or other substitutes for minerals such as neodymium. However, copper remains problematic owing to increasing demand, the concentration of smelting in China and the 15 or more years it takes to bring a new ore discovery into production. In **Archipelagos**, this issue is further exacerbated owing to the important role of copper in armaments. It is often used as a driving band in artillery shells, as a liner in shaped-charge antitank munitions and in jackets for small-arms rounds. Minerals are no longer just commodities; they are foreign-policy tools. Supply reliability eclipses price, with companies and governments preferring slightly costlier but geopolitically neutral supply. Every major power builds domestic stockpiles.

Fossil fuel share of primary energy in the three scenarios



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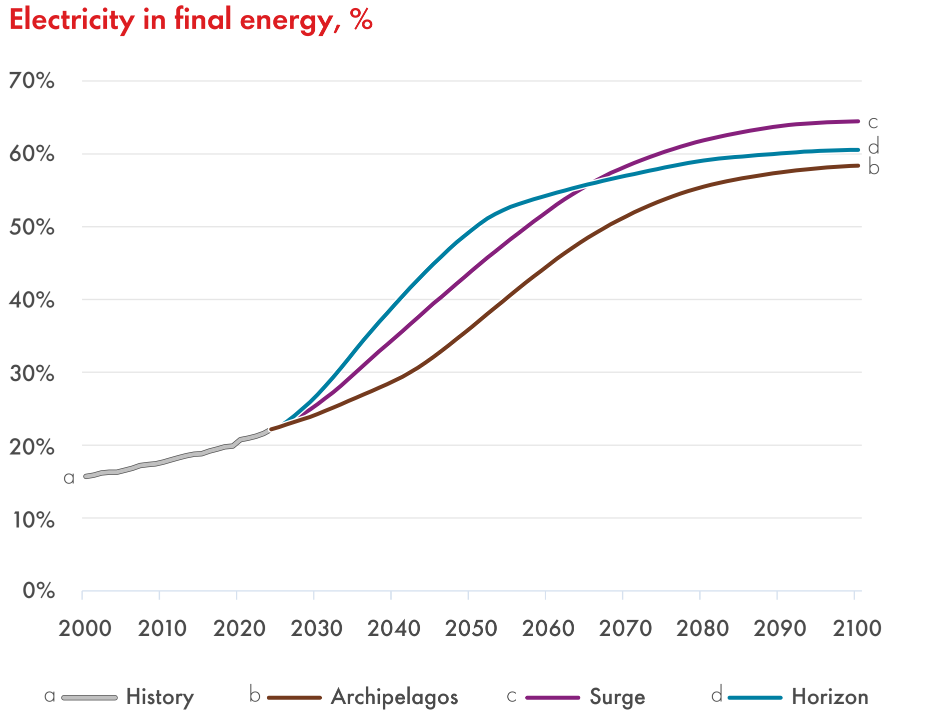
Electrification of final energy in the three scenarios



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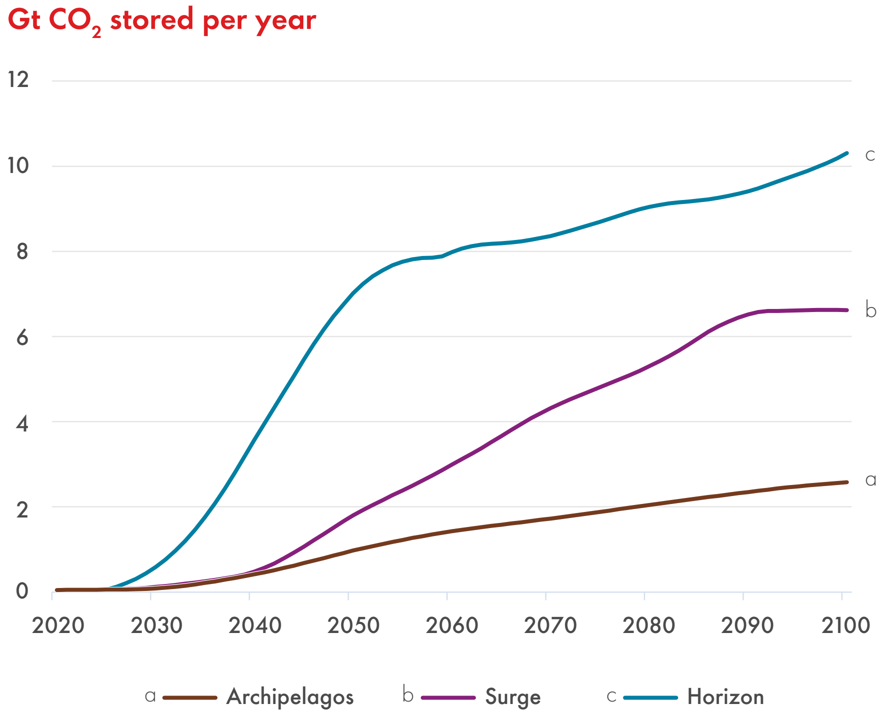
Global geological storage of CO_2 in the three scenarios



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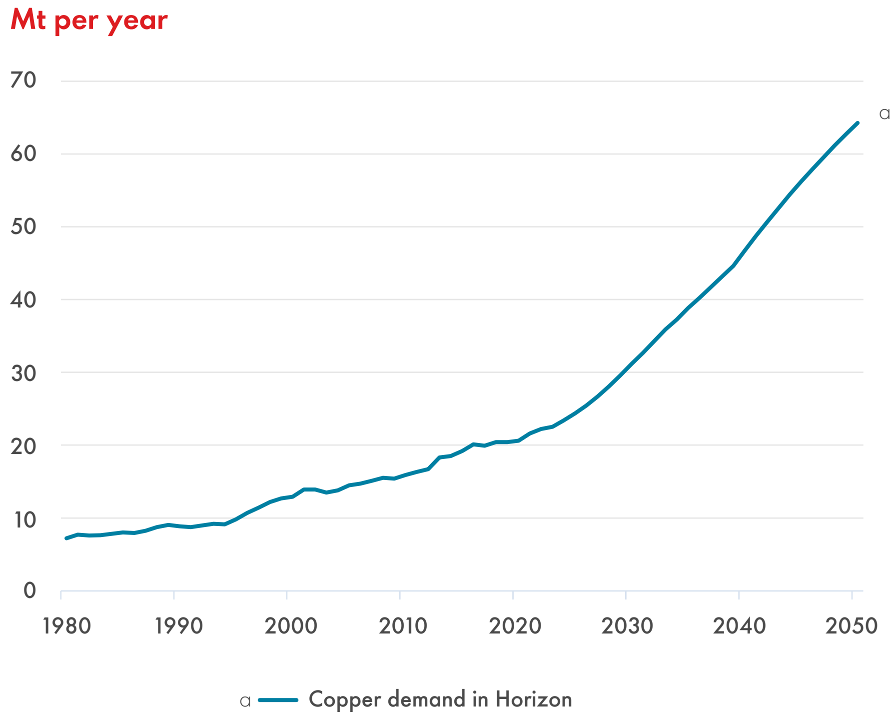
Rapid growing demand for copper in **Horizon**



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Energy demand

In all three scenarios, there is upward pressure on energy demand. Efficiency is key to limiting the growth in overall energy demand, with electrification, insulating buildings and behaviour change all contributing. In **Archipelagos**, despite weaker economic growth and lower demand for energy services, societal demand for energy is highest, resulting almost entirely from maintaining fossil fuel use for decades more than in the other scenarios (see the box "Drivers of energy demand"). In **Surge**, energy demand rises by a quarter on the back of global economic growth and demand for AI services. By contrast, there is little change in **Horizon**, where rapid electrification, imposed change, high carbon prices and mandated efficiency improvements such as building retrofits are important in limiting energy use.

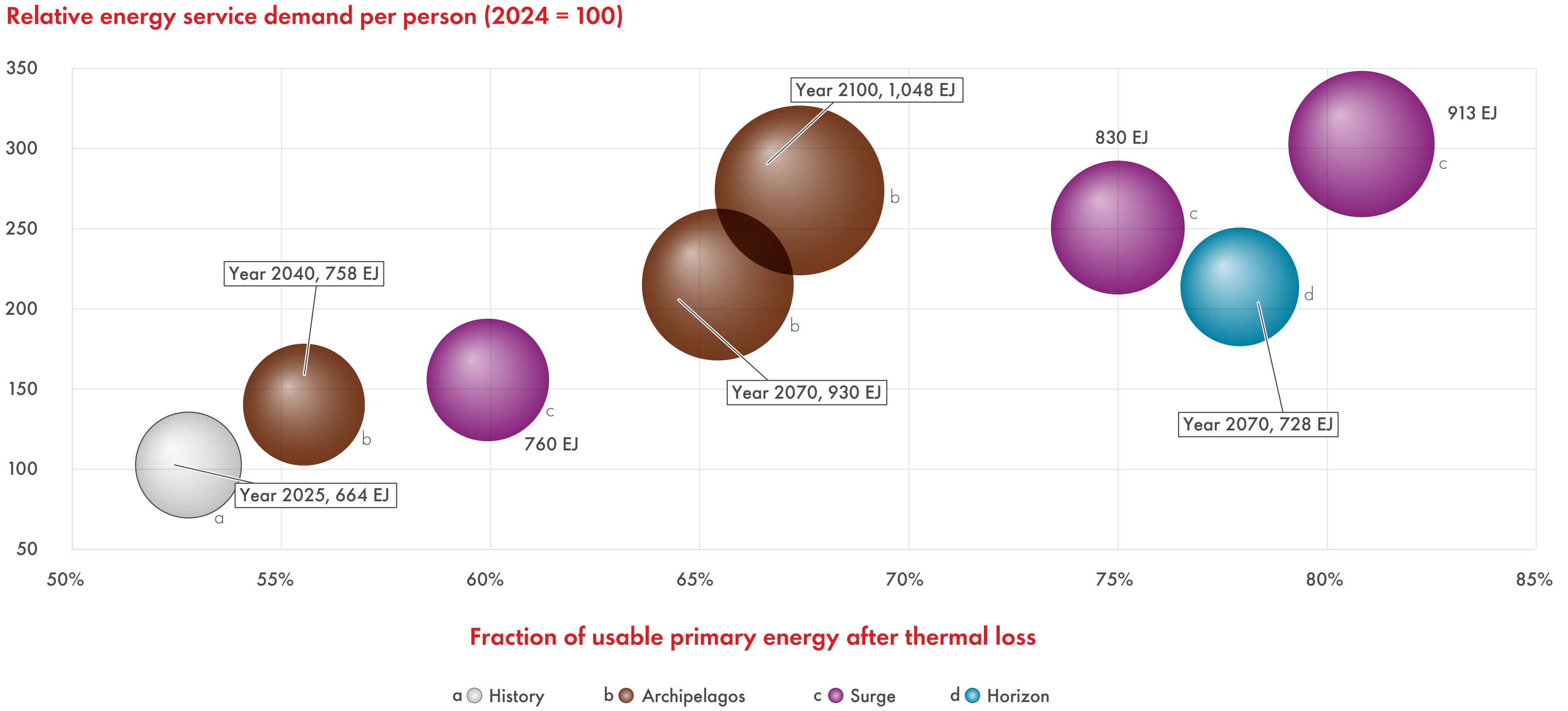
Drivers of energy demand

Energy is essential for delivering goods and services, but the amount of energy society uses is dependent on many factors. The starting point is the overall demand for goods and services, which in turn is impacted by development, economic growth, technology choices and societal preferences (for instance, we now access more news online rather than through newspapers, periodicals and even broadcast television). The next factor to consider is the efficiency of the process to deliver those goods and services, which in turn impacts the energy requirement. Finally, there is the mechanism used to deliver the energy, which also changes the overall efficiency of delivery.

Generating electricity from a wind turbine, transmitting it to a city for storage in an electric vehicle battery, then powering an electric vehicle motor for mobility can have a 70% overall efficiency. By contrast, producing oil, refining it, transporting petrol and combusting it in an engine for mobility has an overall efficiency of about 25%. This means that the choice of energy sources and the mechanisms for manufacturing or delivering the desired goods or services can have a larger effect on total energy demand than the underlying demand for the actual goods and services. This difference in system efficiencies is why the **Archipelagos** scenario has a higher overall energy demand, despite having a lower demand for energy goods and services.

Total primary energy, usable primary energy and energy service demand in the three scenarios

(Bubble size represents primary energy consumption)



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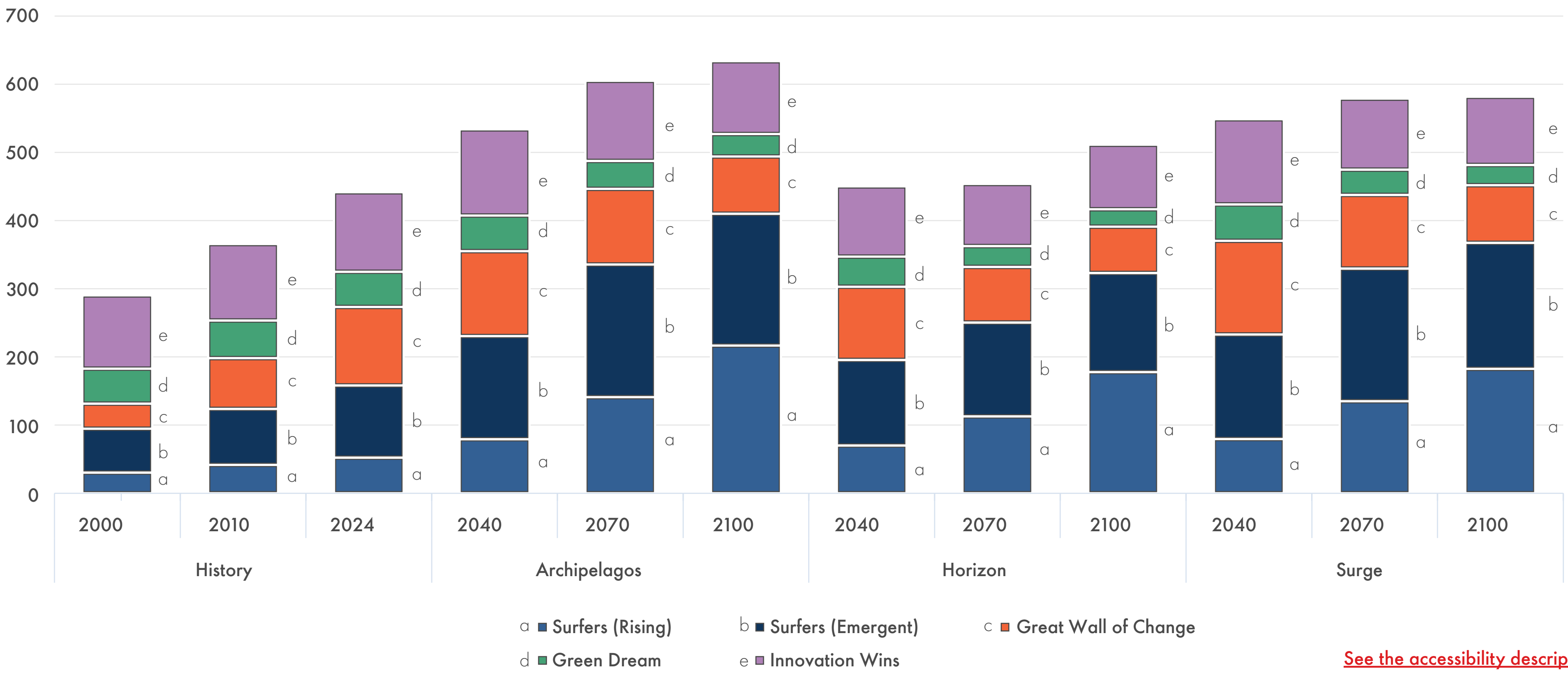
Evolution of final energy demand in the three scenarios across regional archetypes (**Surfers** drive future demand in all scenarios)

Final energy, EJ per year



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

The **Rising Surfers** see the fastest growth in energy demand. In the scenarios, the population of this group of countries increases from 2.2 billion in 2020 to 4.7 billion in 2100.

Importantly, over the same time frame, access to energy services becomes widespread. As a result, energy demand more than quadruples for this group by the end of the century.

If the **Surfers** maintain their current modest per person 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.

A shift in the north–south balance of energy use also emerges as the **Surfers** make increasing use of solar photovoltaic technology, particularly in **Surge**. Solar photovoltaic becomes very beneficial for equatorial regions where there are about 12 hours of sunlight every day of the year. Combined with batteries, this creates an efficient daily cycle of charge and discharge.

Additionally, cooling needs are naturally aligned with sunshine, making for an efficient system with much less seasonal variation than in northern regions like Europe. This gives rise to rapid development over the course of the century – faster than might be the case for fossil fuels. By 2080, the global final energy demand profile has noticeably shifted south as a result.

The rapid large-scale deployment of solar photovoltaic also gives rise to lifestyle benefits in many developing countries, with a visible convergence of the global energy and development indices over the next 50 years (towards 0.9 in the UN Human Development Index at about 75 gigajoules per person). Wealthier economies maintain their energy service levels but energy demand falls with efficiency gains. Developing economies trend towards greater access to energy services, but on a lower energy pathway than that followed by other economies in years gone by.

Future oil demand

In all three scenarios, the electrification of road transport is the main reason for the world reaching peak oil demand, with a growing supply of low-carbon fuels also contributing to the subsequent decline of oil over the ensuing decades. Demand for oil continues into the 22nd century, although in Horizon oil is used solely for petrochemicals by 2100.

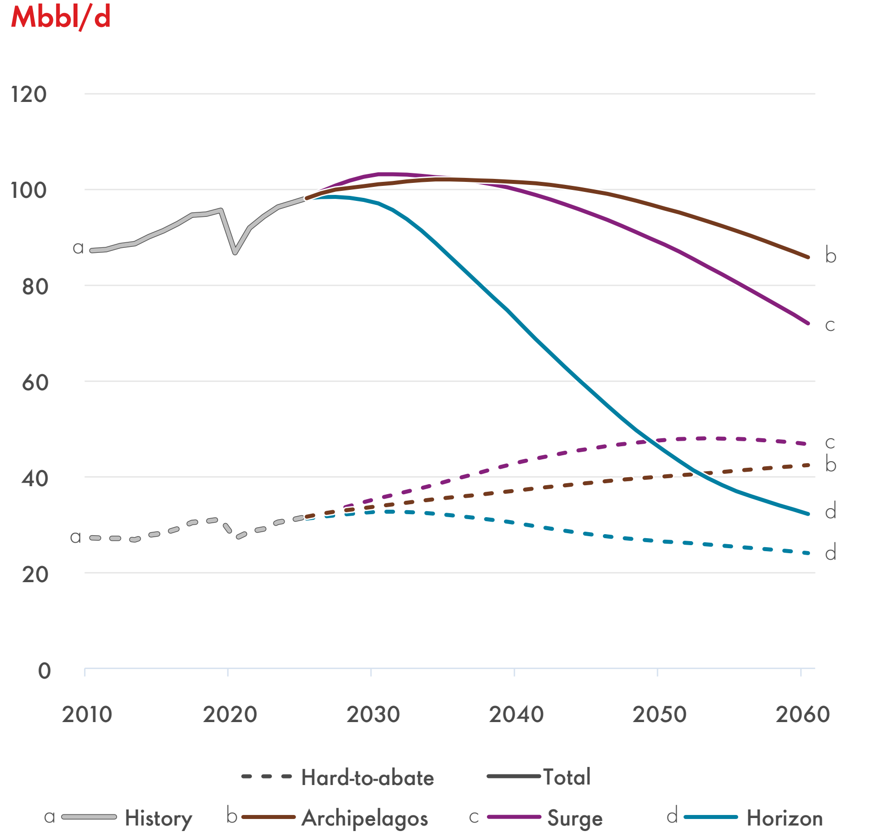
Three key growth sectors for crude oil – marine fuel, aviation fuel and petrochemicals – expand in total by at least 50% in the next 25 years in **Archipelagos** and **Surge**, but in the case of **Horizon**, they show a flat-to-slow decline pathway. Although considerable transition efforts are made, overall demand growth in these three sectors, as well as limits to the rate at which suitable low-carbon fuels achieve scale, means that net oil demand remains robust in these sectors. Even an eventual decline in oil and LNG shipping is offset by growth in mineral and manufactured goods shipments.

A feature of oil production is that individual field output declines, sometimes quite rapidly. Given a typical decline rate of about 5–6% per year for existing fields, continuing demand for oil will require production from new fields in all three scenarios to at least 2040. In **Archipelagos** and **Surge**, some 40% of oil production in 2040 will be from new fields not currently producing. Where practical, production from existing fields is also bolstered with enhanced oil recovery techniques, augmented by AI.

Surge will require significant new production to meet continued oil demand. The major resource holders of the Organisation of Petroleum Exporting Countries (OPEC) and Russia (OPEC+) will continue to rely on their substantial existing resource base, supplemented by production from new conventional fields. For the rest of the world, there will be a significant contribution of new supply from unconventional sources, particularly shale in the USA, which benefits from AI-enabled improvements in the supply chain and drilling optimisation to reduce costs and unlock new resources.

In **Archipelagos**, the push for domestic supply brings some smaller new fields into production.

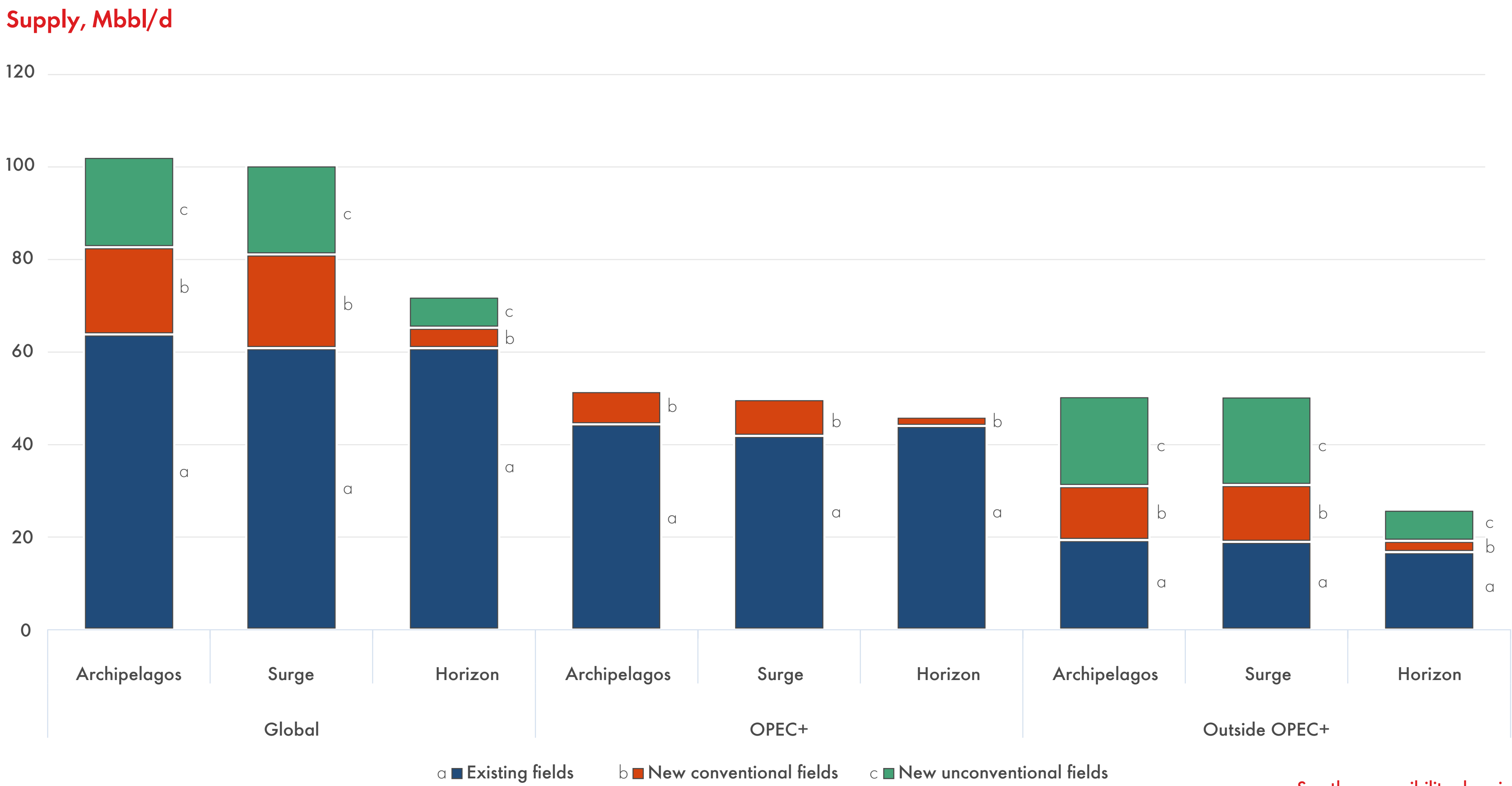
Global oil demand in the three scenarios
Demand shown in key hard-to-abate sectors*



***Note:** Marine, aviation and petrochemicals

See the accessibility description

Oil supply in 2040 and the production from new fields



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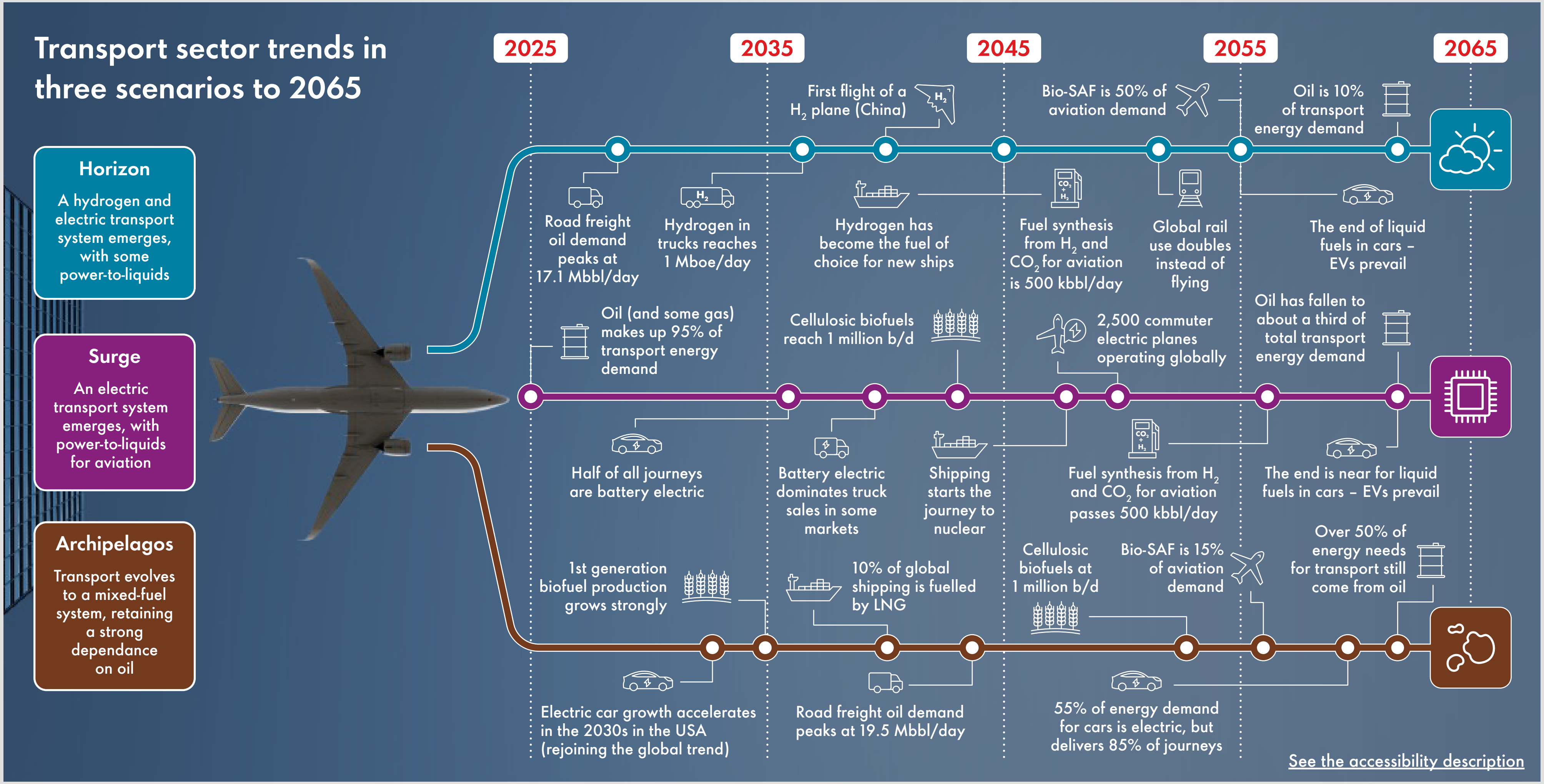
Although global oil demand is similar in **Archipelagos** and **Surge**, the trends in the underlying transport sectors are very different. Further differences emerge in **Horizon** related to its rapid decline in global oil demand. Hydrogen for transport only plays a role in **Horizon** because of the extreme decarbonisation pace required to reach net zero emissions. By the 2040s in **Horizon**, hydrogen is the choice for new ships, heavy duty trucks and even some planes.



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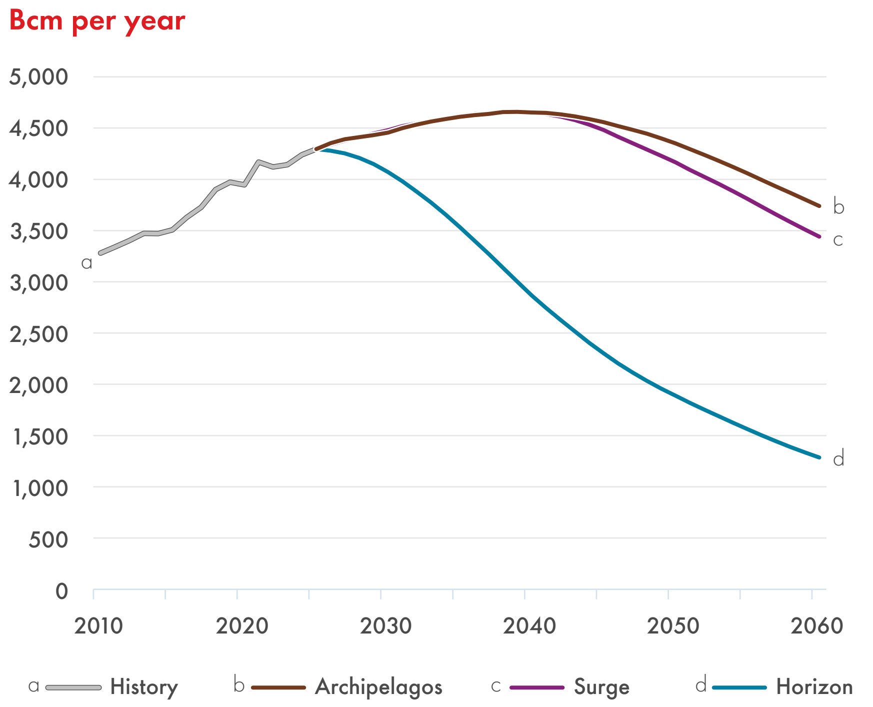
The future for natural gas

Archipelagos sees growing demand for natural gas through to the early 2040s as regions with plentiful domestic gas seek to maximise production. But gas-poor regions favour domestic resources such as coal and biomass, unless there are spot procurement opportunities in the LNG market. Given the slower energy transition in **Archipelagos**, gas demand declines the least of the three scenarios, still at 2,000 bcm per year in 2080. Later in the century, new demand for natural gas emerges in Africa off the back of domestic production.

The **Surge** scenario sees robust medium-term demand for natural gas. It reaches about 4,500 billion cubic metres (bcm) per year in the mid- 2030s, driven by demand in power generation, industry and chemicals, particularly in Asia, but also in Africa and India. By contrast, gas demand in developed countries is in decline after 2030. With coal use decreasing across Asia before 2030, natural gas takes on a transitional role in the scenario for Asia until around 2045, when renewables and nuclear power outstrip demand growth. The global decline in natural gas demand is steep after 2045, falling by half from its peak in just 20 years.

In **Horizon**, natural gas demand peaks in the very near term as the energy transition quickly accelerates to meet net zero emissions by 2050.

Global natural gas demand in the three scenarios



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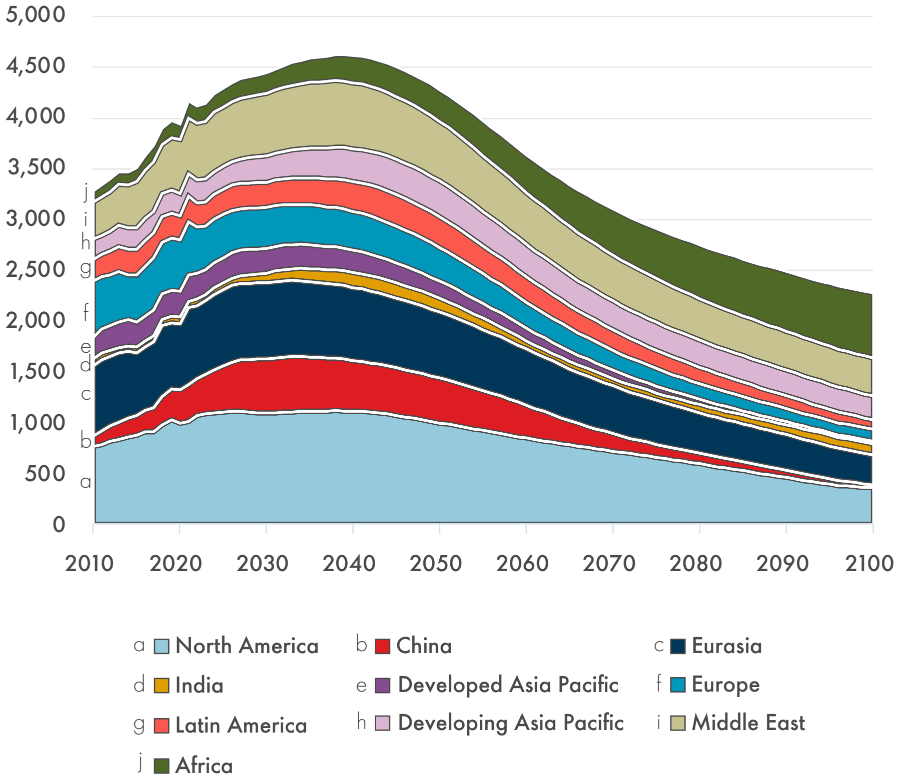
Regional natural gas demand in **Archipelagos**



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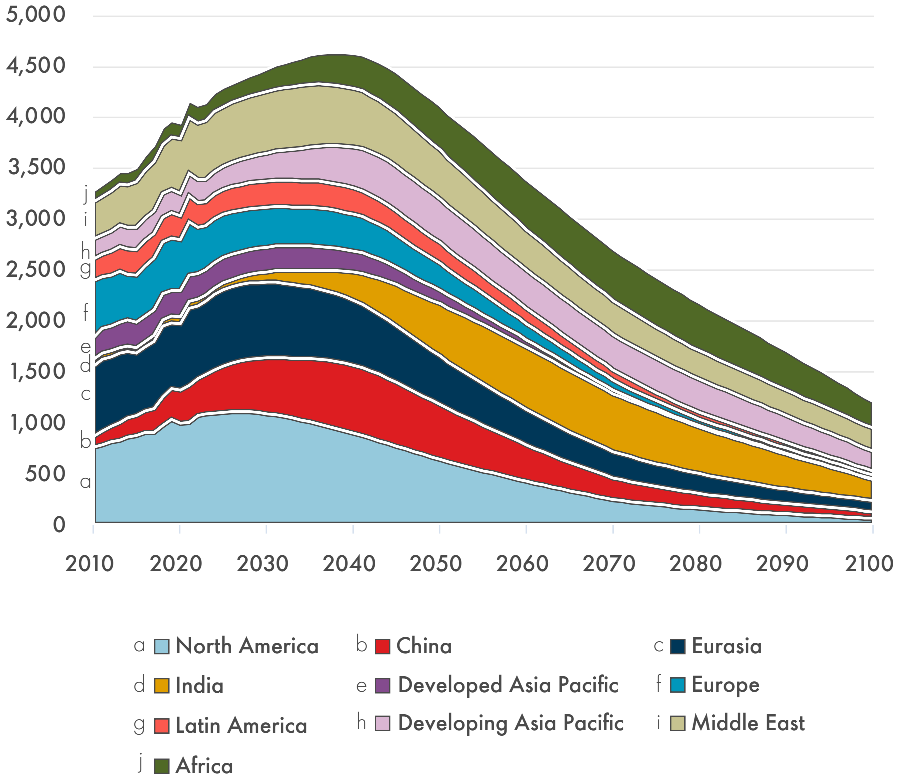
Regional natural gas demand in **Surge**



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LNG in the three scenarios

In all three scenarios, LNG shows significant growth in the near term, fuelled by ongoing projects in Qatar and the USA, reaching about 550 million tonnes per year (mtpa) by the end of the decade. Divergence between the scenarios is modest up until about 2030, but after that the scenarios diverge significantly as the different drivers take hold.

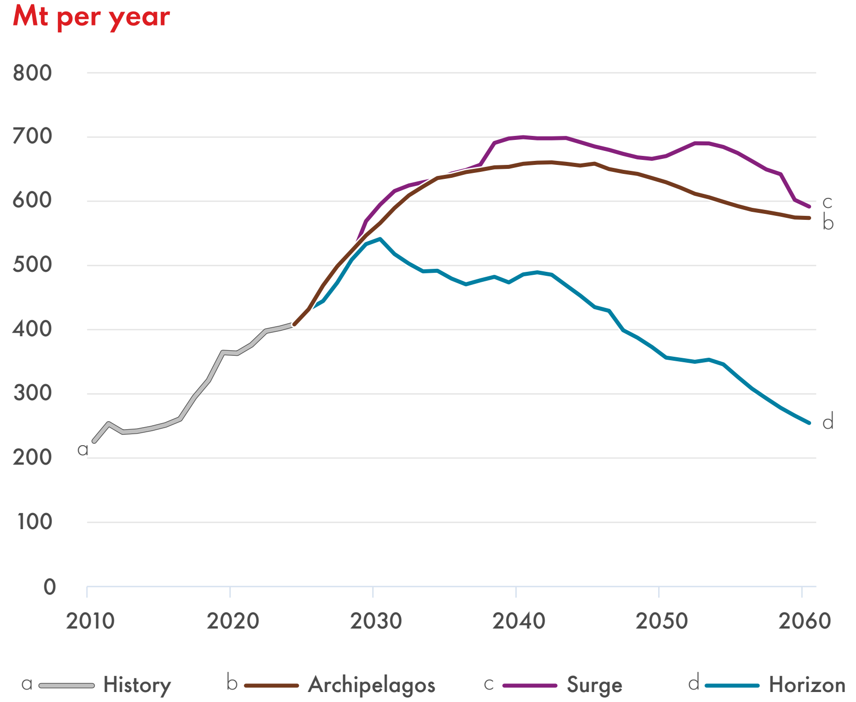
Archipelagos presents a prolonged use of LNG, even in the face of weaker economic growth. A heightened focus on energy security is evident in different ways: the EU continues to import LNG from the USA to offset the loss of Russian pipeline deliveries, whereas China relies on gas imports from Central Asia and domestic production to moderate its LNG demand. The net effect is a well-supplied LNG market throughout the 2030s, plateauing at just under 700 mtpa.

Surge also envisions growing demand for natural gas throughout the 2030s, as developing economies seek to use as many different types of energy as possible to meet their increasing needs. Without major international pipelines, LNG supply continues to grow, reaching 700 mtpa, with most new projects located in North America, some of which will involve new field production and new LNG facilities. LNG's market share of overall global gas demand reaches about 25% by 2050, up from about 14% in 2024.

The LNG trading conditions in **Archipelagos** are more challenging than in **Surge**. As China strives to lower LNG imports, suppliers must seek new buyers in more price-sensitive markets. A higher risk, more transactional environment emerges, but with a broader swathe of customers in multiple countries.

In **Horizon**, the global decline in gas demand that begins in the 2020s as a normative requirement for net zero emissions in 2050 starts to affect LNG, with demand peaking in the early 2030s. This results in existing infrastructure operating at low utilisation rates as demand falls faster than the natural decline rate of the assets.

Global LNG demand in the three scenarios



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The continuation of coal

Coal has proved hard to dislodge in the global energy system, but peak coal use before 2030 is common across the scenarios.

By the 2060s, coal is well on its way to exiting the global energy mix in **Surge** and **Horizon**, but not in **Archipelagos**. A slower energy transition impeded by weaker economic growth, trade disputes and energy security priorities favours the use of domestic fossil fuels, with global coal demand proving resilient.

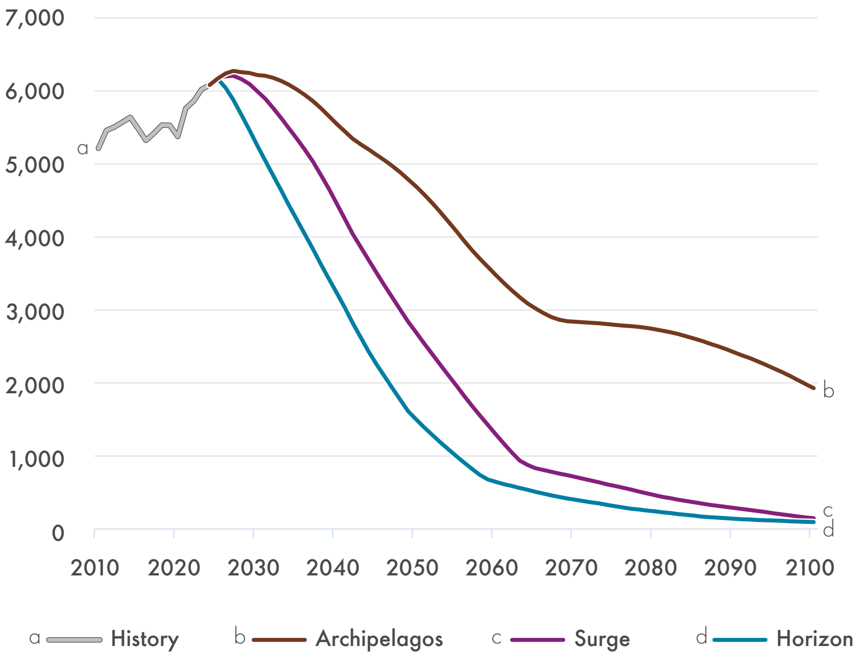
Like in **Surge** and **Horizon**, coal use in **Archipelagos** peaks in the near term as renewables and natural gas compete, but within this there is wide regional variation. From the late 2020s, China changes course, with coal rapidly declining in the power generation sector, to a point of zero coal-fired generation by 2065. Industry follows, but even in 2100 there is still some remaining industrial consumption of coal in China.

The fall in coal demand in China is so pronounced from 2030 onwards that it sets the trend globally, even as other regions continue to make greater use of coal.

In India (1.5 billion people), Africa (1.5 billion people rising to 4 billion by 2100) and the developing Asia region (1.5 billion people), coal use continues to rise in **Archipelagos**. Peak coal use in India and Asia is reached by mid-century, but at a level far below that of China in the 2020s (1.4 billion people). After that, a long plateau sets in with a slight decline. In Africa, however, coal use continues to increase until late century, but at even lower levels on a per-person basis. By that time industry is powered by more than 50% electricity, alongside a mixture of other fuels, including some coal. However, by 2100 African heavy industry output is close to the level in China today, where coal currently dominates.

Global coal demand in the three scenarios

Mt per year



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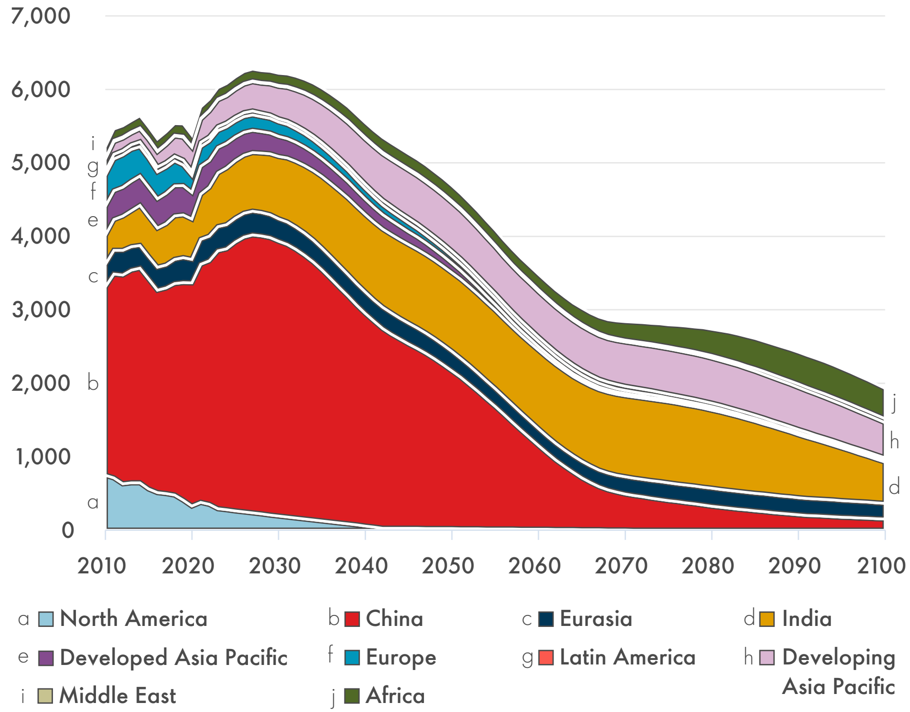
Regional coal demand in Archipelagos

Mt per year



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The much-anticipated leapfrog

Europe, the UK, Russia, the USA, Australia and more recently China all developed their economies on coal and oil, with natural gas emerging as a later energy source. The cumulative impact of this coal and oil use has added some 1 trillion tonnes of CO_2 to the atmosphere (about 0.6 °C warming), for a population of 2.5 billion people.

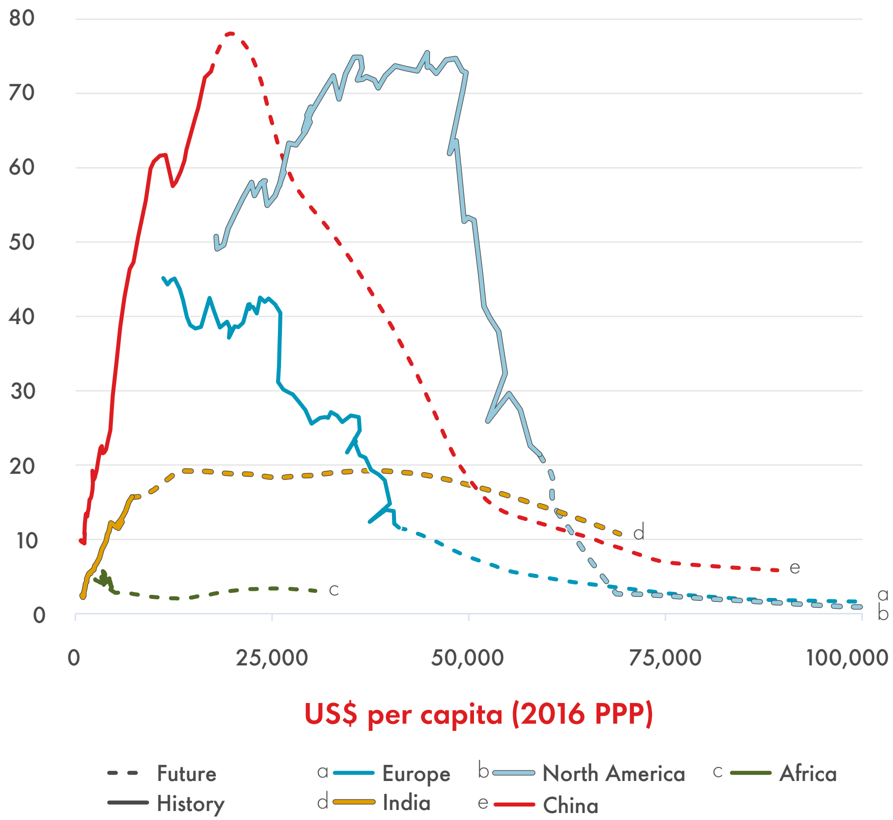
India is following, and although not developing entirely on coal and oil, these two energy sources provide 70% of current Indian energy demand. In the 1970s in the above countries, fossil fuels supplied more than 95% of demand. India has 1.45 billion people in 2025, slightly more than China. Energy demand in India is still about one quarter that of China, so a key consideration is how India will develop going forward.

Africa has a similar population of 1.5 billion, and currently uses 20% less energy than India, but its population is expected to approach 4 billion by later in the century. How Africa's energy system develops is a critical determinant of CO_2 in the atmosphere by 2100.

With more than 5 billion people in India and Africa by late in the century, fossil-fuel consumption on a per-person scale equivalent to China today or Europe in the 1990s would mean emissions of 40 billion tonnes of CO_2 per year, pushing the world rapidly to over 3 °C of warming. But there should be no need for such a development. Africa is poised to leapfrog centralised fossil-fuel systems and embrace decentralised solutions, using mainly renewable electricity and building hybrid infrastructure tailored to local contexts. India currently has a foot in both camps but is making great efforts to develop away from the centralised use of coal.

The **Surge** scenario is illustrative of such leapfrog development and **Horizon** requires the outcome given its very tight carbon budget restriction. But in **Archipelagos**, a tension plays out, in that although India and Africa follow new routes, they are not fast enough. Trade restrictions, technology timelines, the use of secure domestic energy resources and limits on climate finance all contribute to a growing use of coal in those regions.

Coal use development ladders in **Archipelagos**



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A tale of two countries – China and India

In 2005, China produced 2,000 terawatt-hours of electricity with 80%, or some 800 million tonnes, coming from coal. Hydroelectricity ran second at 15% of demand.

In 2025, coal demand for electricity is more than two billion tonnes per year, but seemingly at or near a plateau as China pivots to new energy sources. Like Europe and the USA from 1850 to 1950, China has developed its economy on coal. Looking to the future, China has excellent solar and wind resources and is building a large fleet of nuclear power plants. It also benefits from numerous hydroelectricity opportunities. Although global climate concerns were growing during the period of most rapid growth in China (2000–2015), the Paris Agreement didn't emerge until after China's major industrial development cycle was nearing completion.

In 2025, India produced more than 1,700 terawatt-hours of electricity with 70% coming from coal, or nearly 600 million tonnes, positioning it like China in 2005. But India is now growing in a world where climate concerns have increased and the Paris Agreement is in operation.

In **Archipelagos**, India faces difficult choices. Economic growth and development remain paramount, but the world around is challenging. Energy is seen through a lens of trade and security tensions even though India has pledged net zero emissions by 2070. Although reaching high levels of solar photovoltaic for electricity generation doesn't come easily in **Archipelagos**, India's electricity mix over the 35 years from 2025 to 2060 develops very differently from that of China in the 35 years from 2005 to 2040. The country makes good use of its solar and wind resources and rapidly develops nuclear power, but the balance stays with coal, largely available as a domestic resource. In **Archipelagos**, coal use for electricity continues to grow until the late 2070s, but never exceeds one billion tonnes per year, compared with more than two billion tonnes per year in China in 2025.

Surge sees smart grid systems evolve quickly and battery developments and manufacturing capacity make rapid advances. In **Surge**, the coal peak for electricity generation is about 500 million tonnes per year. Natural gas acts as a partial transition fuel for many decades, but solar is the majority source by 2055.

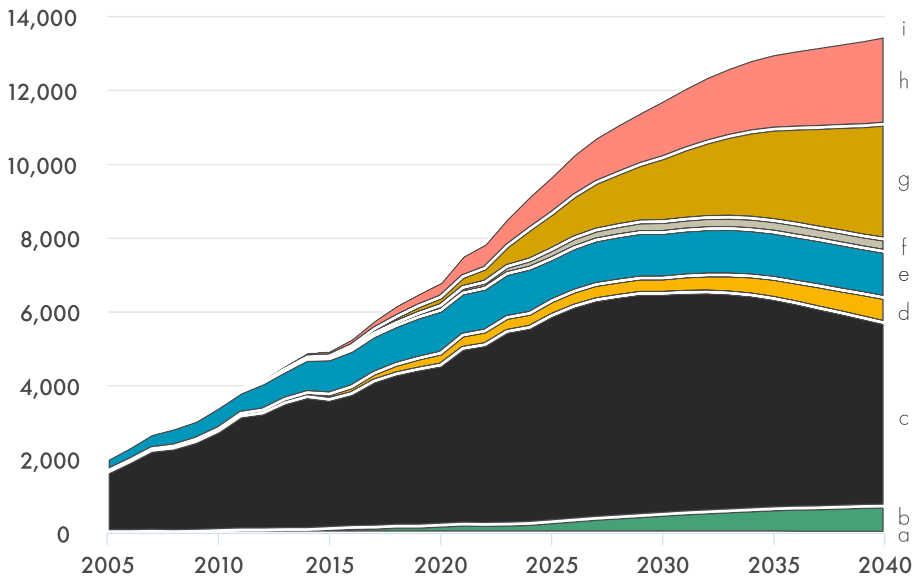
Surge is a scenario of rapid technology development and a new manufacturing paradigm, enabling solar to eventually dominate.

In **Horizon**, which is indicative of what needs to happen to meet the goal of the Paris Agreement, coal generation declines rapidly in India from 2025, with growth largely supported by solar, wind and nuclear power.

By the end of the century in all scenarios, India generates most of its electricity needs from wind, solar, biomass and nuclear, making extensive use of grid batteries. But the middle of the century is somewhat problematic for India in **Archipelagos**, leading to continued reliance on coal for decades to come even as it falls below 50% of generation by 2035.

Electricity mix in **China** from 2005 to 2040 (History and **Archipelagos**)

TWh per year

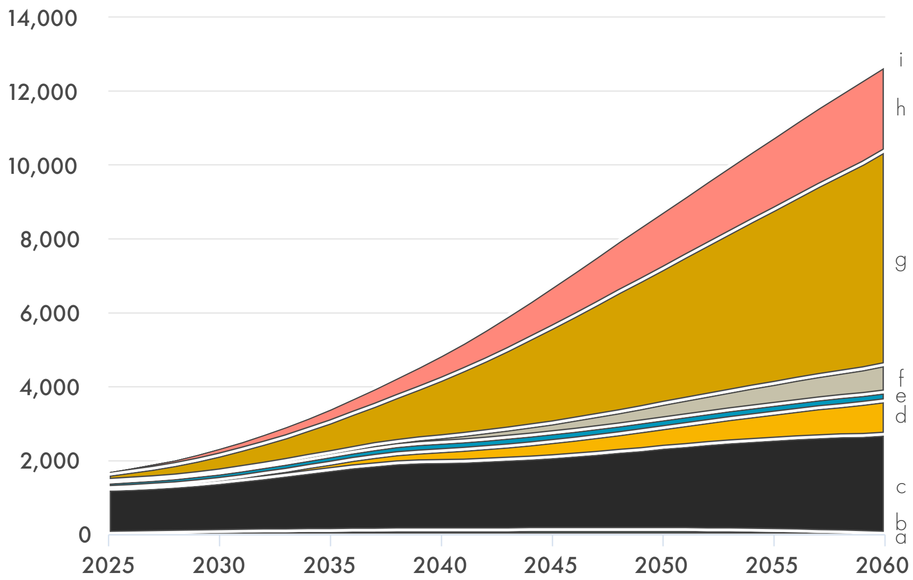


a Oil
b Natural gas
c Coal
d Nuclear
e Hydroelectricity
f Biomass
g Solar
h Wind
i Other renewables

See the accessibility description

Electricity mix in **India** from 2025 to 2060 in **Archipelagos**

TWh per year



a Oil
b Natural gas
c Coal
d Nuclear
e Hydroelectricity
f Biomass
g Solar
h Wind
i Other renewables

See the accessibility description

Low-carbon fuels

Biofuels have been part of the energy system for decades, but largely for reasons of energy security due to domestic production. Brazil is an excellent example, with its development of sugar-cane ethanol for passenger cars, starting after the OPEC oil crises of the 1970s.

But as concerns over carbon emissions from fossil fuels have increased, the importance of biofuels and, more recently, hydrogen produced by water electrolysis using renewable electricity (so-called renewable hydrogen), or from natural gas with carbon capture and storage, has risen in prominence. Renewable hydrogen is also seen as a precursor for ammonia and renewable synthetic fuels.

However, the original rationale for biofuels remains: energy security, which features as an important trend in **Archipelagos**.

Low-carbon fuel use grows in all three scenarios, but the production pathways and applications vary. The progression is illustrated in the Sankey diagrams, starting with the current global production, which is largely ethanol coming directly from corn and sugarcane. Production is largely centred on the USA and Brazil.

Looking towards 2060, which the Sankey diagrams focus on, the global low-carbon fuel system becomes increasingly complex, incorporating hydrogen, aviation fuel and the adoption of advanced biomass processing using cellulosic processes.

In **Archipelagos**, which has a focus on national energy security, there is a rapid expansion of first-generation biofuel production in several countries. By 2070, global first-generation production is more than triple 2025 levels and considerably more than that seen in **Horizon** and **Surge**, where advanced biofuel production, such as cellulosic processing, dominates. Ultimately, the world makes much greater use of biofuels in **Surge** and **Horizon** as carbon concerns mount, but in **Archipelagos** national security interests see first-generation production remain high throughout the century.

The hydrogen pathway in **Archipelagos** is confined to industrial applications and limited in scope compared with **Surge** and **Horizon**. The hydrogen that is produced is primarily through electrolysis by the 2050s, as this supports the desire for domestically sourced fuels.

Given the limited role for hydrogen, the weak support for carbon management and the lack of direct air capture as a technology, a synthetic fuel market never materialises in **Archipelagos**.

The role of low-carbon fuels is mixed in the 2030s in **Surge**, with several technologies jostling for position. The road freight sector follows passenger road transport and heads towards electrification, albeit with some liquid fuel use continuing for many decades. Efforts to use hydrogen fuel cells flounder.

After two decades of mixed progress in shipping, the sector shifts progressively to nuclear over the period 2050–2100 as small modular reactors commercialise. This brings the efforts to develop and scale low-carbon marine fuels to an end.

Aviation makes use of the booming direct air capture market to shift towards synthetic fuels, although this only becomes pronounced in the second half of the century, with bio-based sustainable aviation fuels being key until 2050.

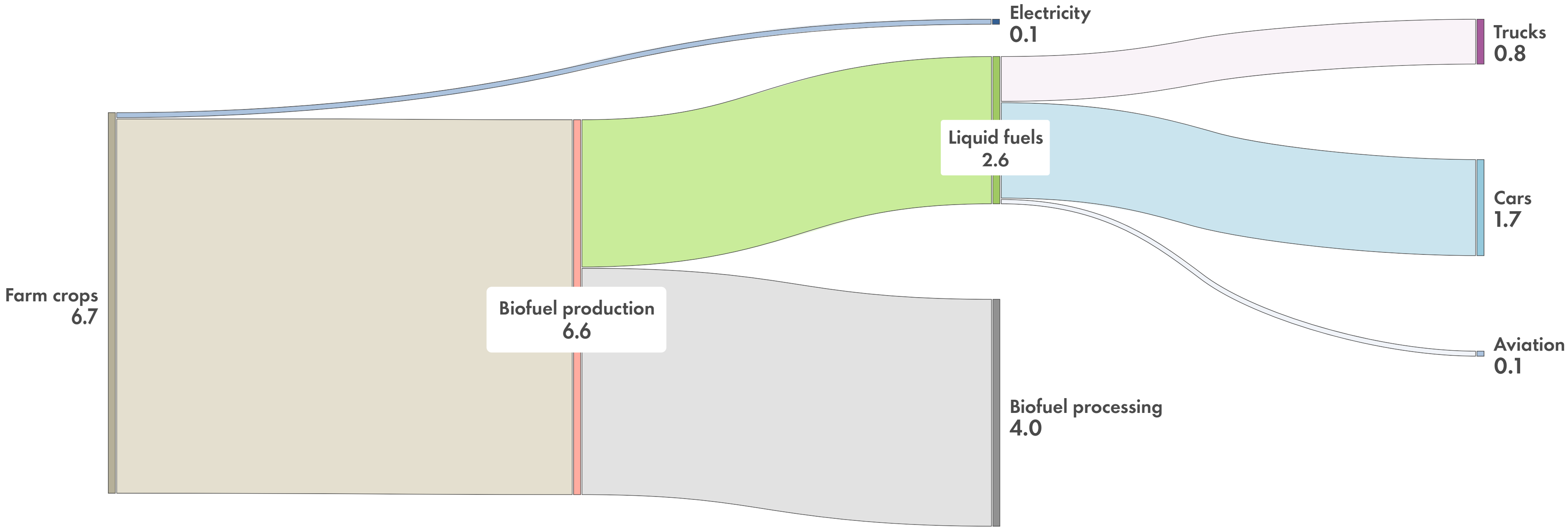
In **Horizon**, there is rapid early growth in liquid biofuels, such as sustainable aviation fuel, mostly to replace oil in hard-to-decarbonise transport.

The shift from liquid fuels in passenger vehicles means that ethanol plays a new role in the market, both as a chemical feedstock and for upgrading to aviation fuel.

As direct air capture matures and hydrogen electrolysis costs decline, synthetic liquid fuels emerge in the 2040s.

Renewable hydrogen also plays an important role in **Horizon**, providing a solution for certain heavy-duty road freight applications, as a fuel for ships (either in fuel cells or as ammonia) and later for planes, but also for industrial applications such as iron ore smelting. By 2060, nearly half of the smelters in the world run on hydrogen in **Horizon**.

Global low-carbon fuel production in the mid-2020s, Mboe/d



Reading a Sankey chart: The evolution of the global low-carbon fuel story is presented as a series of Sankey charts. All figures are shown in millions of barrels of oil per day equivalent (Mboe/d). The charts show the originating feedstock on the left, for example “Farm crops”. They should be viewed from left to right, as that feedstock transforms into an energy source and is then used in a particular sector on the far right. Some of the original available energy is consumed within the conversion process; this is shown as terminating flows labelled “process energy” or “production losses”.

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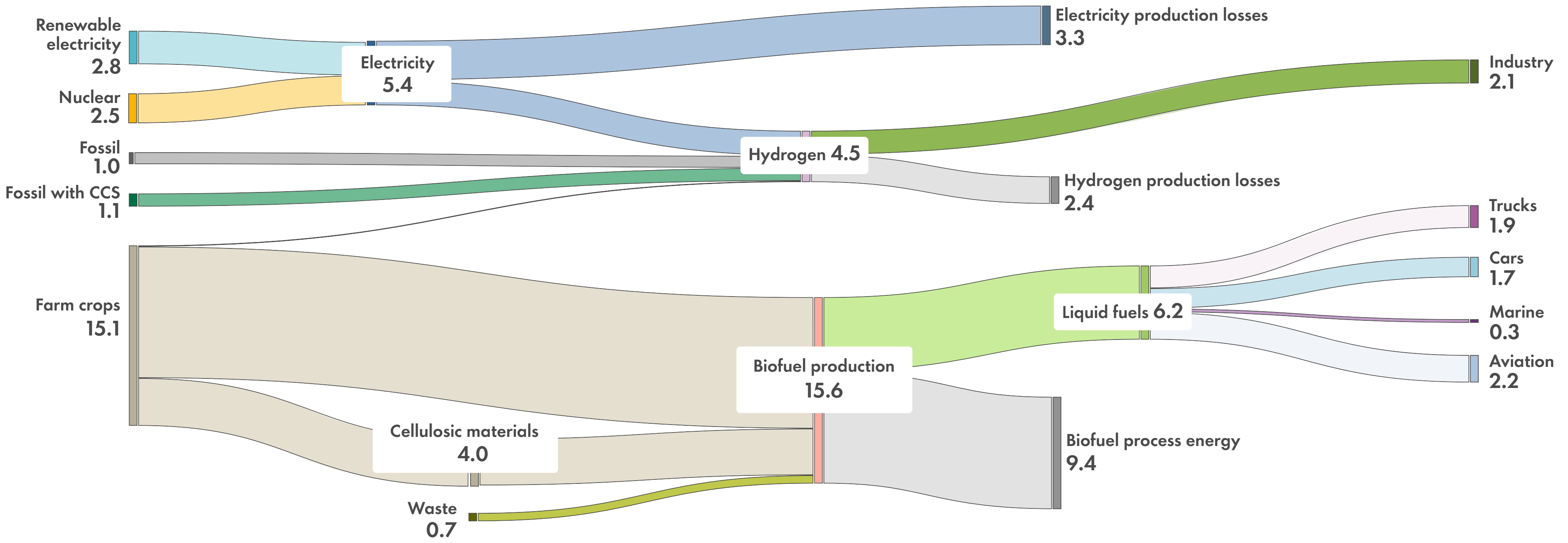
Global low-carbon fuel production in 2060 in **Archipelagos**, Mboe/d



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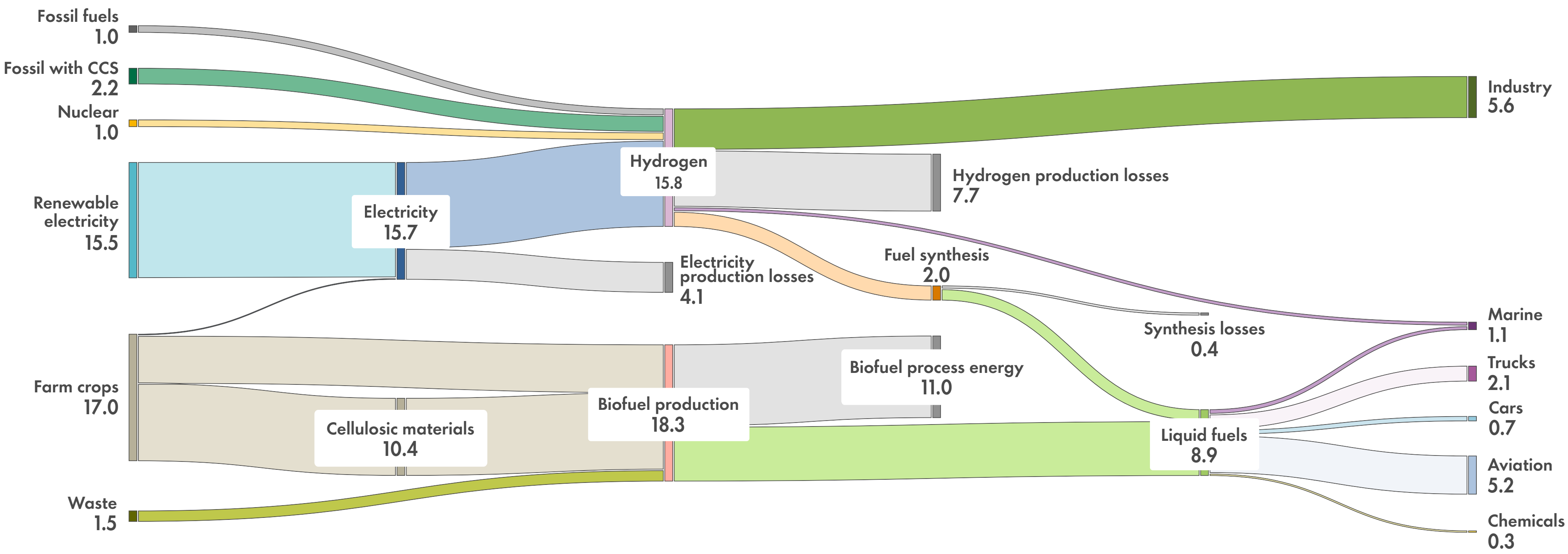
Global low-carbon fuel production in 2060 in **Surge**, Mboe/d



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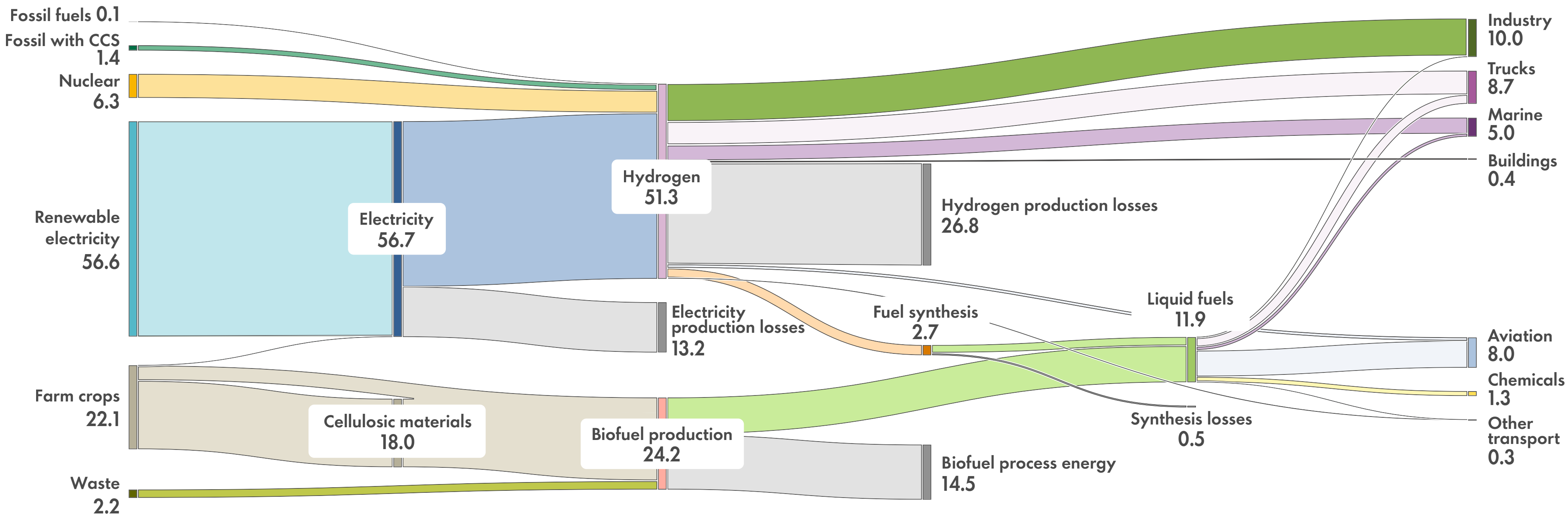
Global low-carbon fuel production in 2060 in Horizon, Mboe/d



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The rise of renewables

For solar photovoltaic alone, the world is already adding more than 600 gigawatts of capacity per year, delivering some 600 terawatt-hours of electricity. As recently as 2015, the annual capacity addition was a tenth of this amount. Solar photovoltaic capacity is now being supplemented with extensive grid battery capacity, which means that in locations such as California, a significant portion of the evening load that would have been supplied by natural gas is now supplied via battery from solar photovoltaic. So, is the energy system at a renewable-energy turning point?

In **Archipelagos** the changes are more complex to decipher. There is considerable momentum in wind and solar deployment, with solar reaching net deployment levels of more than 1,000 gigawatts per year in 2040. However, China accelerates its deployment rate on the back of weaker demand from other countries, leading to a more China-centric distribution of solar photovoltaic by 2060.

A resurgence in nuclear power also competes with renewables and by 2100 nuclear has taken considerable market share compared with **Surge**, particularly in countries where nuclear becomes a national priority, such as India.

After 2070, the largest global deployment of solar has shifted to Africa.

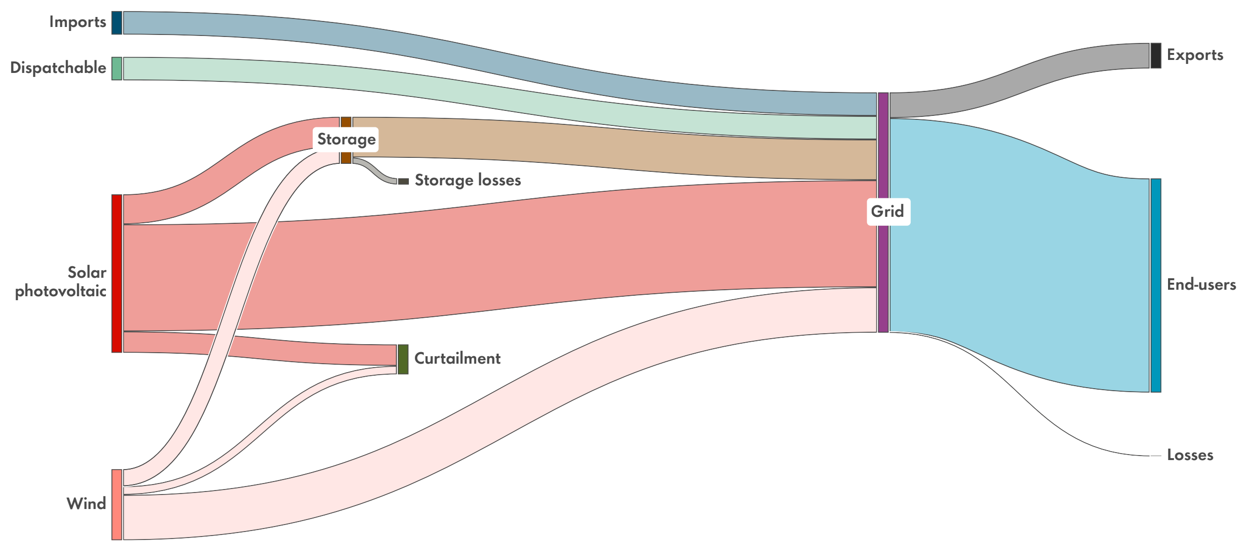
Integrating intermittent renewables into the grid

Within certain contingents of society there continues to be scepticism about the large-scale use of renewable energy sources. Although the concerns highlight the challenge of intermittency, they are a simplification that overlooks the emerging solutions in the field, such as energy storage, grid flexibility, grid interconnection and diversified renewable sources. Nevertheless, given current and anticipated technologies, there are limits to the extent to which renewable sources of electricity can be used in the grid.

In the **Archipelagos** scenario, which features a world of lower economic growth and less drive to optimise renewable energy, it will take time to reach high levels of renewable penetration. That level is dependent on weather, geography, grid interconnections, storage, sophisticated grid management to balance the system and dispatchable power from sources such as natural gas or nuclear. For example, at a latitude of 35–40° north or south in 2060 in a location with reliable solar conditions and good interconnection with other grids, the system could look as shown to the right.

This is a near-ideal case where solar and wind provide 80% of the electricity, but it also requires grid storage capacity roughly equivalent to every home having a single wall unit with about 15 kilowatt-hours storage. Other regions will have different outcomes dependent on prevailing conditions. A stable 80% renewables grid would require significant installed capacity. This could include solarphotovoltaic capacity equivalent to twice peak demand, wind equivalent to peak demand and battery capacity for half peak demand for at least six hours, supported by dispatchable capacity and interconnectors each equal to half peak demand. A system with capacity equivalent to 4.5 times peak demand brings significant additional cost beyond the basic solar photovoltaic cells.

Supply of electricity in a 35–40° north location with reliable solar conditions, illustrating the dependence on interconnections, storage, dispatchable supply (e.g. gas turbine) and wind for a largely solar photovoltaic powered grid.



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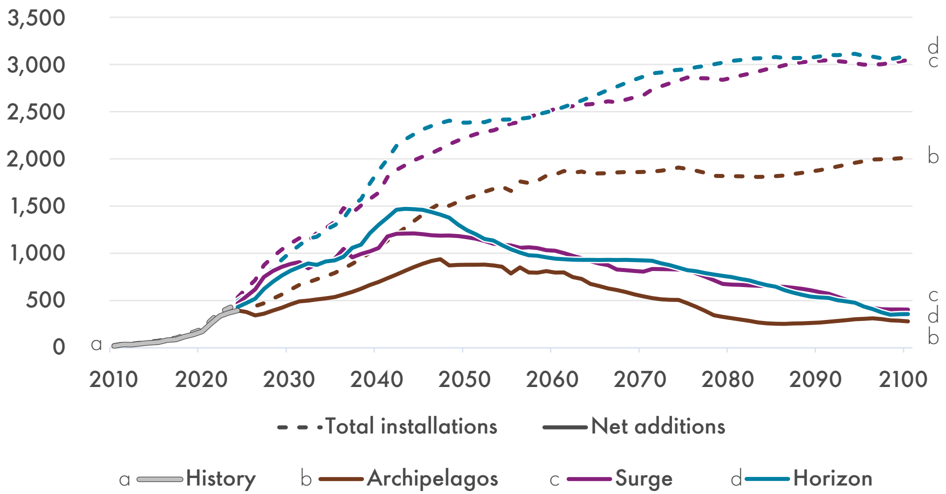
As the century ends, solar and wind provide about 40% of global electricity in **Archipelagos**, considerably less than in **Surge** at 70%. Nuclear, commercial biomass and some remaining fossil fuel uses supply most of the balance. The diversification of supply in **Archipelagos** emerges from global security concerns.

In **Surge**, the combination of increasing battery production and AI grid optimisation, including the use of battery storage in parked electric vehicles, improves the use of solar photovoltaic capacity, further cementing its position in the energy mix. Solar photovoltaic is so dominant in the scenario that it becomes the major primary energy source after 2050. In both **Surge** and **Horizon**, there is rapid growth in solar photovoltaic deployment, with 1,200 gigawatts and 1,400 gigawatts respectively installed annually by the early 2040s. Following from this in both **Surge** and **Horizon**, coal stops growing as a source of electricity before 2030, with natural gas following by 2035. After these dates, there is no further net addition of generation from these energy sources.

In **Horizon**, the decline of coal and natural gas for electricity generation is a necessity for achieving net zero CO_2 emissions in 2050, but in **Surge** the decline is dictated by commercial pressure. Solar panel and grid battery manufacturing capacity is growing rapidly in the scenario, and major new electricity users such as technology companies become increasingly concerned about their growing carbon footprints.

Global solar photovoltaic panel production and net installations in the three scenarios

Nominal capacity, GW per year



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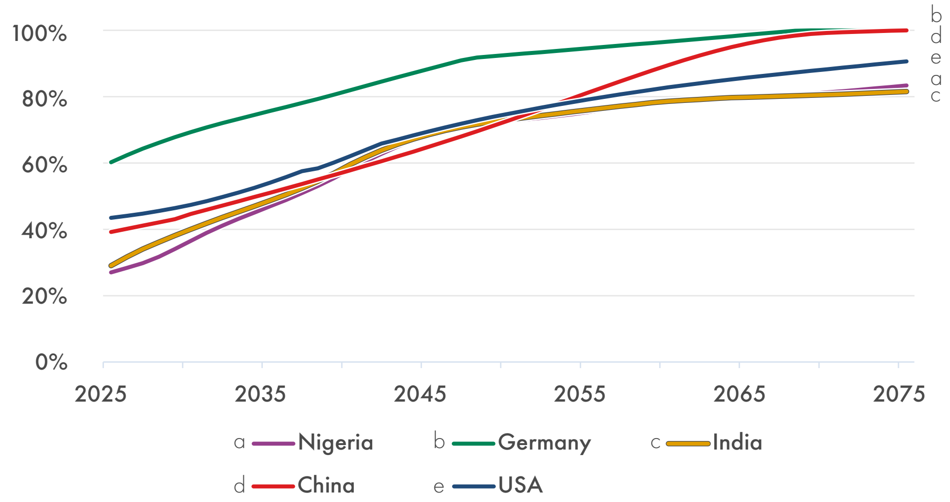
The growing role of non-fossil electricity generation in key countries in **Archipelagos**

Non-fossil share of total electricity, %



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Electrification of final energy

Electrification is critical to achieving net zero emissions. The major energy system shift in the three scenarios is the rise of electricity in the final energy mix. There is a major change in the role of electricity, starting in the late 2020s in **Archipelagos** and **Surge**, and even earlier in **Horizon**, owing to the 2050 timeline for net zero CO_2 emissions.

The scenarios carry unprecedented change, with electricity growing at over 5 percentage points of final energy market share each decade in **Archipelagos**. In **Surge** and **Horizon**, the increase is about 10 percentage points every 10 years. This compares with a century-long historical trend closer to 2 percentage points per decade but rising in recent years to more than 3 percentage points per decade.

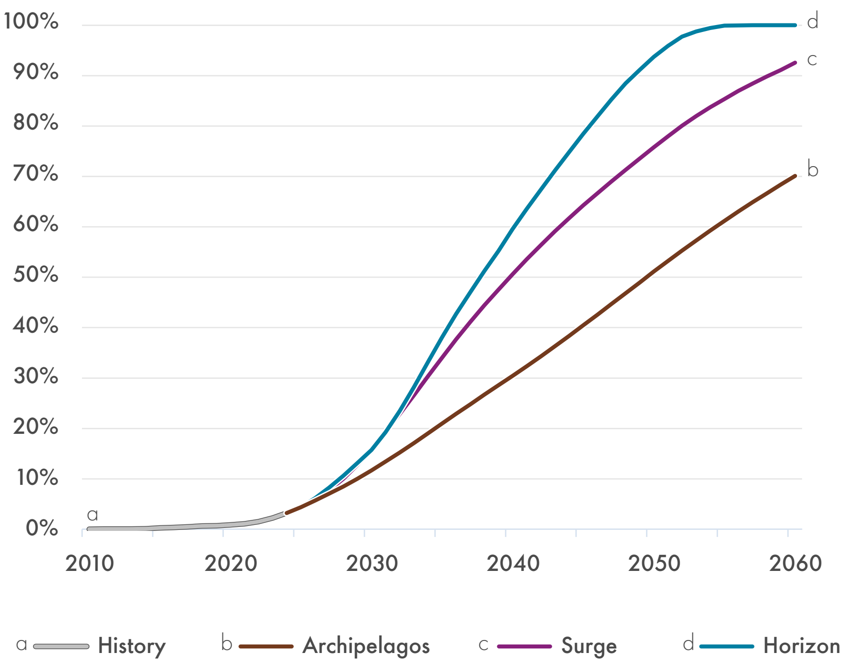
The electrification of passenger road transport kick-starts the shift, followed by residential and commercial electrification. In **Archipelagos** and **Surge**, electrification eventually spreads to all forms of road transport, displacing technologies such as hydrogen fuel cells for large trucks. An important interim step in **Archipelagos** is the rise in use of the plug-in hybrid electric vehicle.

In all scenarios, but particularly in **Archipelagos**, electrification is not a singular trend globally. Significant regional variation occurs. For example, for passenger vehicles, China reaches full electrification by 2065 in **Archipelagos**, a few years earlier than the EU, but 40 years before North America, and at a time when combustion vehicle use is still rising in Africa. By comparison, in **Surge**, global electrification of passenger vehicles is essentially complete by 2070, with only modest regional variation.

Much greater use of electricity will involve a substantial increase in demand for certain minerals. Examples are copper, nickel, lithium and cobalt. These are needed for critical components within the emerging technologies underpinning the transformation.

Electrification of passenger cars in the three scenarios

Share of vehicle use



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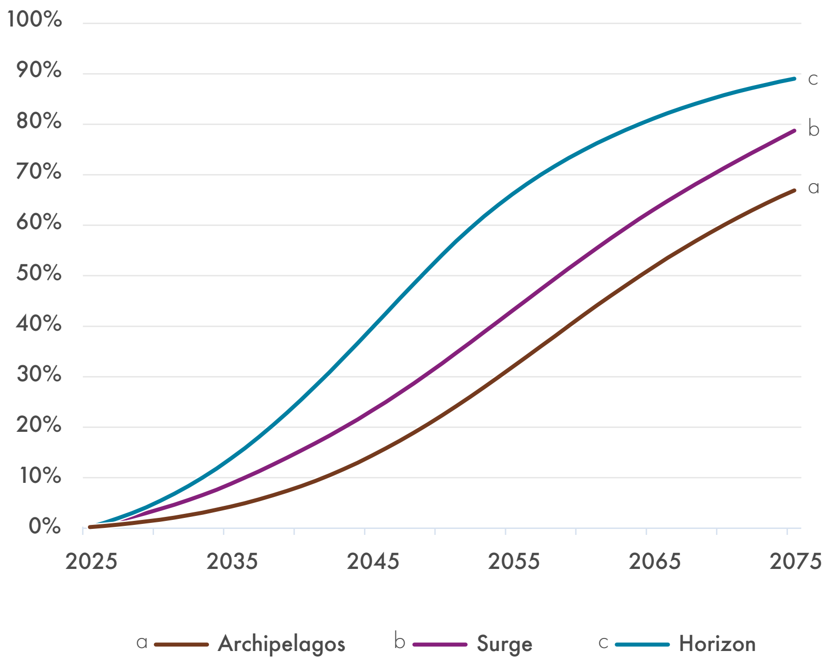
Electrification of road freight vehicles in the three scenarios

Share of freight moved



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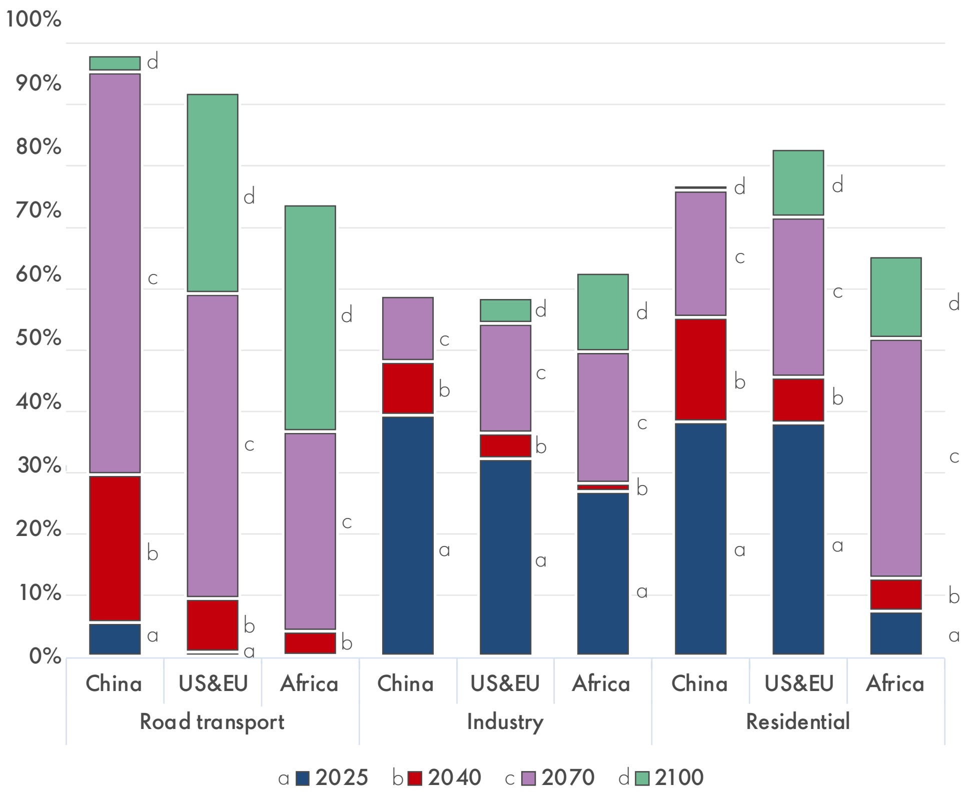
Electrification in key sectors and regions – Archipelagos

Share of final energy



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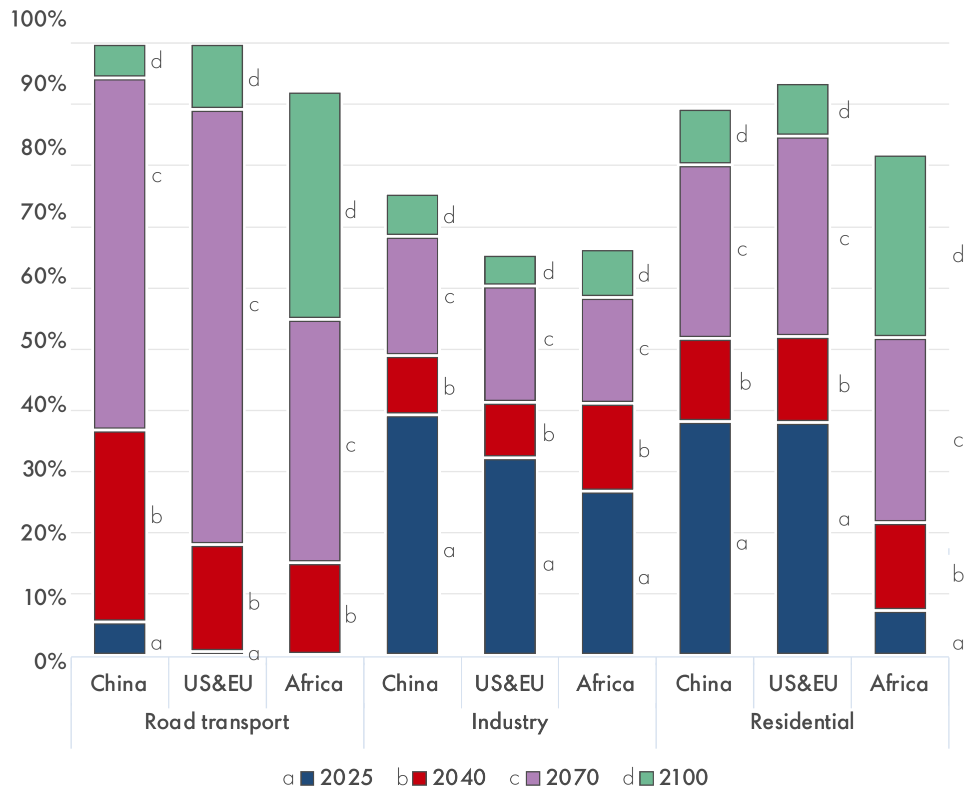
Electrification in key sectors and regions – Surge

Share of final energy



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So far, the progress towards increased electrification differs across regions and sectors.

The buildings sector is generally leading the way in terms of electrification, because of lighting, air conditioning, refrigeration and data systems. Heating in buildings is changing but still lags in the regions where it is used extensively. An important exception is in the least developed regions, where building energy demand is dominated by traditional biomass to fuel cookstoves.

Industry is in the middle category, hiding a large variety of different electrification rates for different industries. The lighter industries, as well as non-ferrous metals processing, are highly electrified – but the world is still struggling to electrify iron, steel, cement and the chemicals sector.

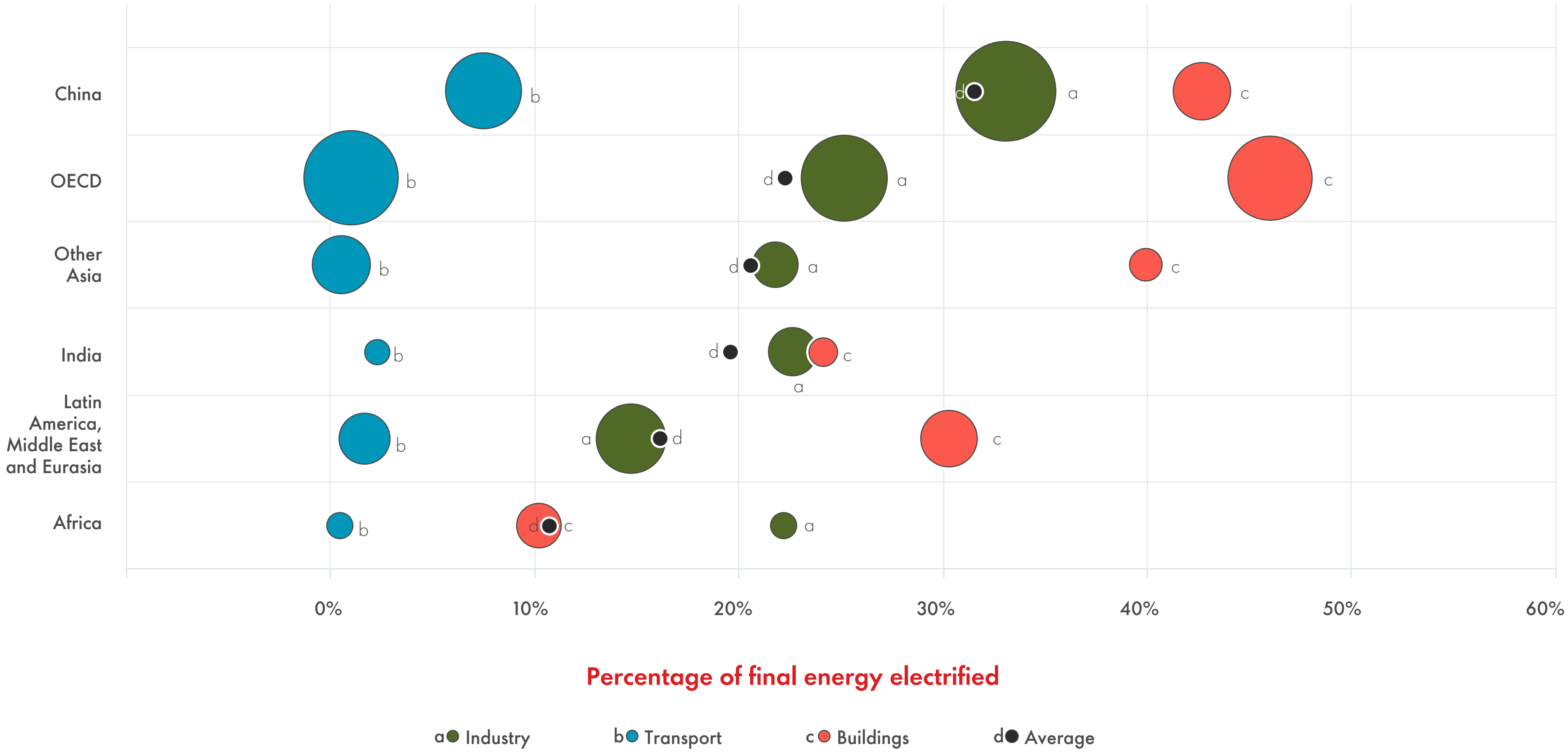
Electrification in transport has only recently started, now that electric cars are becoming cost-competitive with traditional cars. Electrification of road freight is under way, but in the aviation and marine sectors progress towards electrification is marginal. Railways tend to be heavily electrified, particularly for short-to-medium-distance passenger transport.

Regionally, there are important differences. China leads the world in aggregate electrification, as it has a dominant industrial sector with relatively high electrification. The dominance of industry is typical for lower-income countries, which is seen when contrasting China with the OECD. Chinese industrial electrification is high as it has been built more recently, adopting new processes and practices.

There is also a high exposure to aluminium and light industries, where electrification is more prevalent. This exposure has increased since the complete stop of cement demand growth some years ago. In addition, the electrification of the Chinese road fleet is the highest in the world.

Electrification by sector and region in 2025

(Bubble size represents primary energy consumption)



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A nuclear renaissance

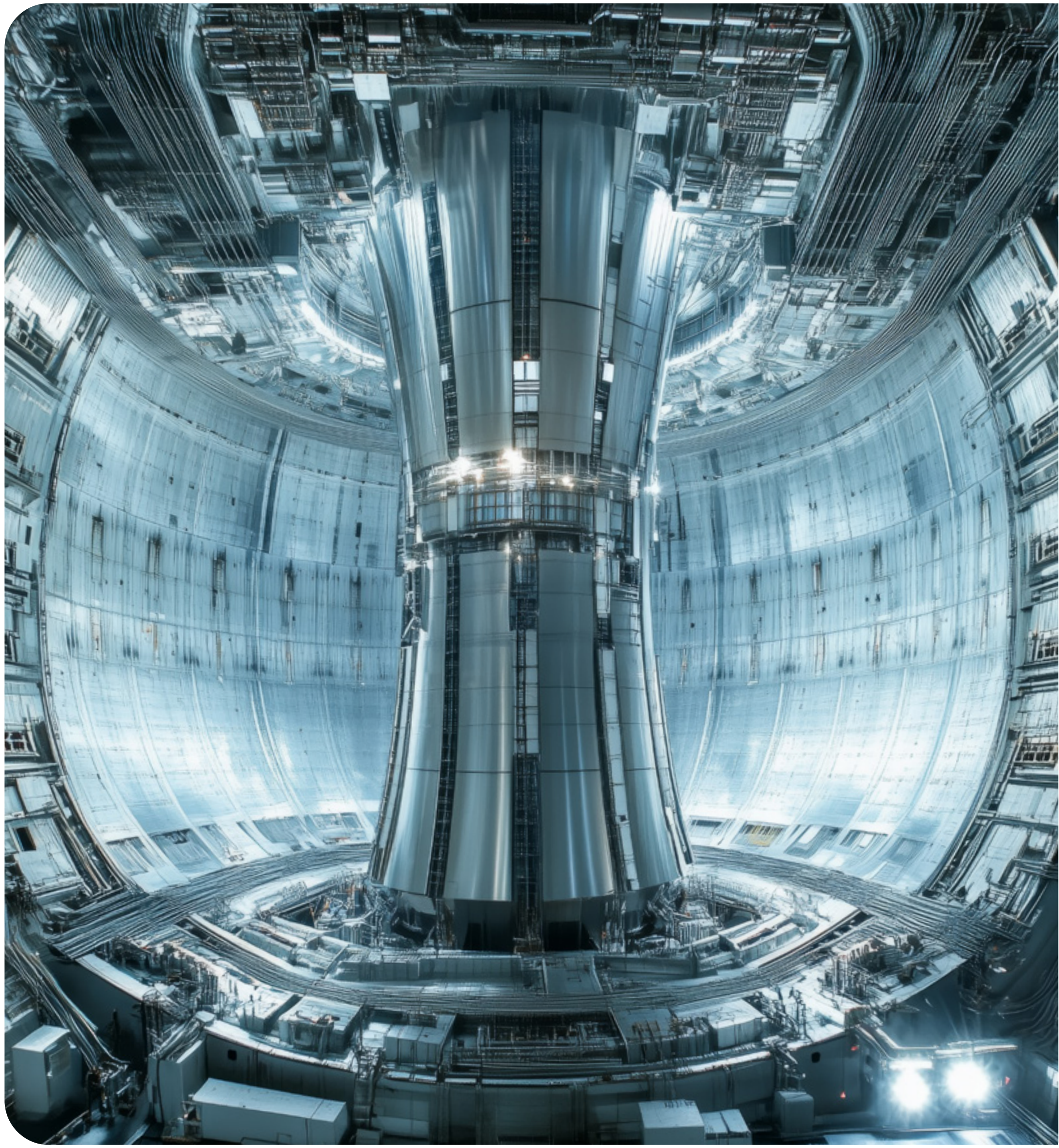
Such was the hope for nuclear power in the mid-20th century that the then-chairman of the US Atomic Energy Commission, Lewis Strauss, claimed in a 1954 speech that "Our children will enjoy in their homes electrical energy too cheap to meter". A different path emerged, and although electricity has become globally ubiquitous, nuclear power has not. This changes in the three scenarios.

In the shorter term, into the 2040s, the shift in nuclear power use is modest. Older 1970–1990 units are retired, largely replaced by new projects in China and India, but from the late 2040s onwards a nuclear renaissance is in progress.

In **Archipelagos**, with energy security a key consideration, large projects get under way on every continent. New-generation thorium designs from start-up companies in the USA and Europe, and from Chinese and Indian state enterprises, mean that the technology is more available than in the 20th century and early 2000s. Thorium designs are both safer and less likely to lead to nuclear proliferation than earlier nuclear technologies, and thorium resources are found widely in more than 35 countries all over the world, with India leading. Thorium designs offer new opportunities for energy security in a troubled world.

But in **Archipelagos**, a fierce competitor emerges: nuclear fusion. Funded by sizeable grants from the Defence Advanced Research Projects Agency (better known as DARPA) in the USA, and in response to Chinese fusion development, the first generation of American reactors appear in 2040, after decades of promises, disputed breakthroughs and multiple failures. A new nuclear era is born, and nuclear power in the USA becomes the largest single source of electricity for the country by 2060, progressively driving out natural gas through the second half of the century.

In **Surge**, the small modular nuclear reactor comes into the picture in the 2030s as major AI technology companies fund development, seeking new energy solutions for very large data centres. The technology matures quickly and AI itself helps solve early technical design issues.



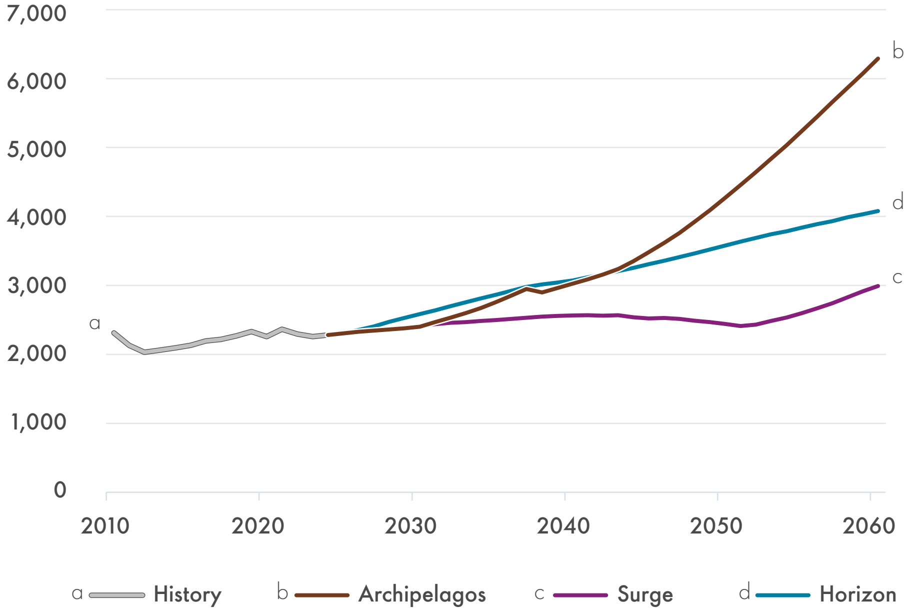
Small modular reactors use is much broader than data centres, with assembly-line-style production bringing down costs, leading to a near plug-and-play nuclear customer experience in the 2040s.

In the late-2040s, after years of stop–start progress in alternative marine fuels, a major Chinese shipping company takes delivery of five nuclear-powered container ships, each with twin 30-megawatt small modular reactors. These are put into service in 2050 on well-established routes from Shanghai to the US West Coast and to Rotterdam in the Netherlands. Following a successful start, the technology becomes established throughout the industry, to the extent that, by 2090, all large vessels have nuclear propulsion.

In **Horizon**, nuclear sets off on a new growth trajectory, driven by the need for a rapid transition away from fossil fuels. Even with older facilities in the USA and Europe reaching end of life, the global portfolio expands, in part supported by the emergence of the small modular reactor and thorium designs, led by many new projects in India and China.

Nuclear power in the three scenarios

Generation, TWh per year



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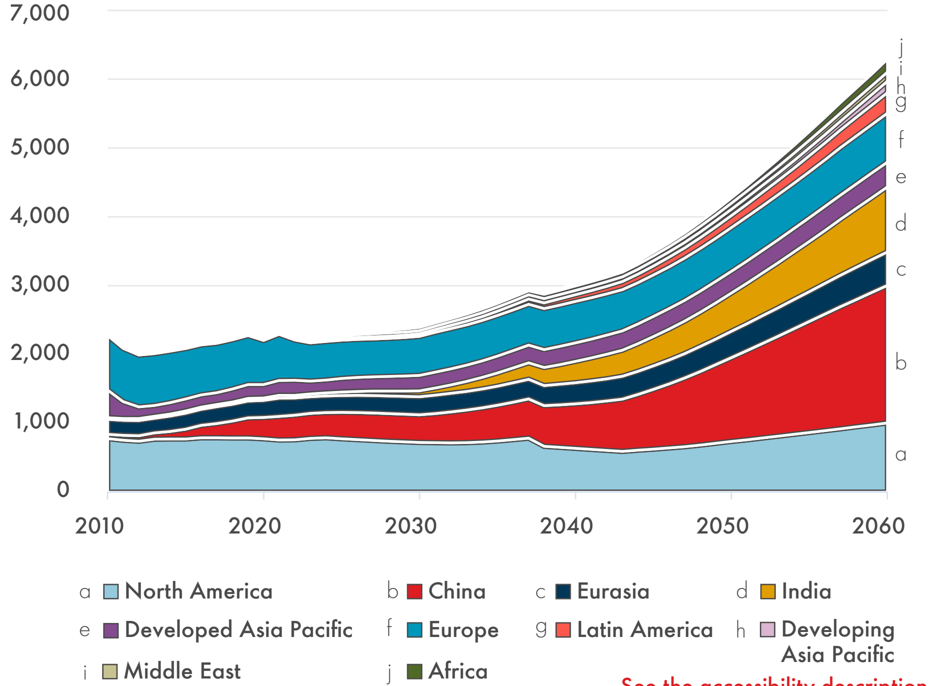
Nuclear power by region in **Archipelagos**

Generation, TWh per year



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Is **Archipelagos** a slow transition?

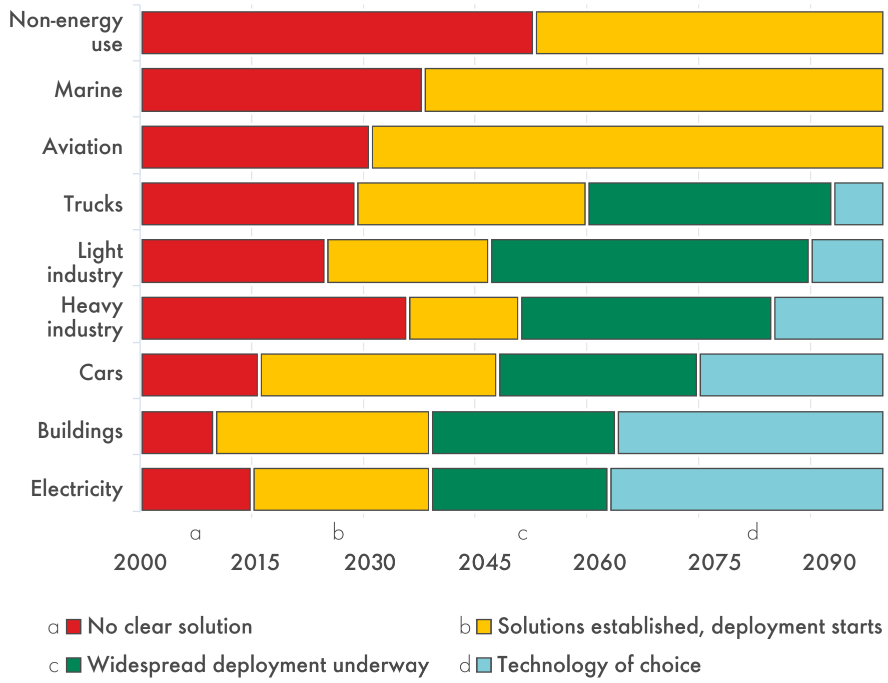
While **Surge** represents a transition built on a new energy-infrastructure construction paradigm and rapid advances in a variety of technologies, **Horizon** illustrates the very rapid pace of change now required for net zero emissions by 2050. But where does that leave **Archipelagos**?

Although **Archipelagos** takes over a century from now to reach net zero CO_2 emissions, it is still a relatively rapid transition, but just not in all parts of the energy system. Clear low-carbon solutions have emerged for electricity generation and passenger vehicles, and these continue to deploy rapidly in **Archipelagos**, at least within the geopolitical constraints of the scenario.

Other solutions are appearing rapidly, such as battery electric drive trains for trucks. But solutions in sectors such as aviation, marine and parts of industry are not only unclear but require a strong government policy push to catalyse. That push is largely missing in **Archipelagos** as governments deal with other priorities, meaning that some sectors remain with fossil fuels for decades while others race ahead and transform completely.

Archipelagos is a scenario of multiple transitions, often regionally based. There is little global alignment.

Progress in the energy transition in **Archipelagos**



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Carbon management and emissions

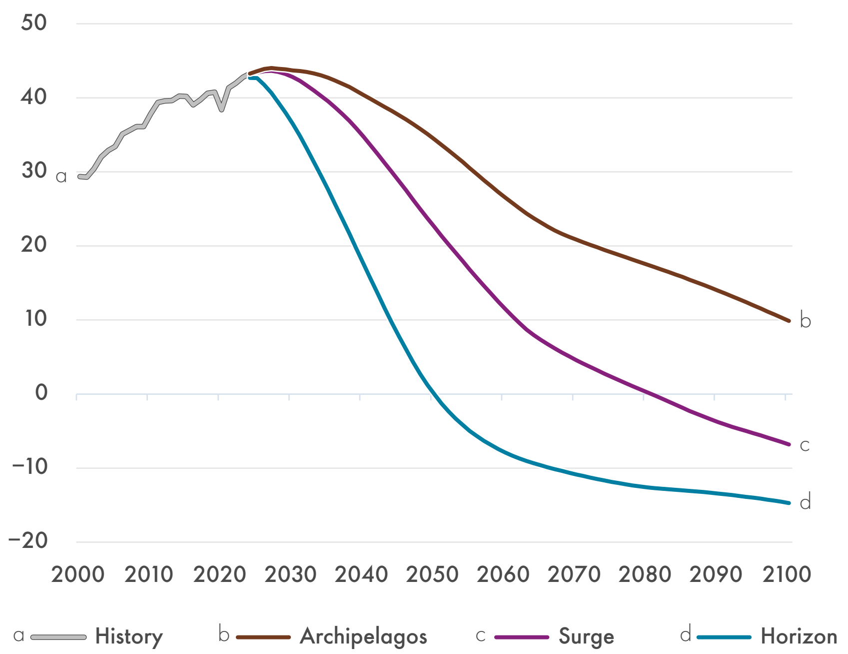
Climate action was facing challenges in many regions in 2025. The co-operation inherent in the Paris Agreement was superseded by a wave of competition and the starkness of national self-interest.

Yet in 2021, the Intergovernmental Panel on Climate Change (IPCC) reported that if the world were to limit global warming to 1.5°C (versus the 1850–1900 baseline), its carbon budget – the cumulative CO_2 emissions for a given temperature outcome – is 500 Gt, or about 13 years of annual CO_2 emissions at that time. In that same year, well over 100 national leaders attended COP26 in Glasgow and pledged to achieve net zero emissions by 2050 and a 45% reduction in CO_2 emissions by 2030.

The IPCC carbon budget 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 2025, nearly 250 Gt of this budget had been used, leaving 250 Gt. Annual global emissions were more than 40 Gt of CO_2 in 2025, and could be at around the same level in 2026. This means that managing overall emissions within the 250-Gt budget left at the start of 2026 is now a near-impossible task. The world also saw its first 1.5°C year in 2024, although this was a temporary peak attributable to a warm El Niño climate pattern that occurs naturally in the Pacific.

Overshoot of 1.5°C appears almost inevitable, even in a rapid transition. In agreeing to the Glasgow Climate Pact of 2021, countries pledged to reduce “global carbon dioxide emissions by 45% by 2030 relative to the 2010 level”. But given the emissions since COP26 in Glasgow, the world will not achieve this. **Horizon** sees a reduction to around 35 Gt of CO_2 in 2030, which is less than a 10% decline from 2010, but reaching 45% by 2038. **Horizon** achieves net zero CO_2 emissions by design in 2050.

Global anthropogenic CO_2 emissions in the three scenarios



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After society exceeds its remaining 1.5°C carbon budget of 250 Gt, it must balance the excess later in the century to return to that level of warming. It can do this by removing CO_2 from the atmosphere and storing it geologically or by increasing the carbon stock of the land, such as through reforestation. This is an overshoot pathway, and **Horizon** is a 1.5°C overshoot scenario. The recognition by society of the role of CCS and carbon removal from the atmosphere is a critical determinant of the outcome of **Horizon**. The need for large-scale removal capacity in **Horizon** is required for dealing with an overshoot of the carbon budget.

In **Surge** and **Archipelagos**, CO_2 emissions have peaked by the late 2020s at more than 15% above 2010 levels, reaching a 45% reduction by 2050 in **Surge** but nearly two decades later in **Archipelagos**. Net zero emissions are reached in **Surge** in 2080 and in **Archipelagos** not until well into the 22nd century.

The innovation boost in **Surge** that leads to more energy service demand growth than in **Archipelagos** facilitates more rapid growth of low-carbon energy over fossil energy and the development of direct air capture of CO_2. This gathering pace for low-carbon energy production is the crucial reason why **Surge** sees a much earlier realisation of net zero emissions than **Archipelagos**.

Carbon management in the three scenarios

Carbon management is illustrated for the three scenarios in the subsequent emission flow charts. These start with the situation in 2025, where large-scale carbon management has little impact on the emissions of CO_2 from fossil fuel use.

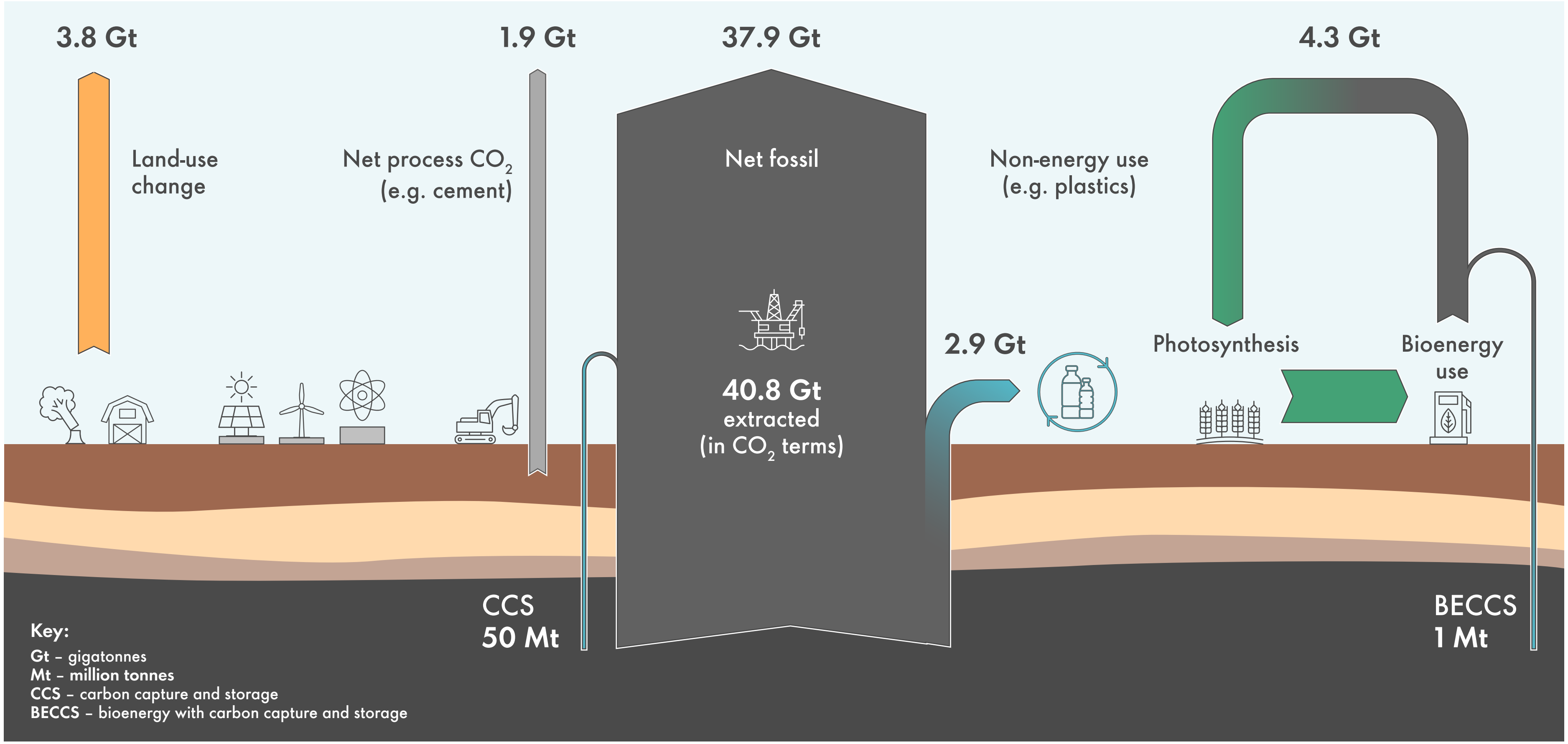
By 2060, large-scale carbon management in **Surge** and **Horizon** is having a material impact on overall emissions and, in the case of **Horizon**, has resulted in a net drawdown of CO_2 from the atmosphere.

In 2060, the impact is small for **Archipelagos**, and therefore not shown, because carbon management practices have limited application. However, as illustrated, by 2100 the impact is starting to show, although it remains modest. By comparison, **Surge** in 2100 is also showing a net drawdown of CO_2 from the atmosphere given the large-scale implementation of direct air capture and storage.

Global sources and sinks of anthropogenic carbon (as CO_2) in 2025

Global emissions of 43.6 Gt CO_2 per year

2025



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While **Archipelagos** features an ongoing energy system transition, there is initially only modest attention to carbon management. Other priorities prevail. By mid-century, with less than a 20% reduction in fossil fuel use compared with 2025, net zero emissions are reached in the 22nd century.

The scenario does see some change in land management, and reforestation efforts eventually make progress. The early push to establish a direct air capture industry succumbs to cost pressures as governments withdraw funding, and while progress is made in expanding the use of CCS, the technology falls far short of its full potential.

Nevertheless, by 2040, there are some 300 industrial CCS projects operating throughout the world and the number continues to grow. By the early 2060s, 1.5 gigatonnes of CO_2 are being stored globally each year. China and India are leading the way, with some 75% of all capacity operating in those two countries. In 2100, annual CO_2 storage is more than 3 Gt per year globally, spread throughout the world. The rising global temperature is forcing adoption as nations attempt to hasten at least the domestic attainment of net zero emissions.

Surge is a world where greenhouse gas emissions, atmospheric CO_2 levels and climate change remain high on the international agenda, but where governments lean more towards private-sector solutions and market-driven voluntary outcomes. This becomes a successful strategy, with the demands of end-product consumers and other companies within supply chains encouraging emitting companies to actively manage their carbon footprints. In the late 2020s, various incentive structures are put in place by numerous governments to encourage carbon management in the private sector. This is mainly done to avoid the imposition of carbon border adjustments and to compete with incentives offered in some parts of the world.

Fossil fuels remain a core part of the energy system for many decades, and governments, largely pushed by the private sector, embrace the need for carbon removals. Investment in natural carbon removals grows, and forest protection and regeneration improve substantially throughout the world. With the expectation of change within industrial processes as electrification takes hold, there is diminished investment in the direct application of CCS technologies.

Instead, direct air capture becomes an appealing alternative, given the declining cost of module production and solar arrays for power and the thriving trade in voluntary carbon removal credits.

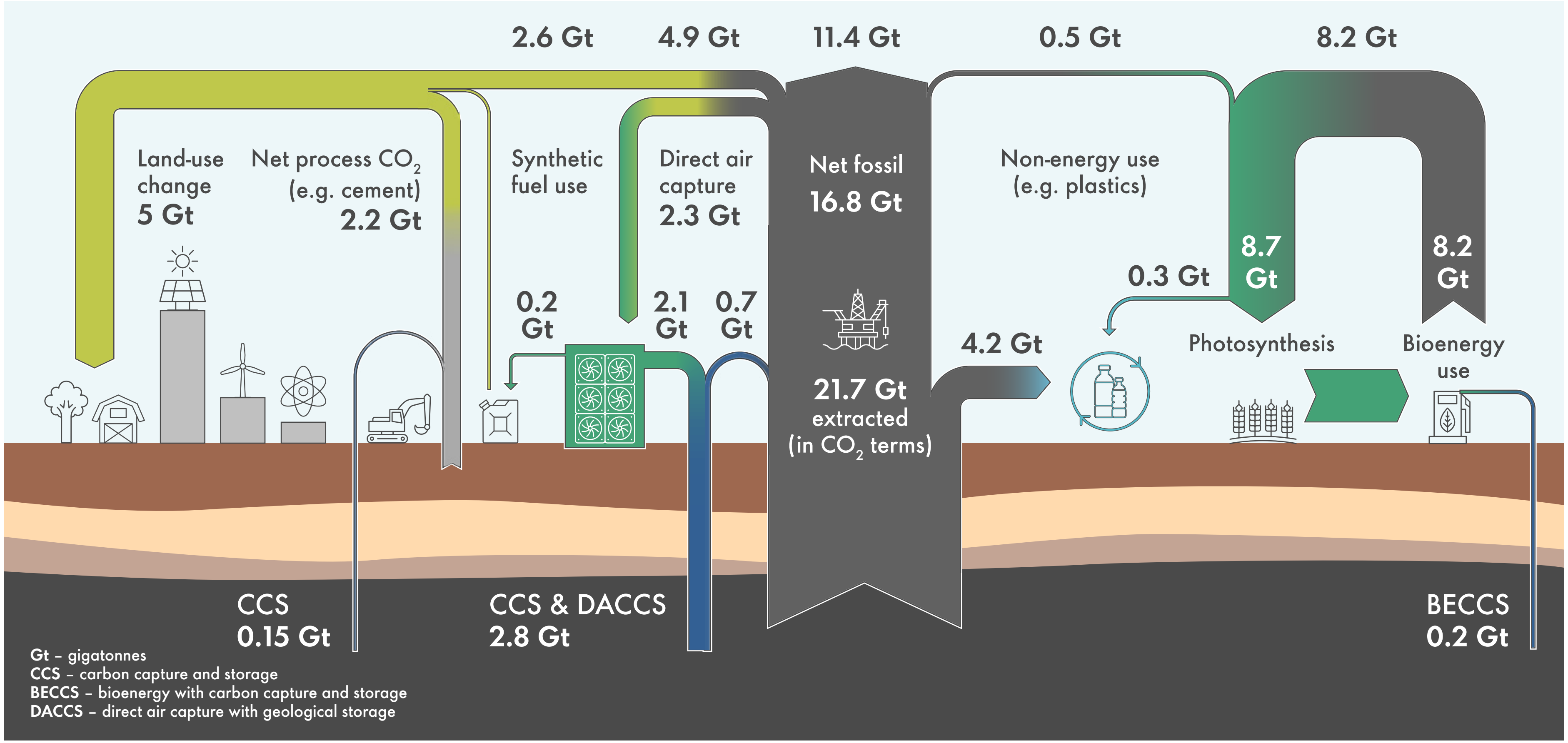
By the late 2030s, direct air capture clusters are appearing in many remote locations where geological storage of CO_2 is available and solar energy, for powering the capture units, is plentiful. The Middle East leads. By 2050, global direct air carbon capture and storage is removing more than 500 Mt of CO_2 from the atmosphere each year, surpassing 1.5 Gt per year by around 2060.

The AI technology seen in **Surge** also delivers a comprehensive and speedy global approach to measuring emissions and identifying sources of methane through remote satellite sensing.

Global sources and sinks of anthropogenic carbon (as CO_2) in Surge

Global emissions of 11.4 Gt CO_2 per year

2060



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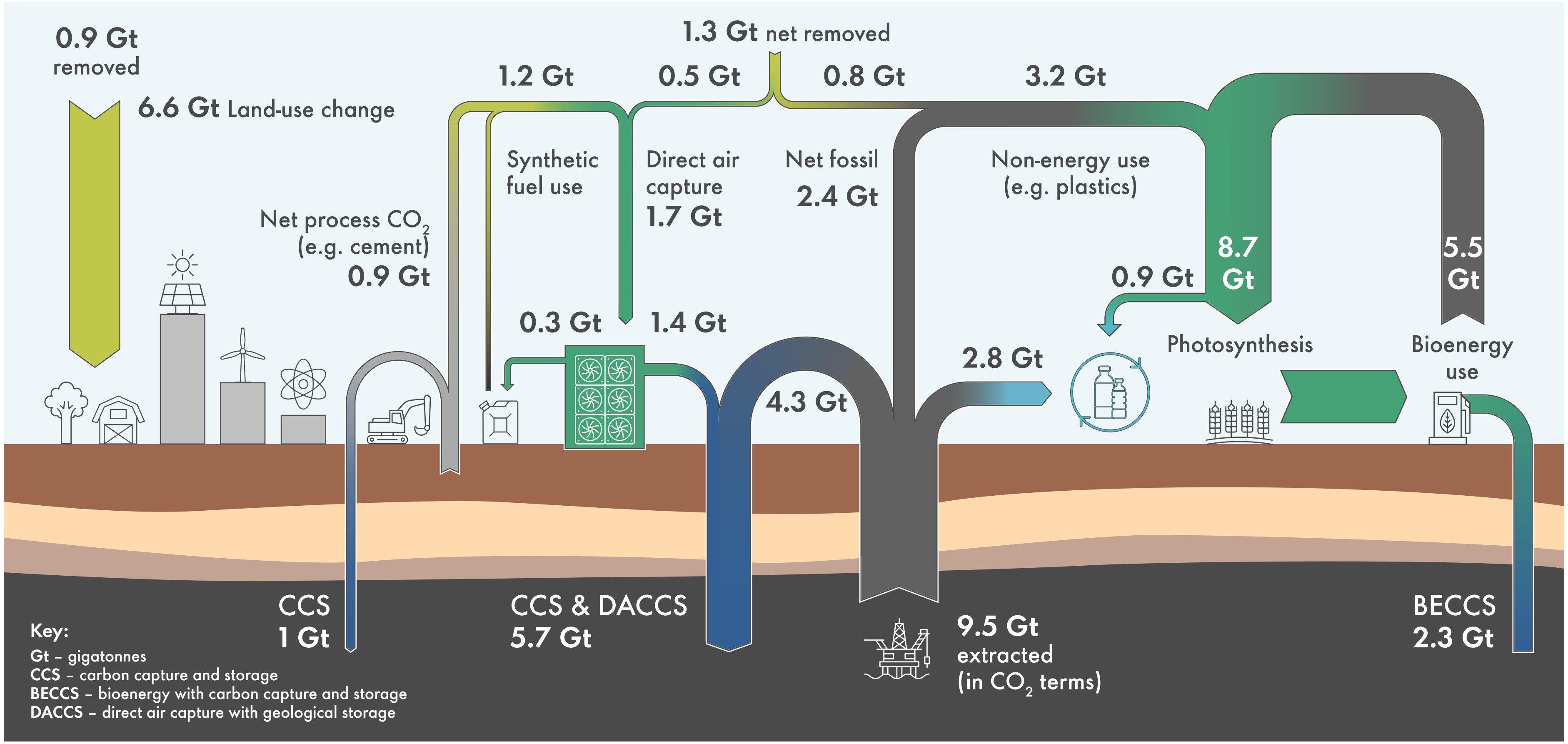
Global sources and sinks of anthropogenic carbon (as CO_2) in Horizon

Global net-negative emissions of 7.9 Gt CO_2 per year, net removal of CO_2

2060



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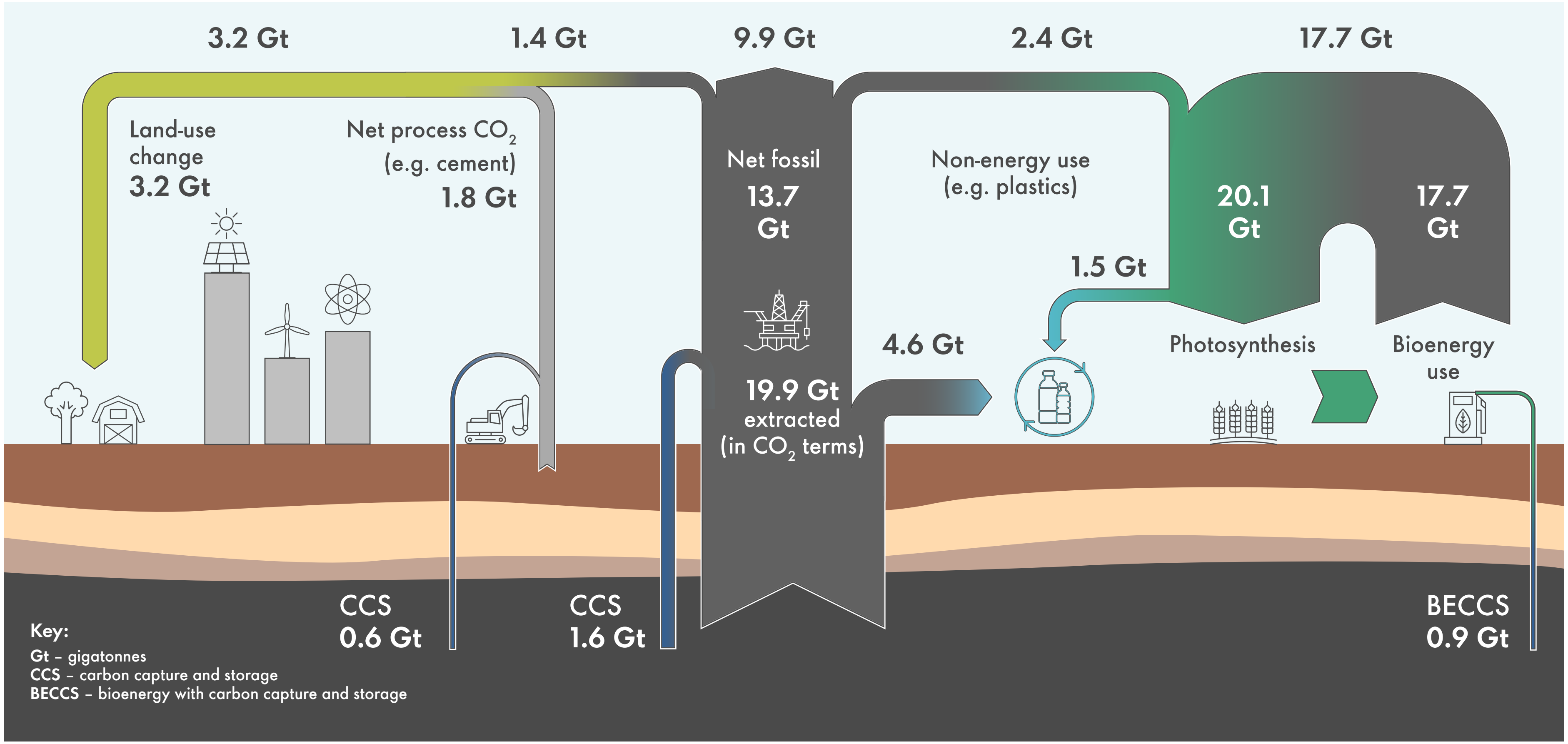
Global sources and sinks of anthropogenic carbon (as CO_2) in Archipelagos

Global emissions of 9.9 Gt CO_2 per year

2100



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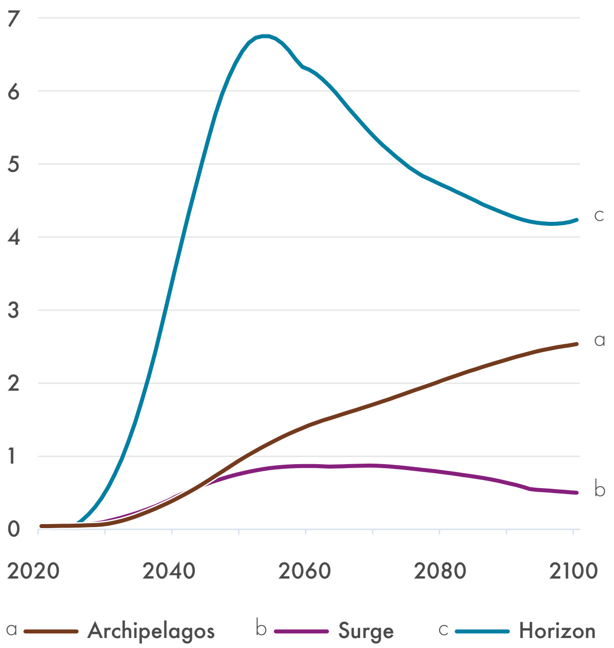
Carbon captured and stored in industry and power generation in the three scenarios to 2100

CO_2 stored, Gt per year



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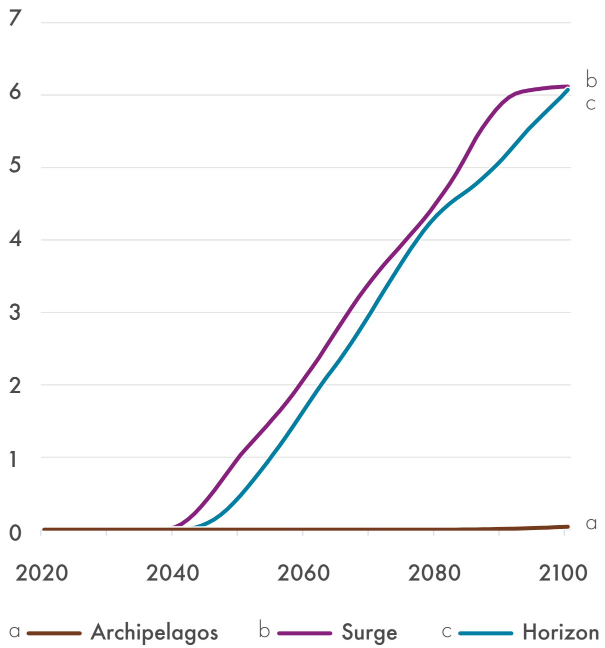
Direct air carbon capture and storage in the three scenarios to 2100

CO_2 stored, Gt per year



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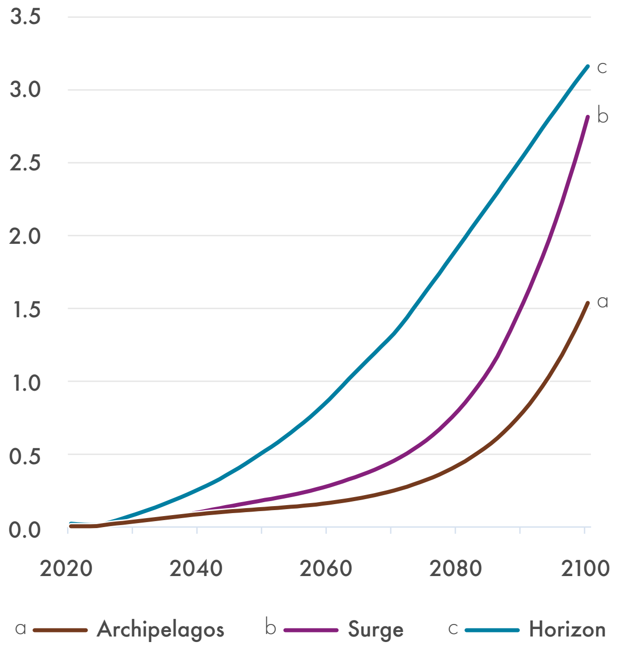
Carbon stored in society as chemical products from bio and synthetic feedstocks

Carbon stored, expressed as Gt CO_2 per year



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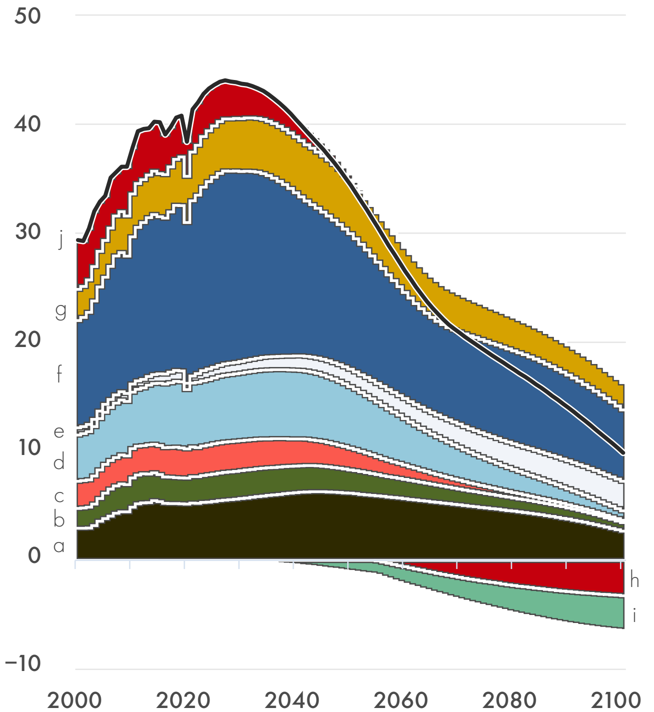
Anthropogenic CO_2 emissions in **Archipelagos** to 2100

Gt CO_2 per year



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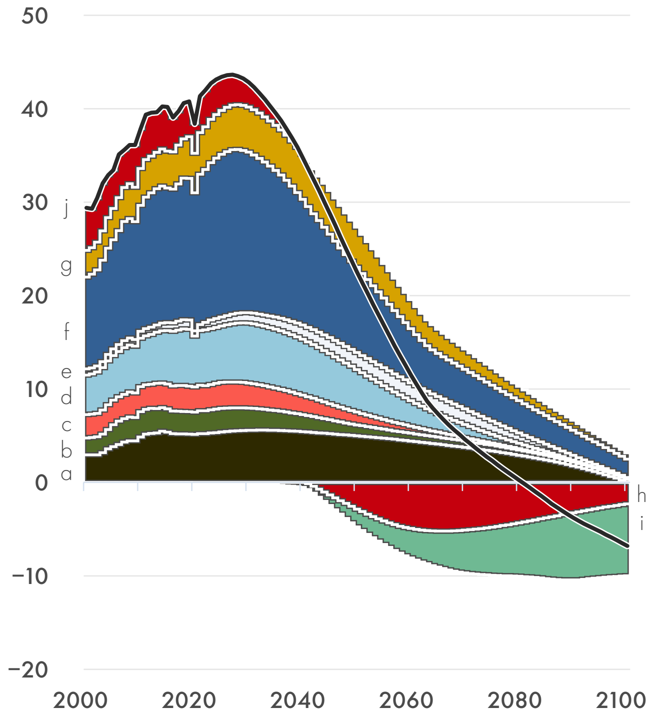
Anthropogenic CO_2 emissions in **Surge** to 2100

Gt CO_2 per year



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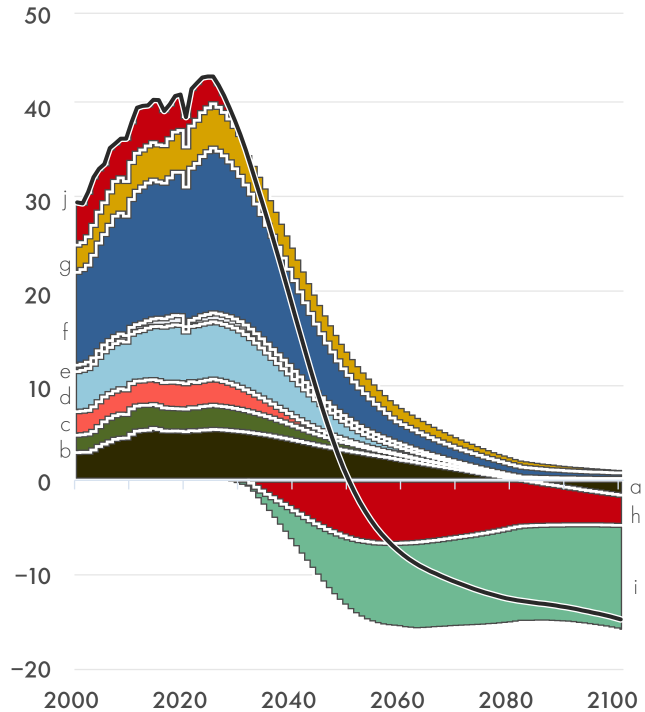
Anthropogenic CO_2 emissions in **Horizon** to 2100

Gt CO_2 per year



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a Heavy industry
b Light industry
c Buildings
d Road
e Aviation
f Electricity production
g Other energy
h Land-use change
i CCS
j Total

Any analysis which seeks to reach net zero CO_2 emissions by 2050, just 24 years away, must fully embrace the use of carbon management and carbon removal technologies and practices. **Horizon** is no exception.

The design of the scenario means a near-term end to deforestation, the rapid scale-up of CCS in legacy industries like cement production, the application of CCS in the burgeoning bioenergy industry (BECCS), the early expansion of the nascent direct air capture sector and a global focus on reforestation, carbon farming through agricultural reform and ecosystem protection.

Such is the scale of removals in **Horizon** to reach net-zero by mid-century that by 2060 the world has entered a prolonged period of net removal of CO_2 from the atmosphere, backed by a growing use of direct air capture, significant use of CCS in combination with bioenergy production and a transformation of land-use practices. Net removal of CO_2 from the atmosphere means a faster decline in the atmospheric concentration of CO_2 than the natural cycle offers, which in turn causes the global average surface temperature to fall.

Delivering negative emissions requires a systematic and robust policy framework for carbon removal. Global use of Article 6 of the Paris Agreement, which governs the trading of carbon credits between nations, 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.

Land-use change

Without a concerted effort to manage the land carbon stock, in addition to major energy system changes, achieving a plateau in warming and certainly reaching the Paris goal of well below 2 °C may not be possible.

All the scenarios envisage greater effort to manage the land, for reasons of carbon management but also, crucially, to reverse the global decline in biodiversity. The issue of biodiversity becomes a key driver in all scenarios.

In **Archipelagos**, land-use remains problematic for much of the world, but new coalitions eventually emerge to set the agenda. As food production expands and there is a renewed push for first-generation biofuels in many countries, forests come under pressure. Efforts to avoid deforestation and establish reforestation projects are hampered by a lack of interest in traded carbon credits, at least until the 2040s. But, as multiple entities recognise that they are far from their net zero goals set in the 2020s, a renewed interest in nature-based solutions emerges and new life is breathed into a lacklustre carbon credit market.

By 2050, the land area for energy has reached 700 million hectares (Mha) and, after a slow start, managed nature-based-solutions projects are approaching 1,500 Mha, losing a decade of action when compared to **Surge**. By 2060, the anthropogenic activities related to land carbon are back in balance in **Archipelagos**.

The late action comes because of Brazil's leadership, forcing change across South America as it becomes apparent that deforestation in the Amazon region is threatening the climate cycle of the continent.

In **Surge**, the voluntary carbon market consolidates and strengthens as multiple technology companies seek to manage their expanding carbon footprints. Voluntary carbon credits gain credibility as more companies make use of them and the underlying projects shift to carbon removal. Through to the 2040s, the prime beneficiary of the financing linked to this trend is land management, while in the decades following there is a split between land management and direct air capture. But the early interest in nature-based solutions means that anthropogenic change in land-use results in the net annual removal of CO_2 by the early 2040s.

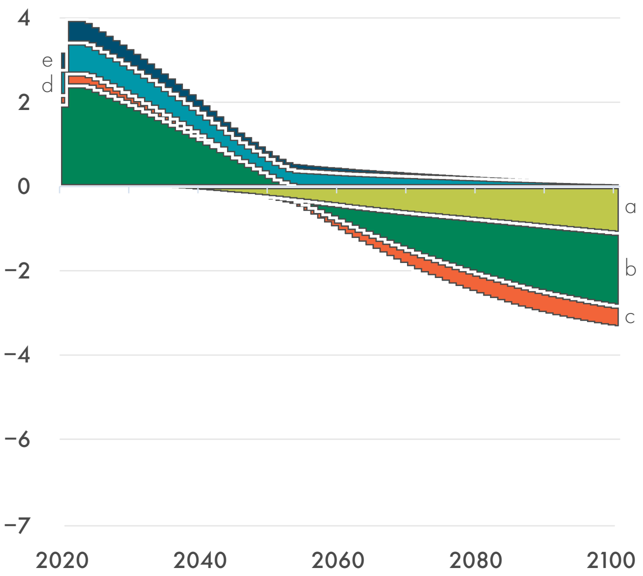
By 2060, with efforts to introduce carbon farming practices backed by carbon credit trade, the land is absorbing more than 6 Gt of CO_2 per year because of anthropogenic activities. The land becomes an important contributor to the journey towards net zero emissions.

By 2070, in **Horizon**, as part of the required effort to limit warming to 1.5°C by 2100, almost all land that humans interact with is 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 after an end to global deforestation by 2035, and the scenario includes the potential to reforest an area up to the size of Mexico: about 200 million hectares.

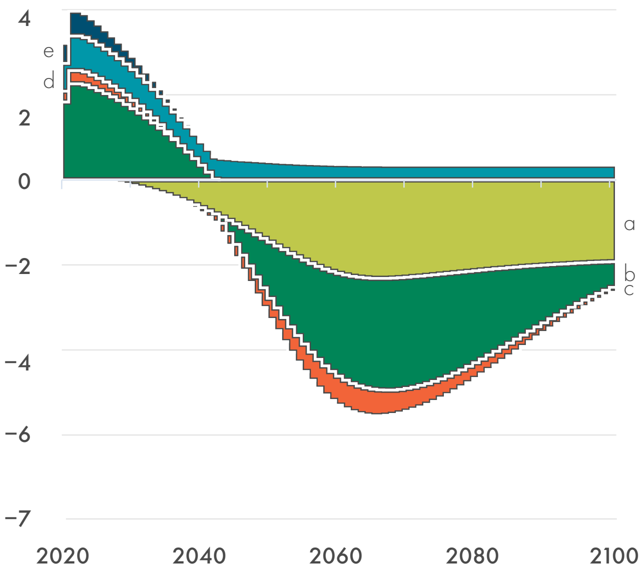
Land-use change emissions in **Archipelagos** by type

Gt CO_2 per year



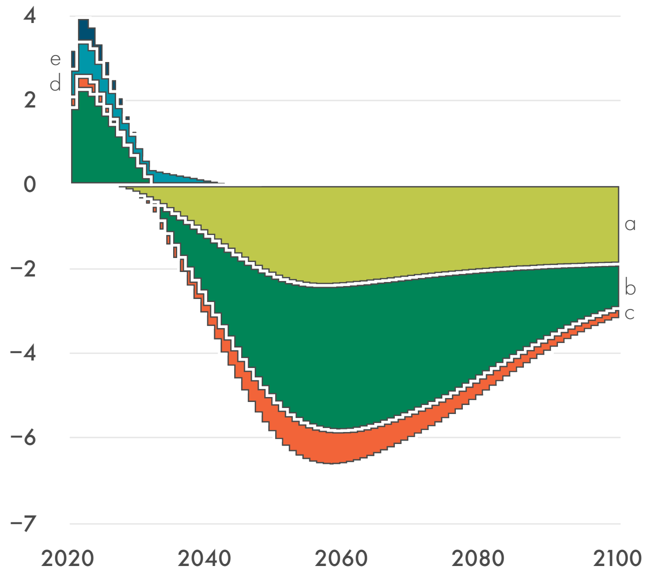
Land-use change emissions in **Surge** by type

Gt CO_2 per year



Land-use change emissions in **Horizon** by type

Gt CO_2 per year



a Agriculture b Forests c Grasslands d Wetlands e Coastal ecosystems

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Climate-change politics and temperature outcomes

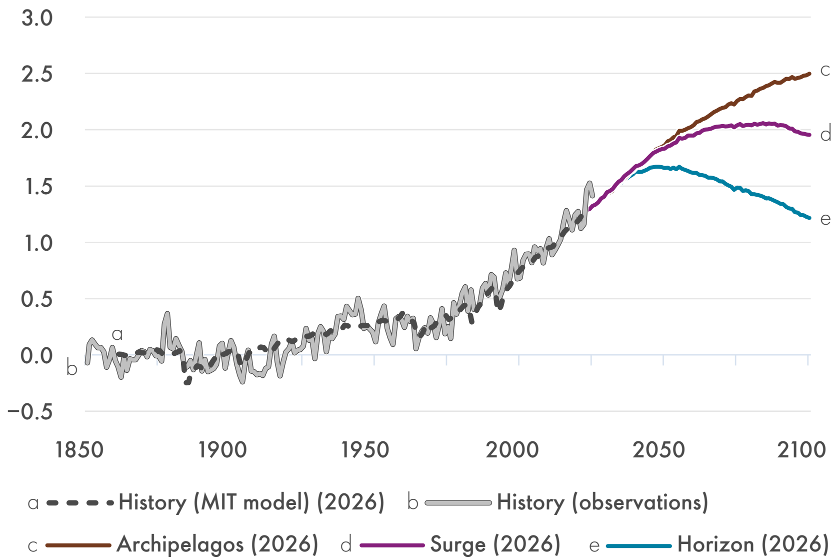
A key consideration regarding the future policy landscape is to recognise there is no scenario where climate is off the agenda. The changes that are becoming apparent in global weather patterns as the climate shifts give rise to growing pressures on policymakers and society to respond. And they do so in all three scenarios, but in different ways.

In **Archipelagos**, the global surface temperature continues to rise and 2°C years become the norm in the late 2040s. With global CO_2 emissions still over 35 Gt per year in 2045, the pressure on governments grows. By 2050, the incidence of extreme weather events has become the one that most challenges governments in terms of response. A drop in outdoor labour productivity and some limits being placed on certain public events contribute to public concern. The reaction is litigation against governments and eco-activism, with policy-makers doing little to further support the energy transition. By this time, the argument has swung to one that the energy transition is well underway, so the only course of action is adaptation. There is a broad belief that a faster transition is not possible.

Nevertheless, rapid deployment of solar photovoltaic, wind and battery electric vehicles continues, with nuclear power and increased bioenergy also becoming prominent. Biofuel use expands, but support for more sustainable technologies, such as cellulosic processing and using ethanol to produce jet fuel, is limited. As a result, there is only modest change in sectors such as aviation, marine and heavy industry. These sectors continue to use fossil fuels, and a new generation of coal-fired industrial facilities is built in Africa, albeit not on a large scale.

Global average surface temperature change in the three scenarios

Temperature anomaly in °C compared with 1850–1900



History = HadCRUT5 (Dec 2025). Scenarios measured as global mean surface temperature (GMST), modelled by MIT Center for Sustainability Science and Strategy (Dec 2025).

See the accessibility description

The losing technologies in **Archipelagos** are those related to carbon emissions management, which have only modest political support when other priorities and spending commitments are present. Issues relating to trade and security hamper the development of carbon markets. Under the auspices of a weakened United Nations and UN Framework Convention on Climate Change, the money needed for **Rising Surfers** to build clean energy infrastructure does not materialise, so coal persists for longer in many economies.

Climate policies remain in the scenario, but instruments such as carbon pricing are not applied at the levels needed to usher in rapid change. Rather, the focus is on domestic energy production. However, in a world of trade tension, some countries and regions apply carbon border adjustments, which have an impact on the policy decisions of trading partners or force the private sector to implement mitigation actions. The use of CCS in industry benefits from these tariffs, but related technologies such as direct air capture of CO_2 fail completely through lack of initial government funding.

Land management practices such as reforestation and carbon farming develop, but they largely rely on the voluntary carbon market for funding. While net global deforestation is achieved, and by the mid-2050s land carbon stocks are again rising, older forests are still subject to degradation and loss for some years, but at a much slower rate than currently seen.

The sheer scale of technological change drives emissions down and net zero CO_2 is reached in the first half of the 22nd century. In 2100, the global average surface temperature rise is around 2.5°C.

In **Surge**, a richer world is more attuned to environmental needs, which in turn prompts government policy development. While governments are instrumental in seeding technology development and early-stage demonstration, **Surge** is a scenario in which commercial interests in the energy transition are at the forefront. But a strong business-government collaboration is still required to deliver local incentives for infrastructure construction, planning permission, international trade of verified carbon units (such as carbon removal credits) and to underpin legislation for technologies like small modular nuclear reactors.

The large information technology companies see rapidly growing energy demand from their own operations, which also brings with it an expanding carbon footprint. There are both cost and reputational issues to deal with. This prompts a significant response, with technology companies pushing themselves into the energy markets, initially as major buyers but then as suppliers as they build their own energy infrastructure.

With expertise in supply chain management, they opt more for a modular infrastructure, which can be easily added to and expanded. Solar photovoltaic, batteries, heat pumps and hydrogen electrolysers all benefit from this push.

With climate change higher on the consumer agenda, the same companies turn their attention to carbon management, opting for nature-based solutions and direct air capture, given the latter's modular design and discretionary geographic placement.

Several large technology companies build their own energy infrastructure production facilities, mimicking the gigafactory model developed by Tesla in the 2010s. The transition accelerates rapidly as a result. Global net zero CO_2 emissions are achieved in 2080, and by 2100 the global average surface temperature rise has been limited to 2°C.

Horizon illustrates the broad policy approach required for both a transition away from fossil fuels and the need for carbon emissions management. The latter is essential in the short term for net zero emissions and critical for the remainder of the century to correct the overshoot of 1.5°C by removing CO_2 from the atmosphere. The **Horizon** policy landscape is as follows:

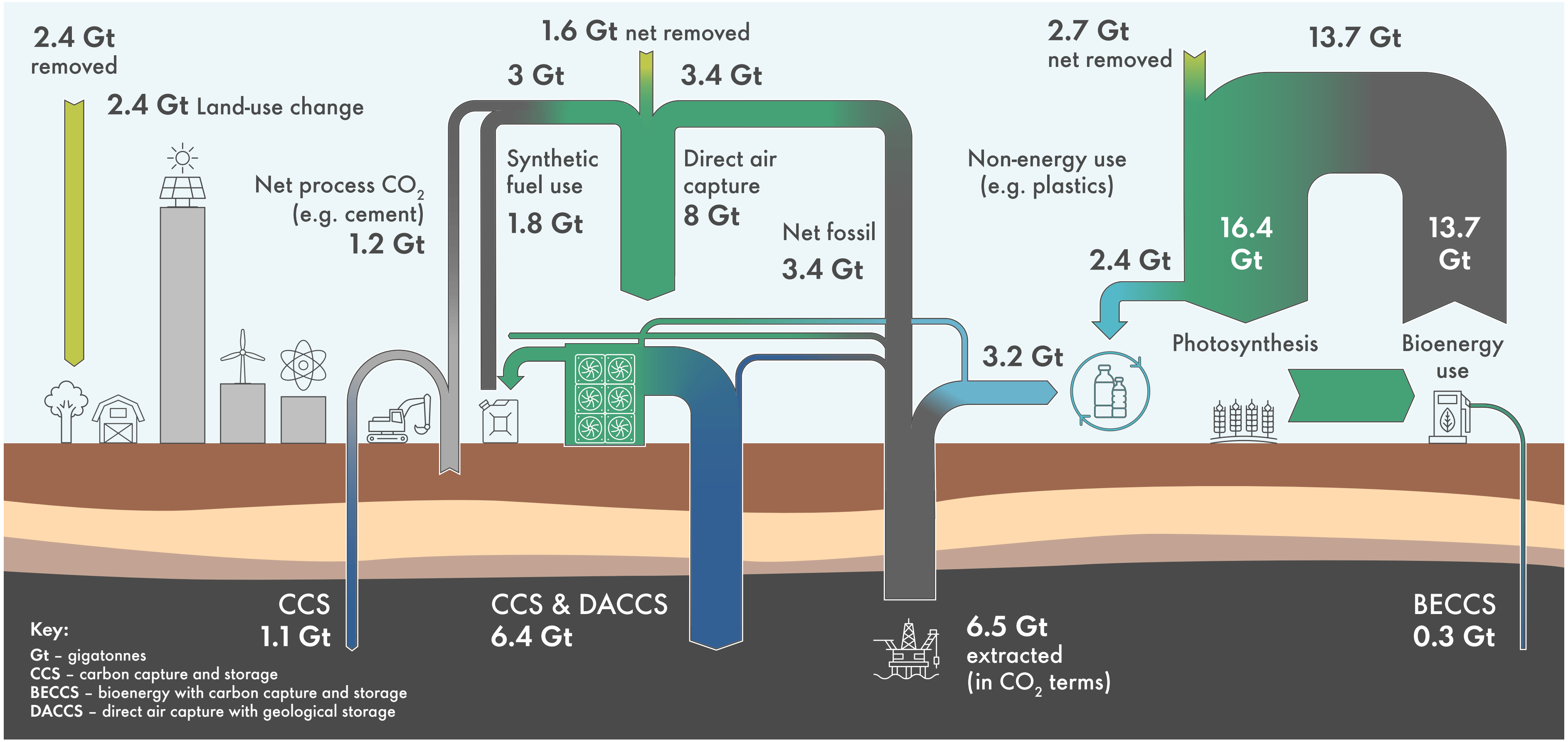
- Apply carbon pricing widely, through changes in the taxation system and the implementation of emissions cap-and-trade systems. These are applied primarily to power generation and industrial facilities.
- Create clear incentives for renewable energy deployment and the use of low-carbon fuels.
- Drive consumers away from incumbent technologies, such as internal combustion engines and natural gas boilers. This may include mandates, scrappage and replacement incentives or direct grants.
- Build a very large-scale CCS industry, including transport infrastructure for CO_2.
- Establish early-stage demonstration facilities and include incentives for new technologies such as direct air capture.
- Reduce the length of time it takes to gain permits and planning permission, including for wind, solar, hydro and nuclear power generation, for the geological storage of CO_2 and for expansion in the mining sector to bring a range of key minerals to market that are essential for the energy transition, such as copper.
- Create a system for international trade in carbon assets, such as removals, nature-based credits and various types of offset.
- Change land management practices, end deforestation, engage with farmers to increase their focus on soil carbon and protect ecosystems such as mangroves, grasslands and wetlands. Large-scale reforestation activities are a priority.
- Significantly reduce methane emissions, with actions to eliminate fugitive methane emissions in industry and to curtail agricultural methane.
- Encourage citizens to change their daily behaviour regarding travel, waste management and energy use.

As is the case for **Surge** and **Archipelagos**, **Horizon** overshoots 1.5°C, but it quickly reaches a plateau at around 1.7°C as the world achieves net zero CO_2 emissions in 2050. With a large-scale carbon removal industry growing as the century progresses and land management goals achieved, the global average surface temperature rise is well below 1.5°C in 2100 and falling.

Global sources and sinks of anthropogenic carbon (as CO_2) in Surge

Global net-negative emissions of 6.7 Gt CO_2 per year, net removal of CO_2

2100



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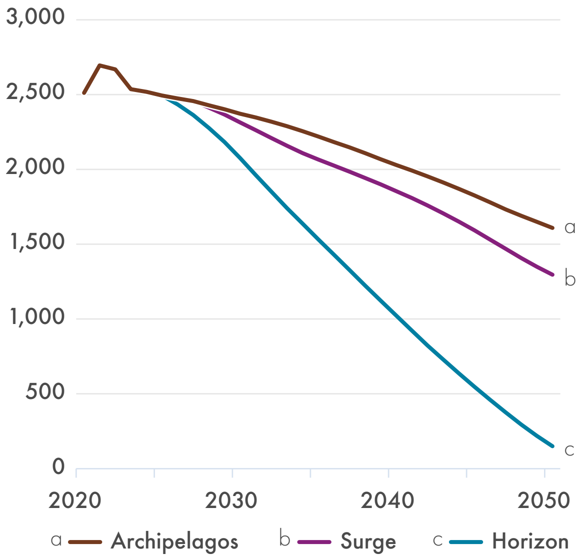
The EU emissions goals in the three scenarios

The EU has in place the most ambitious set of policies globally to reduce greenhouse gas emissions and targeting net zero greenhouse gas emissions by 2050. But the policies are largely dependent on domestic action, with an agreed modest allowance for international trade in carbon removal units. The framework effectively requires net zero CO_2 emissions by 2040, given the interim 90% greenhouse gas reduction target for that year, and the need to make room for agricultural and industrial non-CO_2 emissions (like sulphur hexafluoride in transformers) which constitute about 10% on their own. All the scenarios become dependent on land-use change in Europe and international trade in carbon units.

Net energy CO_2 emissions in the EU to 2050 in the three scenarios

CO_2 emissions, Mt per year



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Horizon, which illustrates a pathway to net zero CO_2 emissions globally by 2050, still shows around 1 Gt of energy CO_2 emissions for Europe in 2040, more than the legislation allows for. **Archipelagos** is particularly problematic, with more than 2 Gt of CO_2 in 2040. In this scenario, the tension emerging from ambitious targets and a Europe facing clear security threats leads to a near breakdown in the cohesion of the EU. A middle ground becomes hard to find and eventually the target framework is the casualty, leading to an erosion of power in Brussels.

By contrast, in **Horizon**, a further relaxation of the domestic contribution allows international credits to fill the gap, and significant investment flows to multiple countries in return. This contributes to the important task of global land management. In **Surge**, much-prized economic growth allows for a compromise solution to be reached that sees Europe invest heavily in the global emergence of direct air capture (DAC) technologies and a preferential inflow of the early creation of carbon removal credits from DACCS.

Implications of a warmer world in **Archipelagos**

With a temperature outcome around 2.5°C in **Archipelagos**, the world will likely pass through 2°C by the 2060s, with implications for governments, people and potentially geopolitical stability.

In 2026, at around 1.3°C warming, farmers are already facing changes to rainfall patterns and temperature levels, affecting the predictability of their crop production. Adaptation efforts include improvements to soil and an increase in water storage. Further, world markets have remained sufficiently adaptable to maintain food supplies.

In **Archipelagos**, given the somewhat superficial appearance of a rapid transition, it is some time before broad realisation sets in that efforts are not wide-ranging enough to deliver net zero emissions in the second half of the century. Furthermore, the slow development of carbon sinks is increasing anxiety about the ability to achieve net zero emissions and ultimately to take large amounts of CO_2 out of the atmosphere, which could eventually reduce surface temperature warming. All the while, the pressures on agriculture become more pronounced.

Growing seasons change and areas within countries that had historically been well suited for certain crops diminish. While the world could adapt to such change through macro changes in agricultural practices, an **Archipelagos** world may not be able to make such changes as it would involve new cross-border arrangements and trade patterns.

A potential outcome of the national stresses that emerge later in the century is that some countries turn to locally implementable solutions that have much broader impact. This further heightens tensions. One such solution is to engage in geo-engineering practices to reduce the global temperature over the short term. This means deliberate large-scale interventions in the earth's climate system intended to counteract climate change.

Over the hundreds of years that temperature records have been maintained, a large set of valuable data has been amassed. These temperature records have been used to identify the impact of globally relevant events, such as large volcanic eruptions. For example, the Mount Pinatubo eruption in the Philippines in 1991 caused global temperatures to cool by about 0.5–1°C for roughly two to three years due to stratospheric aerosols reflecting sunlight. The eruption injected large amounts of sulphate aerosols into the stratosphere. These scattered and absorbed incoming sunlight, reflecting it back into space.

It is theoretically possible to achieve the same result by using hundreds of aeroplanes to seed the stratosphere with a sulphate aerosol. The ability to do this is within the capability of a single nation, and in the **Archipelagos** scenario it is plausible to imagine such an outcome. However, the broader impact of such action is highly uncertain. Seeding the atmosphere with the intent of restoring agricultural yields in a particular region could well have severe knock-on effects throughout the world.

In a situation where this occurs, military confrontation could result, as nations might object in the most strenuous terms to unilateral climate action using geo-engineering.

Large-scale geo-engineering is a practice that we should all hope the world never has to engage in, or even consider, but in the **Archipelagos** scenario it is both plausible and deeply concerning.

Final thoughts

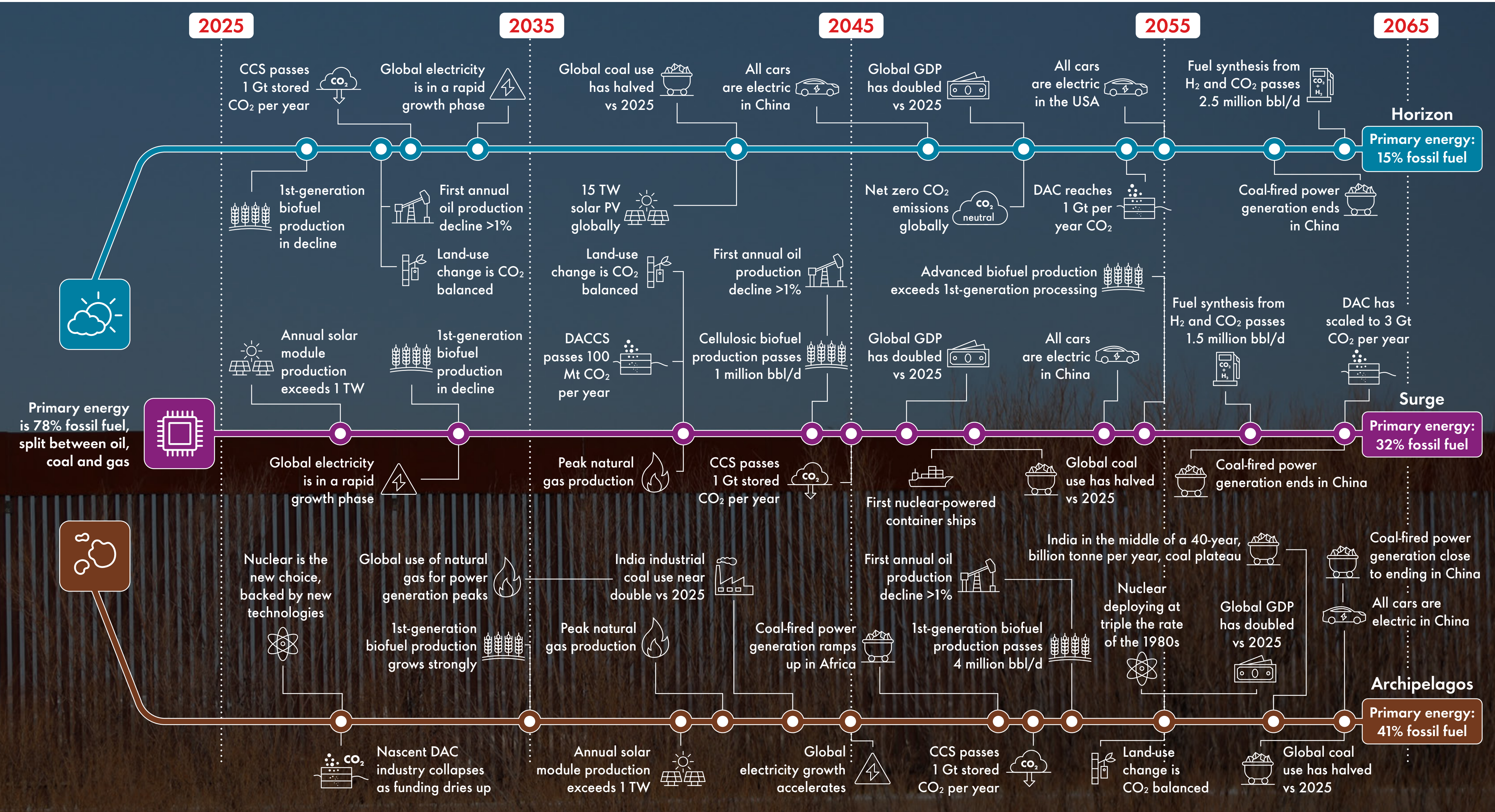
The energy transition is nearing a tipping point; the questions at hand are not whether society can reach net zero CO_2 emissions or whether society is able to limit surface temperature warming, but how soon net zero emissions will be realised and where the eventual temperature plateau might be.

Horizon presents a reference case for meeting the goal of the Paris Agreement, with an important emphasis on the need for carbon management and the technologies and practices required.

Surge illustrates that, even in a period of higher economic growth with increased access to energy services throughout the world, a plausible outcome sees warming limited to 2°C by 2100.

But **Archipelagos**, with its tensions, trade friction and focus on more immediate security issues, offers a warning. While a temperature outcome in 2100 around or even below 2°C above that in 1850–1900 is entirely possible, given where the world is today, it cannot be taken for granted. A world beset by restrictions, be they trade-based, related to the legal movement of people or the result of regional conflict, will turn to what it knows best and is immediately available. For energy supply, this may mean a much longer period of high coal use, along with increased use of oil and natural gas. The consequence is a world that is warmer by around 2.5°C in 2100, rather than one that is below 2°C compared to the 1850–1900 temperature baseline.

Security choices timeline in the 2026 Energy Security Scenarios



CCS – carbon capture and (geological) storage
DAC – direct air capture
DACCS – direct air capture and (geological) storage
Gt – gigatonne (or billion tonnes)
Mt – million tonnes
TW – terawatt
bbl/d – barrels per day (liquid fuels)
GDP – gross domestic product
PV – photovoltaic

See the accessibility description

References and acknowledgements

We wish to thank the many people consulted externally in the development of The 2026 Energy Security Scenarios. We would like to recognise the Massachusetts Institute of Technology (MIT) Center for Sustainability Science and Strategy (MIT CS3) for assessing the climate impacts of the three scenarios presented in this publication. MIT modelled the impact using its Integrated Global System Modelling framework. Shell makes an annual contribution of USD 150,000 to MIT CS3. In addition, Shell makes one-off donations to support CS3 research projects. Currently, Shell is contributing USD 200,000 towards a study with MIT CS3 on methane pathways and abatement.

We also wish to thank the International Energy Agency (IEA). Our scenario modelling is founded on historical data from IEA Extended Energy Balances. The work in these scenarios was prepared by Shell International B.V. and does not necessarily reflect the views of the IEA.

Accessibility descriptions

Full data set available via the underlying data.

Gross domestic product in the three scenarios

A line chart showing global GDP from 2010 to 2060, in 2016 US dollars at purchase power parity, for the three scenarios. Historically, GDP grew from 90 trillion USD in 2010 to 135 trillion USD today. In 2060, GDP in the **Surge** scenario has grown most, to 400 trillion USD. GDP in **Archipelagos** has grown least, to 315 trillion USD. GDP in **Horizon** ends up in the middle at 345 trillion USD.

Return to page 11

Development of primary energy in **Archipelagos** (Left)

An area chart from 2010 to 2060, showing the evolution of the primary energy mix in **Archipelagos**, broken down by source. Overall primary energy demand is rising from 540 EJ in 2010 to 660 EJ today to 880 EJ in 2060. The fossil wedge peaks in the 2030s around 540 EJ, and renewables and nuclear rise to 470 EJ in 2060.

Return to page 19

Development of final energy in **Archipelagos** (Right)

An area chart from 2010 to 2060, showing the evolution of the final energy mix in **Archipelagos**, broken down by energy product. Demand rises nearly linearly from 330 EJ in 2010 to 560 EJ in 2060. Liquid fossil fuels fluctuate around 150 EJ of the mix, gaseous fuels around 100 EJ and solid fossil fuels around 30 EJ. Electricity demand is the main feature of the chart, as it grows from 75 EJ in 2010 to 120 EJ in today to 290 EJ in 2060.

Return to page 19

Growing global electricity demand in **Archipelagos** (Left)

An area chart from 2010 to 2060, showing the evolution of the global electricity mix in **Archipelagos**, broken down by source. Electricity demand has been rising from 18,000 TWh in 2010 to 28,000 TWh today and 75,000 TWh in 2060. While fossil is over half of the mix today, it's less than 20% by 2060, being overtaken mostly by solar (30,000 TWh) and wind (16,000 TWh). Hydroelectricity, bioenergy and nuclear are important sources throughout.

Return to page 20

Development of the molecular fuel mix in **Archipelagos** (Right)

An area chart from 2010 to 2060, showing the evolution of the molecular fuel mix in **Archipelagos**, broken down by type. It shows peak molecules around 2045 with a slowly opening wedge of biofuels. 20 EJ is non-fossil by 2060.

Return to page 20

Development of primary energy in **Surge** (Left)

An area chart from 2010 to 2060, showing the evolution of the primary energy mix in **Surge**, broken down by source. Overall primary energy demand is rising from 540 EJ in 2010 to 660 EJ today, converging to 810 EJ in 2060. The fossil wedge peaks in the late 2020s around 540 EJ, and renewables and nuclear rise to 500 EJ in 2060.

Return to page 22

Development of final energy in **Surge** (Right)

An area chart from 2010 to 2060, showing the evolution of the final energy mix in **Surge**, broken down by energy product. Demand rises nearly linearly from 330 EJ in 2010 to 550 EJ in 2060. Liquid fuels decline slowly from 150 EJ to 120 EJ in 2060 and gaseous fuels from 100 EJ today to 70 EJ. Electricity passes 50% of final energy in the 2050s.

Return to page 22

Growing global electricity demand in **Surge** (Left)

An area chart from 2010 to 2060, showing the evolution of the global electricity mix in **Surge**, broken down by source. Overall demand grows fast, from 18,000 TWh in 2010 to 28,000 TWh today and 91,000 TWh in 2060. While fossil sources are over half of the mix today, it is less than 10% by 2060, being overtaken mostly by solar (54,000 TWh) and wind (19,000 TWh). Hydroelectricity and nuclear are important sources throughout.

Return to page 23

Development of the molecular fuel mix in **Surge** (Right)

An area chart from 2010 to 2060, showing the evolution of the molecular fuel mix in **Surge**, broken down by type. This shows peak molecules around 2035 with substantial wedges of biofuels and hydrogen, 35 EJ in total.

Return to page 23

Development of primary energy in **Horizon** (Left)

An area chart from 2010 to 2060, showing the evolution of the primary energy mix in **Horizon**, broken down by source. Overall demand rises from 540 EJ in 2010 to 660 EJ today to 680 EJ in 2060. The fossil peaks today around 520 EJ, and renewables and nuclear rise to 550 EJ in 2060.

Return to page 26

Development of final energy in **Horizon** (Right)

An area chart from 2010 to 2060, showing the evolution of the final energy mix in **Horizon**, broken down by energy product. Final energy demand in total is fairly flat from 2030, fluctuating between 400 EJ and 425 EJ. Electricity is 75 EJ in 2010, 120 EJ today and 260 EJ in 2060. The remainder consists of predominantly liquid fuels and gaseous fuels, and a fast-opening wedge of hydrogen to 40 EJ in 2060.

Return to page 26

Growing global electricity demand in **Horizon** (Left)

An area chart from 2010 to 2060, showing the evolution of the global electricity mix in **Horizon**, broken down by source. Electricity demand grows from 18,000 TWh in 2010 to 28,000 TWh today and 91,000 TWh in 2060. While fossil is over half of the mix today, it's thickness of the line by 2060, being overtaken mostly by solar (54,000 TWh) and wind (25,000 TWh). Hydroelectricity and nuclear are important sources throughout.

Return to page 27

Development of the molecular fuel mix in **Horizon** (Right)

An area chart from 2010 to 2060, showing the evolution of the molecular fuel mix in **Horizon**, broken down by type. The demand for molecular fuels goes down from 280 EJ today to 150 EJ in 2060. Hydrogen and bioenergy grow aggressively as part of that mix, to 70 EJ in total by 2060.

Return to page 27

Fossil fuel share of primary energy in the three scenarios (Left)

Line chart showing the share of fossil in the primary energy mix. The share has been stable at 80% for decades. That share falls in all scenarios. In 2050, fossil shares have fallen to 30% in **Horizon**, 50% in **Surge** and 60% in **Archipelagos**. By 2100, those numbers are 5%, 10% and 25%.

Return to page 31

Electrification of final energy in the three scenarios (Right)

Line chart showing how much of final energy demand is delivered by electricity. This share has been rising slowly from 16% in 2000 to 22% today. However, in 2050, this share has risen to 50% (**Horizon**), 45% (**Surge**) and 35% (**Archipelagos**). In 2100, the lines converge near 60%.

Return to page 31

Global geological storage of CO_2 in the three scenarios (Left)

Line chart showing the amount of geological CO_2 storage in the scenarios. **Horizon** sees an early uptake to almost 8 Gt/year in 2050, leaving **Archipelagos** and **Surge** at 1 to 2 Gt/year. By 2100, capture rates are 10 Gt/year in **Horizon**, 6 Gt/year in **Surge** and 2 Gt/year in **Archipelagos**.

Return to page 32

Rapid growing demand for copper in Horizon

A line chart showing copper demand in the **Horizon** scenario. In 2010, demand was 10 Mt per year. Today, it's at 20 Mt/y. In 2050, demand exceeds 60 Mt/y.

Return to page 32

Total primary energy, usable primary energy and energy service demand in the three scenarios

Bubble chart with bubbles for history (2025 only), **Surge** (2040, 2070, 2100), **Archipelagos** (2040, 2070, 2100) and **Horizon** (2070 only). Bubble size relates to final energy and shows that this grows in **Surge** and **Archipelagos** but not in **Horizon**.

The horizontal axis shows the fraction of usable primary energy after thermal loss, which is around 53% today. All scenarios grow along these axis – but **Surge** and **Horizon** fast (>75% in 2070), and **Archipelagos** slow (67% in 2100). The vertical axis shows the relative demand for energy services in the scenarios, where **Surge** rises fastest (+150% in 2070 and +200% in 2100), then **Archipelagos** (+175% in 2100) and then **Horizon** (+120% in 2100).

Return to page 34

Evolution of final energy demand in the three scenarios across regional archetypes

Bar chart of final energy demand in EJ/year with four sections. One section for history in 2000, 2010 and 2024. And three sections for the three scenarios for 2040, 2070 and 2100. Bars are subdivided into five parts, each part represents an archetype (**Green Dream**, **Innovation Wins**, **Great Wall of Change**, and the two **Surfers** archetypes). Historical growth, dominated by **Great Wall of Change** and **Surfers**, was from 290 EJ to 440 EJ. Future growth is dominated by **Surfers**, who seem to grow to represent more than half of demand between 2040 and 2070. In 2100, total demand is 630 EJ (**Archipelagos**), 510 EJ (**Horizon**) and 580 EJ (**Surge**).

Return to page 35

Global oil demand in the three scenarios Demand shown in key hard-to-abate sectors

Line plot showing the evolution of global oil demand in the scenarios for 2010 to 2060. Oil demand is around 100 Mboe/day today. In **Horizon**, demand goes down from today to just over 30 Mboe/day in 2060. **Surge** peaks slightly above 100 Mboe/day in 2030 and is down to 70 Mboe/day in 2060. **Archipelagos** is showing a demand plateau just above 100 Mboe/day until the 2040s, then slowly declines to 85 Mboe/d in 2060.

Underneath the oil lines are dashed lines at lower values, representing the Mboe/d of oil demand that comes from hard-to-abate sectors: marine, aviation and chemicals. These are at 30 EJ today, and either rise to 40 EJ (**Archipelagos**) or 45 EJ (**Surge**), or very slowly decline to 25 EJ in 2060.

Return to page 37

Oil supply in 2040 and the production from new fields

Chart breaking down 2040 oil supply, by scenario, into field types: existing, new conventional and new unconventional fields. This is further broken down into OPEC+ and rest of world. Global supply is 100 Mboe/d in **Surge** and **Archipelagos**, and 70 Mboe/d in **Horizon**.

In all three scenarios, production from OPEC+ is ~45 Mboe/d from existing fields and ~5 Mboe/d from new conventional fields – relatively constant. Outside OPEC+, new fields dominate, and unconventional fields within that. In **Surge** and **Archipelagos**, production outside OPEC+ is comparable to OPEC+ production, around 40 Mboe/d. In **Horizon**, production outside OPEC+ is 25 Mboe/d.

Return to page 38

Global natural gas demand in the three scenarios

A line chart on natural gas demand. Natural gas demand has been rising from 3,300 bcm/year in 2010 to 4,300 bcm/year today. In **Horizon**, the trend turns today and demand drops to 1,300 in 2060. **Surge** and **Archipelagos** both peak in 2040 at roughly 4,600 bcm/year and slowly decline to 3,500 to 3,700 bcm/year in 2060.

Return to page 40

Regional natural gas demand in **Archipelagos** (Left)

An area chart of natural gas demand broken down by major regions, from 2010 to 2100. Decline is expected in most regions, except Developing Asia Pacific and Africa, the latter growing to be the biggest gas using region globally. China has a temporary big share of global demand for the next 20 years.

Return to page 41

Regional natural gas demand in **Surge** (Right)

An area chart of natural gas demand broken down by major regions, from 2010 to 2100. A fast decline is expected in most developed regions, but India and China are important growth regions. Demand in Africa and Developing Asia Pacific remains robust.

Return to page 41

Global LNG demand in the three scenarios

Line chart showing LNG demand in the three scenarios. LNG demand has risen from 220 Mt/y in 2000 to 400 Mt/y today. In **Horizon**, demand peaks around 2030 just under 550 Mt/y and then declines to 250 Mt/y in 2060. In **Surge** and **Archipelagos**, LNG demand rises rapidly and moves within the 600 to 700 Mt/y bands from 2030 to 2060.

Return to page 42

Global coal demand in the three scenarios (Left)

A line chart showing overall coal demand in the three scenarios from 2010 to 2100. The second breaks down coal demand by region for the **Archipelagos** scenario. The first chart shows that coal demand has been moving within the 5,000 to 6,000 Mt/y range since 2010, and all scenarios have demand peaking within the next five years. In **Archipelagos**, the decline is slowest, with 4,500 Mt/y demand in 2050. Demand in **Surge** and **Horizon** by then is 2,500 and 1,500 Mt/y, respectively. By 2100, demand is 2,000 Mt/y in **Archipelagos** and around 100 Mt/y in **Horizon** and **Surge**.

Return to page 44

Regional coal demand in **Archipelagos** (Right)

An area chart showing coal demand broken down by region from 2010 to 2100. China has been generating more than half of the global coal demand. Decline in China sets in in the late 2020s, and even though Europe and North America decline too, the Chinese demand affects the total the most. Indian demand and demand from developing Asia is close to flat until the end of the century. Africa shows growth towards the end of the century.

Return to page 44

Coal use development ladders in **Archipelagos**

Line chart for **Archipelagos** showing coal demand per capita on the vertical axis (in GJ/cap) and GDP per capita on the horizontal axis. The chart shows that China is peaking just under 80 GJ/capita within the next few years, levels similar to the historical North American peak. Although Europe peaked lower, at 40 GJ/capita, demand has been significantly falling to 10 to 20 GJ/capita for both North America and Europe. India is also expected to peak soon, but then around 20 GJ/cap and Africa is not expected to significantly exceed 5 GJ/cap. All regions end up below 10 GJ/cap by the end of the century.

Return to page 45

Electricity mix in China from 2005 to 2040 (History and **Archipelagos**) (Left)

Area chart on electricity demand in China, 2005 to 2040, broken down by energy source. The demand grows from a starting point of 2,000 TWh/year to about 12,500 TW/h. Coal is the largest source of electricity throughout the time period, although renewables make up about 60% of the mix at the end of the period.

Return to page 47

Electricity mix in India from 2025 to 2060 in **Archipelagos** (Right)

Area chart on electricity demand in India, 2025 to 2060, broken down by energy source. The demand grows from a starting point of 2,000 TWh/year to about 12,500 TW/h. While coal is the most important source of electricity today, its role reduces to approximately 15% at the end of the period.

Return to page 47

Global low-carbon fuel production in the mid-2020s, Mboe/d

A Sankey chart showing energy flows for hydrogen and renewable liquid hydrocarbons. On the left, it shows the inputs for making these fuels. On the right, it shows where those fuels are used. This chart is for 2024. It shows one type of input, which is farm crops. The total input of farm crops is 6.7 Mboe/d. Of that, roughly 60% is lost in conversion, and 2.6 Mboe/d is left as final liquid fuel – of which 1.7 Mboe/d is used to fuel cars, 0.8 Mboe/d to fuel trucks and 0.1 Mboe/d for aviation.

Return to page 49

Global low-carbon fuel production in 2060 in **Archipelagos**, Mboe/d

A Sankey chart showing energy flows for hydrogen and renewable liquid hydrocarbons. On the left, it shows the inputs for making these fuels. On the right, it shows where those fuels are used. This chart is for 2060 in the **Archipelagos** scenario.

The main final energy products are 4.5 Mboe/d of hydrogen and 6.2 Mboe/d of liquid fuels. The hydrogen is made using about 50% electricity and 50% fossil fuels. The liquid fuels required 15.6 Mboe/d of farm crops.

Hydrogen is predominantly used in industry. Liquid fuels are predominantly used in aviation, marine and trucks.

Return to page 50

Global low-carbon fuel production in 2060 in **Surge**, Mboe/d

A Sankey chart showing energy flows for hydrogen and renewable liquid hydrocarbons. On the left, it shows the inputs for making these fuels. On the right, it shows where those fuels are used. This chart is for 2060 in the **Surge** scenario. The main final energy products are 8.1 Mboe/d of hydrogen and 8.9 Mboe/d of liquid fuels.

The hydrogen is made using 80% nuclear and other types of electricity, and 20% fossil fuels, mostly with carbon capture and storage.

The liquid fuels required 17 Mboe/d of farm crops and 2 Mboe/d of hydrogen for fuel synthesis. Hydrogen is used in industry. Liquid fuels are primarily used in aviation.

Return to page 51

Global low-carbon fuel production in 2060 in **Horizon**, Mboe/d

A Sankey chart showing energy flows for hydrogen and renewable liquid hydrocarbons. On the left, it shows the inputs for making these fuels. On the right, it shows where those fuels are used. This chart is for 2060 in the **Horizon** scenario.

The main final energy products are 24.5 Mboe/d of hydrogen and 11.9 Mboe/d of liquid fuels. The hydrogen is made almost exclusively from nuclear power and other types of electricity as inputs. The liquid fuels required 22.1 Mboe/d of farm crops and 2.7 Mboe/d of hydrogen for fuel synthesis. Hydrogen is predominantly used in industry, trucks and marine. Liquid fuels are predominantly used in aviation and chemical production.

Return to page 52

Supply of electricity in a 35 to 40° north location with reliable solar conditions, illustrating the dependence on interconnections, storage, dispatchable supply (e.g. gas turbine) and wind for a largely solar photovoltaic powered grid

Sankey diagram describing energy flows in a largely decarbonized electricity grid in a stylised country at about 35 to 40 degrees latitude. Inflows are roughly 60% solar, 20% wind, 20% from storage, 10% imports and 10% dispatachable sources. Outflows are about 85% end-users and 15% exports.

Key feature is that out of the 100% solar and wind generated, 10% is curtailed, 10% is used to charge batteries, and 80% is used directly. Battery cycle efficiency is 80 to 90%.

Return to page 54

Global solar photovoltaic panel production and net installations in the three scenarios (Left)

Chart showing solar photovoltaic capacity additions with GW/y on the vertical axis. Dashed lines are used for gross additions (that is, including replacements) and solid lines for net additions. Both types are around 500 GW today. Net additions peak around 1,500 GW/y (**Horizon**, 2045), 1,200 GW/y (**Surge**, 2040) and 900 GW/y (**Archipelagos**, 2050). Net additions then slowly decline to around 400 GW/y in 2100. Gross additions rise gradually and converge to around 3,000 GW/y (**Surge** and **Horizon**) and 2,000 GW/y (**Archipelagos**) in 2100.

Return to page 55

The growing role of non-fossil electricity generation in key countries in **Archipelagos** (Right)

This chart shows the share of electricity generation that is not from fossil, for the period 2025 to 2075, in the **Archipelagos** scenario, for Nigeria, Germany, India, China and USA. Germany and China both reach 100% by the end of the period, starting from 60% and 40% today, respectively. USA starts from 40% and grows to 90%. Nigeria and India start from 30% and converge to 80%.

Return to page 55

Electrification of passenger cars in the three scenarios (Left)

A line chart showing the electrification rate of passenger cars. The first few percentage points of electrification have emerged in history. **Archipelagos** grows to 60% in 2060, **Surge** just above 90% and **Horizon** reaches effectively 100% by 2055.

Return to page 57

Electrification of road freight vehicles in the three scenarios (Right)

A line chart showing the electrification rate of road freight vehicles. Currently, electrification is at 0%. The chart shows progress from today, with **Horizon** at 90% in 2060, **Surge** 80% and **Archipelagos** just under 70%.

Return to page 57

Electrification in key sectors and regions – **Archipelagos** (Left)

Bar chart showing progress in electrification for road transport, industry and residential, broken down by region (China, USA and EU, Africa) and time period (2025, 2040, 2070, 2100). Electrification of the road transport sector is fastest (compared to industry and residential), with China leading the way (then USA+EU, then Africa). In Industry, Chinese electrification grows from 40% today to 60% in 2100; Africa grows from 30% to 60%. In residential, electrification will reach 60 to 80% end-of-century, but China, USA and EU have a head start at 40%, while Africa starts from 10% today.

Return to page 58

Electrification in key sectors and regions – **Surge** (Right)

Bar chart showing progress in electrification for road transport, industry and residential, broken down by region (China, USA and EU, Africa) and time period (2025, 2040, 2070, 2100). Electrification of the road transport sector is fastest (compared to industry and residential), with China leading the way (then USA+EU, then Africa). In Industry, Chinese electrification grows from 40% today to 75% in 2100; Africa grows from 30% to 65%. In residential, electrification will reach 80 to 95% end-of-century, but China, USA and EU have a head start at 40%, while Africa starts from 10% today.

Return to page 58

Electrification by sector and region in 2025

Bubble chart on electrification in 2025. For six regions on the vertical axis (China, OECD, Other Asia, India, Latin America + Middle East + Eurasia, Africa), it shows the electrification of industry, buildings, transport, and the grand average, on the horizontal axis. Bubble sizes represent the size of the sector.

Largest bubbles are for all sectors in OECD, and industry in China. Smallest sectors are in Other Asia, India and Africa. Transport electrification is close to 0% for all regions. Chinese industry has electrified over 30%, while the Latin America + Middle East + Eurasia region has only electrified just under 15%.

The other regions are between 20% and 25%. Electrification of buildings shows large variation, of 10% in Africa to 45% in OECD. On average, China has the highest electrification rate just over 30%, and Africa has the lowest rate of around 10%.

Return to page 60

Nuclear power in the three scenarios (Left)

Line chart on nuclear energy by scenario, 2010 to 2060. Since 2010, production has fluctuated around 2,200 TWh/year. In **Surge**, this is constant until 2050, and then grows to 3,000 TWh in 2060. In **Horizon**, continuous growth makes demand reach 4,000 TWh in 2060. In **Archipelagos**, a big nuclear boost makes demand reach 6,000 TWh/year in 2060.

Return to page 62

Nuclear power by region in **Archipelagos** (Right)

An area chart showing a regional demand breakdown for the **Archipelagos** scenario. The regional breakdown shows steady production in Europe and USA, and a lot of growth in China and India from 2040 onwards.

Return to page 62

Progress in the energy transition in **Archipelagos**

Bar chart indicating the progress of the energy transition over time for various sectors in the **Archipelagos** scenario. The bar changes colour over time: red is used for "no progress" and green for "deployment underway", with orange a middle category and blue indicating that the transition has been effectively completed. The sectors non-energy use, aviation and marine go from red to orange around mid-century and stay orange. Industrial sectors go to orange within the next 15 years, to green around 2050 and blue after 2080. Cars, buildings and the power sector are already orange, go to green around 2045 and go blue after 2060.

Return to page 63

Global anthropogenic CO_2 emissions in the three scenarios

Line chart of total anthropogenic CO_2 emissions for the three scenarios. Emissions have been rising from 30 Gt/y in 2000 to 43 Gt/y today. **Horizon** emissions decline from today, pass zero emissions in 2050 and reaching −15Gt/y in 2100. Emissions in **Archipelagos** and **Surge** peak at 44 Gt/y in 2027. **Surge** reaches net zero around 2080 and −7 Gt/y in 2100. **Archipelagos** is down to 10 Gt/y in 2100.

Return to page 64

Global sources and sinks of anthropogenic carbon (as CO_2) in 2025

A diagram describing the flows of anthropogenic CO_2 in 2025. Four flow types are visible, adding up to a total of 43.6 Gt of CO_2. Land-use change is 3.8 Gt. Industrial process emissions is 1.9 Gt. Fossil CO_2 extracted is 40.8 Gt, of which 50 Mt is stored through CCS and an additional 2.9 Gt is not emitted but used for chemicals. There is 4.2 Gt CO_2 from bioenergy use – 1 Mt of which is stored through BECCS, and the remainder being re-absorbed by crops, making it a carbon-neutral source of energy.

Return to page 66

Global sources and sinks of anthropogenic carbon (as CO_2) in **Surge**

A diagram describing the flows of anthropogenic CO_2 in the **Surge** scenario in 2060. 21.7 Gt of carbon dioxide from fossil fuels is extracted, but only 11.4 of that is emitted. 4.2 Gt is stored in chemicals or absorbed through a 2.3 Gt DACCS and 0.7 Gt CCS industry. Land-use change emissions are now 5 Gt negative, absorbing part of the remaining fossil and industrial process emissions. Negative-emissions BECCS reaches 0.2 Gt, and 0.3 Gt of biogenic CO_2 is stored in plastics. Overall net CO_2 emissions are 11.4 Gt.

Return to page 68

Global sources and sinks of anthropogenic carbon (as CO_2) in **Horizon**

A diagram describing the flows of anthropogenic CO_2 in the **Horizon** scenario in 2060. Only 9.5 Gt of fossil CO_2 is extracted, and this is captured either through 2.8 Gt of chemicals, 4.3 Gt of CCS, or through the bioenergy industry. Photosynthesis absorbs 8.7 Gt of atmospheric CO_2 for the bioenergy industry, which either comes from 5.5 Gt of biogenic CO_2 emissions or from 3.2 Gt of fossil emissions. 2.3 Gt of bioenergy emissions are stored through negative-emissions BECCS.

The combination of industrial process CO_2, fossil CO_2, biogenic CO_2 and various types of CCS add up to 1.3 Gt of net removals. Land-use change is negative 6.6 Gt. Total emissions are 7.9 Gt negative.

Return to page 69

Global sources and sinks of anthropogenic carbon (as CO_2) in **Archipelagos**

A diagram describing the flows of anthropogenic CO_2 in the Archipelagos scenario in 2100. Still 19.9 Gt of fossil CO_2 is extracted, and 9.9 of that is emitted. The rest is stored in chemicals or absorbed through a 1.6 Gt CCS industry. Land-use change emissions are now 3.2 Gt negative, absorbing part of the fossil and industrial process emissions. Negative-emissions BECCS reaches 0.9 Gt, and 1.5 Gt of biogenic CO_2 is stored in plastics. Overall net emissions are 9.9 Gt.

Return to page 70

Carbon captured and stored in industry and power generation in the three scenarios to 2100 (Left)

A line chart for history, **Surge**, **Horizon** and **Archipelagos** showing the storage of concentrated CO_2 streams. shows capture and storage of CO_2 emissions (CCS) from industry and electricity generation. **Horizon** CCS peaks just under 7 Gt/y in 2050 and then decreases to 4 Gt/y in 2100. CCS in **Archipelagos** and **Surge** rises much slower. **Surge** reaches a plateau in CCS just under 1 Gt/y between 2055 and 2075, and then slowly declines to 0.5 Gt/y in 2100. In **Archipelagos**, CCS is 1 Gt/y in 2050 and keeps slowly rising and is 2.5 Gt/y in 2100.

Return to page 71

Direct air carbon capture and storage in the three scenarios to 2100 (Middle)

A line chart for history, **Surge**, **Horizon** and **Archipelagos** showing capture and storage of atmospheric CO_2. This industry takes off around 2040 in **Horizon** and **Surge** and rises fast to 6 Gt/y in 2100. In **Archipelagos**, DACCS is virtually absent.

Return to page 71

Carbon stored in society as chemical products from bio and synthetic feedstocks (Right)

A line chart for history, **Surge**, **Horizon** and **Archipelagos**. This chart shows the storage of CO_2 in products, obtained by using non-fossil feedstocks in the chemicals industry. In all three scenarios, there is an exponential increase departing from effectively zero today. **Horizon** reaches 3.2 Gt/y in 2100, **Surge** 2.8 Gt/y and **Archipelagos** 1.5 Gt/y.

Return to page 71

Anthropogenic CO_2 emissions in **Archipelagos** to 2100 (Left)

An area chart of anthropogenic CO_2 emissions broken down by point of emission (land-use change, various energy-related sectors, and CCS). Overall emissions peak in 2030 and reach 10 Gt/y in 2100 – 16 Gt/y in total and −6 Gt/y from CCS and land-use change emissions. Electricity remains the dominant source of emissions. Industry is slowest to reduce, still positive in 2100, building is the fastest decarbonising sector.

Return to page 72

Anthropogenic CO_2 emissions in **Surge** to 2100 (Middle)

An area chart of anthropogenic CO_2 emissions broken down by point of emission (land-use change, various energy-related sectors, and CCS). Overall emissions peak in 2030, become net zero in 2080 and reach −8 Gt/y in 2100 –2 Gt/y from energy and −10 Gt/y from CCS and land-use change emissions. Electricity remains the dominant source of emissions and dominates the total by 2100. Industry is slowest to reduce, reaching net zero only in 2100.

Return to page 72

Anthropogenic CO_2 emissions in **Horizon** to 2100 (Right)

An area chart of anthropogenic CO_2 emissions broken down by point of emission (land-use change, various energy-related sectors, and CCS). Overall emissions peak in 2030, reach net zero in 2050, and −14 Gt/y in 2100 – all from CCS and land-use change emissions.

Return to page 72

Land-use change emissions in **Archipelagos** by type (Left)

An area chart of land-use CO_2 emissions broken down by ecosystem: forests, agriculture, grasslands, wetlands and coastal ecosystems. Today, emissions are positive 4 Gt/y, driven by forests (deforestation), and tiny wedges from grasslands, wetlands and coastal ecosystems.

Forests go from positive to negative in the 2050s and reach −2 Gt/y in 2100. Agriculture decreases from 0 today to −1 Gt/y in 2100. As wetlands and coastal ecosystems go from slightly positive to zero in 2100, grasslands reach a small −0.5 Gt/y in 2100.

Return to page 74

Land-use change emissions in **Surge** by type (Middle)

An area chart of land-use CO_2 emissions broken down by ecosystem: forests, agriculture, grasslands, wetlands and coastal ecosystems. Today, emissions are positive 4 Gt/y, driven by forests (deforestation), and tiny wedges from grasslands, wetlands and coastal ecosystems.

Forests go from positive to negative in the 2040s and reach −2.5 Gt/y in the 2060s and bounce back to −0.5 Gt/y in 2100. Agriculture decreases from 0 today to −1 Gt/y in the 2050s and −2 Gt/y in 2070 to 2100. Wetlands remain a small wedge of positive emissions throughout, and grasslands are a small wedge of negative emissions.

Return to page 74

Land-use change emissions in **Horizon** by type (Right)

An area chart of land-use CO_2 emissions broken down by ecosystem: forests, agriculture, grasslands, wetlands and coastal ecosystems. Today, emissions are positive 4 Gt/y, driven by forests (deforestation), and tiny wedges from grasslands, wetlands and coastal ecosystems.

Forests go from positive to negative in the 2030s and reach −3 Gt/y in the 2050s, and −1 Gt/y in 2100. Agriculture decreases from 0 today to −1 Gt/y in the 2040s and −2 Gt/y in 2060 to 2100. No positive emissions remain as of 2050. Grasslands contribute up to −0.5 Gt/y of emissions mid-century.

Return to page 74

Global average surface temperature change in the three scenarios

A line chart showing the average surface temperature increase between 1850 and 2100. It contains 5 series: history, modelled history by the Massachusetts Institute of Technology, and the three scenarios.

The modelled history tracks the history well on average but is less volatile. The baseline is 1850 to 1900, where the temperature increases fluctuate around 0 degrees Celsius, rising to about 1.3 (modelled history) or 1.5 (history, a clear outlier) degrees Celsius in 2024. In all three scenarios, the increase rises at first. In **Horizon**, it rises to about 1.7 degrees Celsius in 2055, then decreases to 1.2 degrees Celsius in 2100. In **Archipelagos**, the temperature rises to 2.5 degrees Celsius in 2100. In **Surge**, it peaks at 2.1 degrees Celsius in the 2080s then drops slightly to 2 degrees in 2100.

Return to page 75

Global sources and sinks of anthropogenic carbon (as CO_2) in **Surge**

A diagram describing the flows of anthropogenic CO_2 in **Surge** in 2100. Only 6.5 Gt of fossil CO_2 are extracted, 3.2 Gt of which are stored in chemicals, and the remainder captured by direct air carbon capture and storage (DACCS). The entire direct air capture industry extracts 8 Gt, also capturing CO_2 from industrial processes and synthetic fuels, in addition to the fossil CO_2.

Return to page 78

Net energy CO_2 emissions in the EU to 2050 in the three scenarios

A line chart showing net energy CO_2 emissions in the EU from 2020 to 2050, with a marker at 2040. Emissions today are around 2,500 Mt/y, going down to 2,000 Mt/y (**Archipelagos**), 1,800 Mt/y (**Surge**) or 1,100 Mt/y (**Horizon**) in 2040. In 2050, emissions in **Surge** and **Archipelagos** are still around 1,500 Mt/y and **Horizon** is just above zero.

Return to page 79

Transport sector trends in three scenarios to 2065

General overview

The infographic presents three scenario lines—**Horizon**, **Surge**, and **Archipelagos**—showing how the global transport sector (cars, trucks, shipping, aviation) transitions from 2025 to 2065. Each line traces the timing and extent of electrification, hydrogen, biofuels, and oil use in transport, highlighting key milestones and differences.

Horizon Scenario line

Pathway: The **Horizon** line shows the fastest and deepest decarbonisation of transport, designed for net zero emissions by 2050. A hydrogen and electric transport system emerges, with some power-to-liquids.

Key milestones:

- By 2035: Road freight oil demand peaks at 17.1 Mbbl/day
- By 2045: Hydrogen in trucks reaches 1 Mboe/day. First flight of a H_2 plane (China)
- By 2055: Fuel synthesis from H_2 and CO_2 for aviation is 500 kbbl/day. Hydrogen has become the fuel of choice for new ships. Bio-SAF is 50% of aviation demand. Global rail use doubles instead of flying. The end of liquid fuels in cars—electric vehicles prevail globally
- By 2065: Oil is 10% of transport energy demand

Visual: The **Horizon** line, indicates the greatest reduction in oil use and the highest adoption of electric and hydrogen transport.

Surge Scenario line

Pathway: The **Surge** line shows a rapid transition. An electric transport system emerges with power-to-liquids for aviation.

Key Milestones:

- In 2025: Oil (and some gas) still makes up 95% of transport energy demand
- Around 2035: Half of all journeys are battery electric
- By 2045: Battery electric dominate truck sales in some markets. Cellulosic biofuels reach 1 million b/d
- By 2055: Shipping starts the journey to nuclear. 2,500 commuter electric planes operating globally
- By 2065: Fuel synthesis from hydrogen and CO_2 for aviation passes 500 kbbl/day barrels per day; Oil has fallen to about a third of total transport energy demand. The end is near for liquid fuels in cars – EVs prevail

Visual: The **Surge** line sits between **Horizon** and **Archipelagos** by 2065.

Archipelagos Scenario line

Pathway: The **Archipelagos** line shows the most fragmented transition. Transport evolves to a mixed-fuel system, retaining a strong dependence on oil.

Key milestones:

- By 2035: 1st-generation biofuel production grows strongly; Electric car growth accelerates in the 2030s in the USA (rejoining the global trend)
- By 2045: 10% of global shipping is fuelled by LNG; Road freight oil demand peaks at 19.5 million barrels per day
- By 2055: Cellulosic biofuels at 1 million barrels per day;
- Hydrogen in trucks reaches 1 million barrels of oil equivalent per day; hydrogen becomes the fuel of choice for new ships
- By 2065: Bio-SAF is 15% of aviation demand. 55% of energy demand for cars is electric, but delivers 85% of journeys. Over 50% of energy needs for transport still come from oil

Visual: The **Archipelagos** line is the highest by 2065, indicating the slowest reduction in oil use and the most persistent fossil fuel reliance.

Acronyms used:

- EV: Electric Vehicle
- Bio-SAF: Bio-based Sustainable Aviation Fuel
- LNG: Liquefied Natural Gas
- H_2: Hydrogen
- CO_2: Carbon Dioxide
- bbl/d: Barrels per day
- Mboe/d: Million barrels of oil equivalent per day

Return to page 39

Security choices timeline in the 2026 Energy Security Scenarios

General overview

The infographic presents three distinct scenario lines—**Horizon**, **Surge**, and **Archipelagos**—each representing a possible pathway for the global energy transition and decarbonisation from 2025 to 2065. Each line traces a different trajectory for the reduction of fossil fuel use and the adoption of low-carbon technologies. All three scenarios start with primary energy being 78% fossil fuel split between oil, coal and gas.

Horizon Scenario line

Trajectory: The **Horizon** line represents the normative scenario, created to achieve net zero emissions by 2050.

Key features:

- By 2065, primary energy is 15% fossil fuel
- Net zero CO_2 emissions globally by 2050
- Global coal use halved vs 2025 between 2035 and 2045
- 15 TW solar PV globally by 2040
- Land-use change is CO_2 balanced by 2035 and remains so
- All cars in China are electric in the late 2040s, and in the USA by 2055
- First generation biofuel production in decline before 2030
- CCS (carbon capture and storage) passes 1 Gt stored CO_2 per year by 2035
- Direct air capture (DAC) scales up to 1 Gt CO_2 per year by 2055
- Fuel synthesis from hydrogen and CO_2 passes 2.5 million barrels per day by 2065

Surge Scenario line

Trajectory: The **Surge** line represents a technology enabled transition.

Key features:

- By 2065, primary energy is 32% fossil fuel
- Annual solar module production exceeds 1TW in the 2030s
- First generation biofuel production in decline before 2035
- CCS (carbon capture and storage) passes 1 Gt stored CO_2 per year by 2045
- DACCS (direct air capture and (geological) storage) passes 100 Mt CO_2 per year in the 2030s
- Global coal use is halved compared to 2025 by 2045
- Annual solar module production exceeds 1 TW by 2035
- Peak natural gas production between 2035 and 2045
- Global GDP doubles compared to 2025 by 2045
- All cars in China are electric by 2055
- DAC has scaled to 3 Gt CO_2 per year by 2065
- Fuel synthesis from hydrogen and CO_2 passes 1.5 million barrels per day by 2055
- Land-use change is CO_2 balanced from 2040 onwards
- Global coal use has halved vs 2025 between 2045 and 2055
- The **Surge** line sits between **Horizon** and **Archipelagos** by 2065

Archipelagos Scenario line

Trajectory: The **Archipelagos** line represents a more fragmented transition.

Key features:

- By 2065, primary energy is 41% fossil fuel
- 1st-generation biofuel production grows strongly by 2035
- Annual solar module production exceeds 1 TW in 2040
- Coal-fired power generation ramps up in Africa
- India's industrial coal use nearly doubles compared to 2025 by 2040
- Global electricity growth accelerates, but fossil fuels remain significant
- Nascent DAC industry collapses as funding dries up in the 2030s
- Nuclear is the new choice, backed by new technologies in the 2030s
- Land-use change becomes CO_2 balanced, but later than in other scenarios

- All cars are electric in China by 2065
- Global coal use has halved vs 2025 by 2065
- The **Archipelagos** line is visually the highest by 2065

Key acronyms and units explained

- CCS: Carbon Capture and (Geological) Storage – technology to capture and store CO_2 emissions underground
- DAC: Direct Air Capture – technology that removes CO_2 directly from the atmosphere
- DACCS: Direct Air Capture and (Geological) Storage – combining DAC with underground storage of captured CO_2
- Gt: Gigatonne – one billion tonnes
- Mt: Million tonnes
- TW: Terawatt – one trillion watts, a unit of power
- bbl/d: Barrels per day – a measure of liquid fuel production
- GDP: Gross Domestic Product – the total value of goods and services produced globally
- PV: Photovoltaic – technology for converting sunlight into electricity, typically used in solar panels
- H_2: Hydrogen – used as a fuel and in fuel synthesis
- CO_2: Carbon dioxide – a greenhouse gas targeted for reduction in all scenarios

Visual structure:

Each scenario line is colour-coded and clearly labelled: **Horizon**, **Surge**, **Archipelagos**. The lines track the percentage of primary energy from fossil fuels over time, with key milestones annotated along each line. Acronyms and units are explained at the bottom of the infographic.

Return to page 82

Legal disclaimer

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