Shell, Sky Scenarios
(2018)

SHELL SCENARIOS

Sky

MEETING THE GOALS OF THE PARIS AGREEMENT

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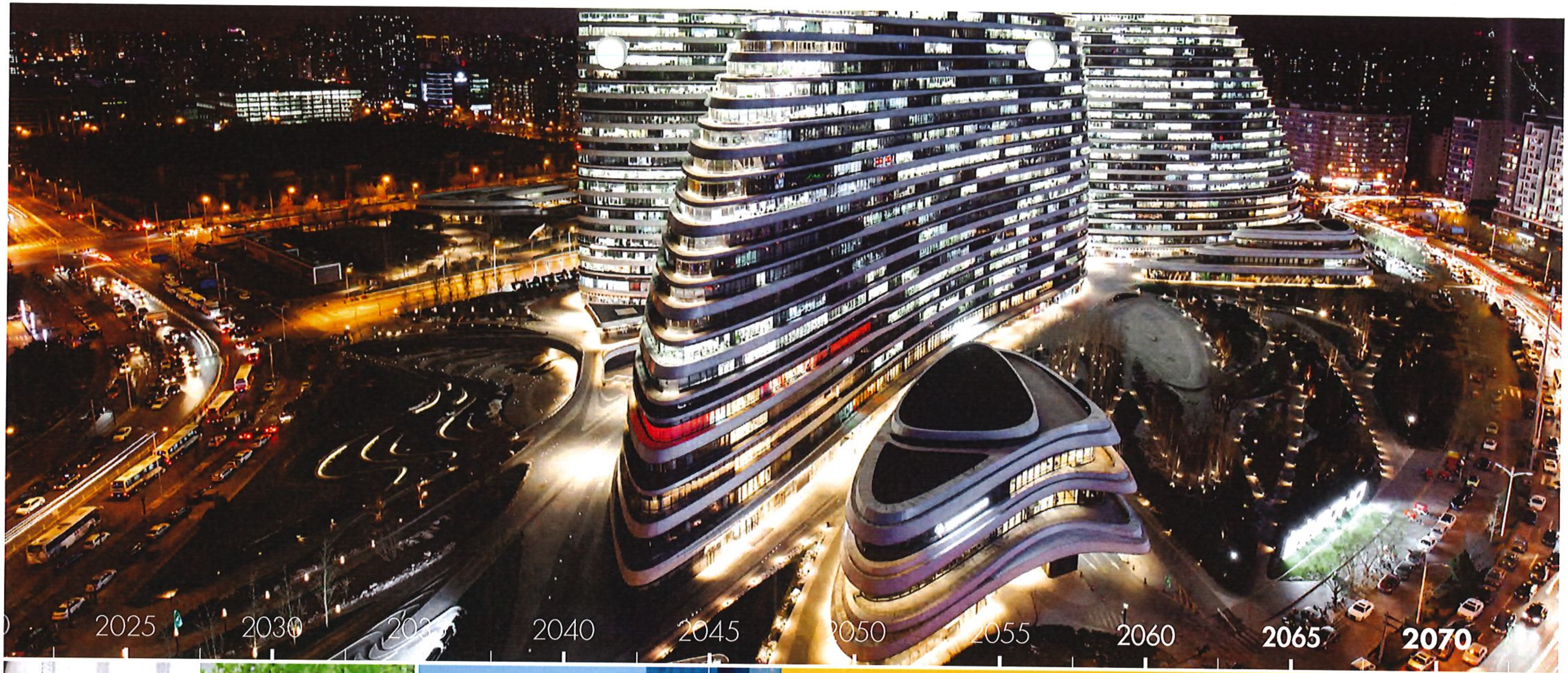


CHAPTER 1

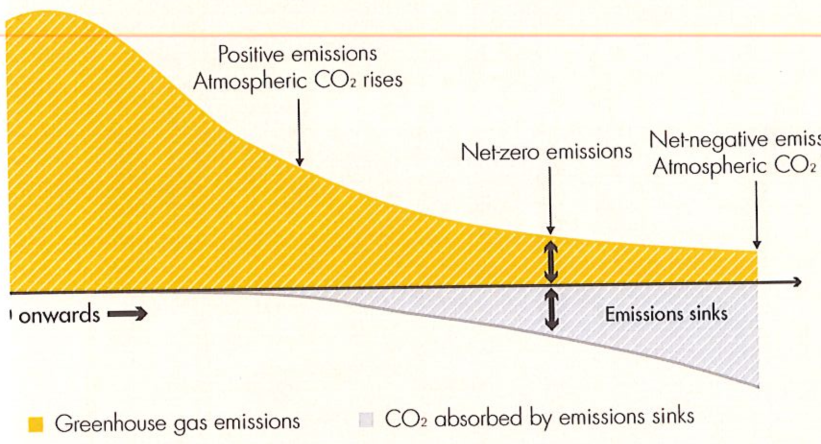
WELL BELOW 2°C: THE PARIS AMBITION

/ELL BELOW 2°C: PARIS AMBITION

ember 2015 Paris Agreement on climate change is a remarkable document. 5 pages it offers a pragmatic blueprint for resolving one of the toughest ciety faces. The aim of the Agreement is to hold the increase in the global temperature to well below 2°C above pre-industrial levels and to pursue limit the temperature increase to 1.5°C above pre-industrial levels.

of this goal, the Agreement calls ance between anthropogenic by sources and removals by sinks ouse gases in the second half of y." This emphasis on "a balance" is also referred to as "net-zero – is a critical development t recognises that surface temperature s directly related to the cumulative total of carbon dioxide (CO_2) emitted to the atmosphere. If total cumulative emissions overshoot a threshold, it may be necessary to go beyond net-zero emissions to achieve "net-negative" emissions, where more CO_2 is extracted from the atmosphere than continues to be released. In such a case, the global average surface temperature can fall.

IS AGREEMENT CALLS FOR AN EARLY PEAK IN EMISSIONS, THEN A DECLINE TO O EMISSIONS DURING THE SECOND HALF OF THE CENTURY



Shell schematic

Implementation of the Agreement is now under way, with most national governments responding quickly to the call for ratification and the delivery of their first national contributions. New coalitions have also formed around government-led carbon pricing and coal phase-out, but the task is only just beginning. Success is hoped for but is not a given.

The context for a pathway forward

Our 2016 publication, **A Better Life with a Healthy Planet**, recognised the desire of a large part of the world's population to have a better life – which means that energy demand will rise in relatively poor countries even as it may fall in relatively rich ones. Within this context of a better life for all, we highlighted the key changes in each main sector of the economy – industry, transport, buildings, and power generation – that were required to deliver a world of net-zero CO_2 emissions from energy.

While we know, in general, what key conditions and energy system changes are required for net-zero emissions, it would be helpful to have a pathway to achieving that goal by 2070 – a timeframe compatible with holding the increase in the global average temperature to well below 2°C. Because the future is unpredictable, especially when it comes to complex global societal systems over an extended period involving technology, government policy, and consumer behaviour, the best approach to exploring this pathway is to use scenarios.

Energy scenarios for the pathways forward

Scenarios are alternative stories of the future that help us learn useful lessons the present. They are not policy prop – they do not argue for what should l done. Nor are they forecasts – what done, by society, industry, or anyone They offer descriptions of what could – plausible pathways for the future ar insights along the way.

For over two decades Shell scenario has incorporated the issue of climate with different scenarios showing vary levels of success in addressing this cri global issue. But with typical forward timeframes of 25 years in the 1990s reaching to 50 years in the early 20(the full resolution of the climate issue complete transformation of the global energy system was never clearly visit

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In Sky, the rate of decline in global emissions after 2035 exceeds the rate of growth we've seen for this century – an eye-watering achievement

sformation has always been, and
a journey measured in generations,
ending out to the end of this century.

Shell published its **New Lens**
s comprising two outlooks named
ns and **Oceans**. For the first time, the
s featured energy-system modelling
to 2100, which allowed long-
sitions to be seen in their entirety.
xploring very different socio-political
the scenarios show that persistent
espread application of CO_2-targeted
ameworks, including large-scale
to renewable energy and extensive
CS (carbon capture and storage),
ad to net-zero emissions in the energy
However, in the two scenarios, that
is achieved around the end of the
century, which means that they fall short of the temperature goal of the Paris Agreement.

Looking beyond Mountains and Oceans

Drawing lessons from that previous work and additional analyses, we now present a possible pathway for decarbonising the global economy with the societal aim of achieving net-zero emissions from energy use by 2070 – a scenario called "**Sky**."

Sky recognises that a simple extension of current efforts, whether efficiency mandates, modest carbon taxes, or renewable energy supports, is insufficient for the scale of change required. The relevant transformations in the energy and natural systems require concurrent climate policy action and the deployment of

**ucing Sky – an ambitious scenario to hold the increase in
obal average temperature to well below 2°C.**

**quires a complex combination of mutually reinforcing drivers
rapidly accelerated by society, markets, and governments.**

ow to 2070 –

ange in consumer mindset means that people preferentially choose low-carbon,
efficiency options to meet their energy service needs.

p-change in the efficiency of energy use leads to gains above historical trends.

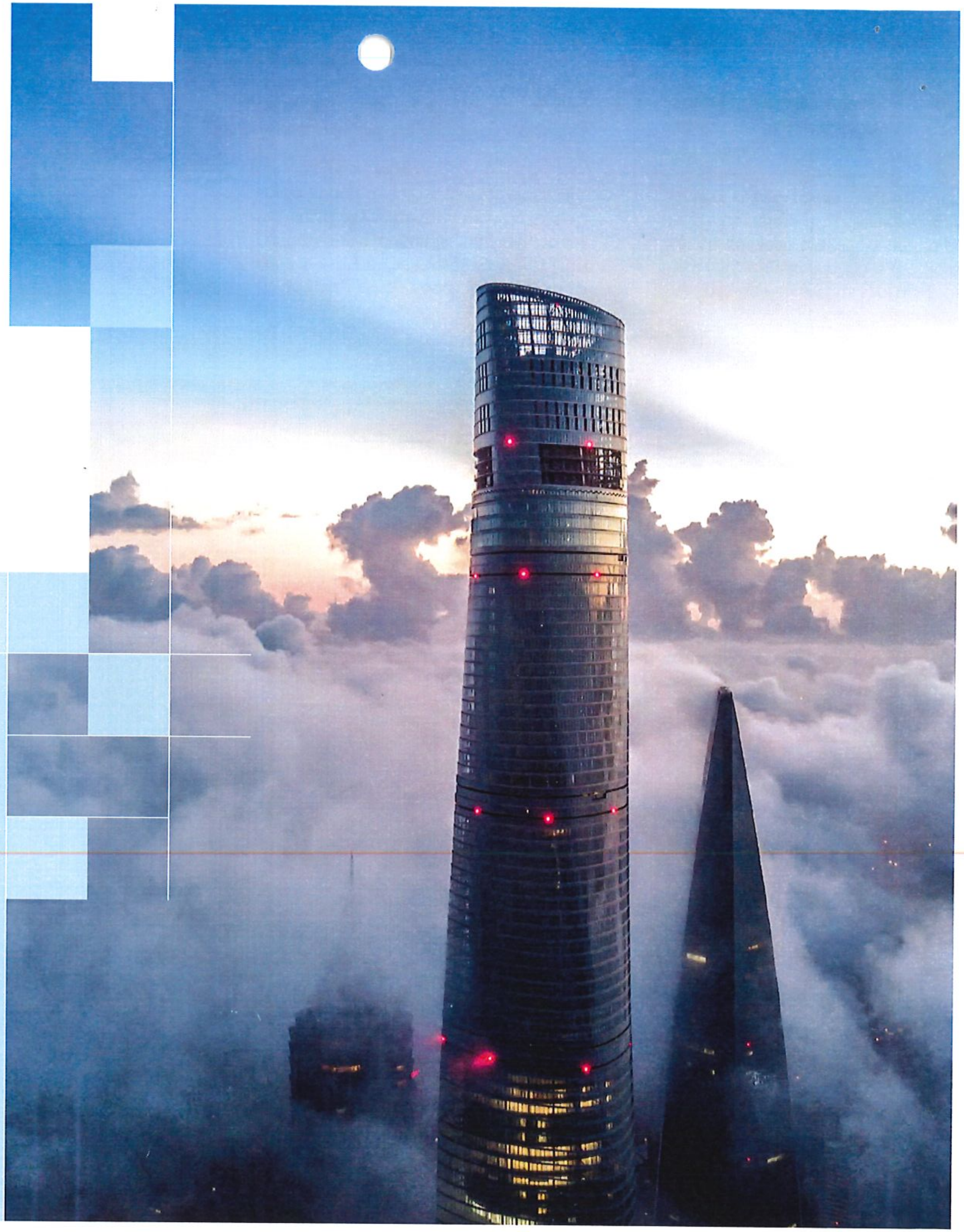
on-pricing mechanisms are adopted by governments globally over the 2020s,
ng to a meaningful cost of CO_2 embedded within consumer goods and services.

ate of electrification of final energy more than triples, with global electricity generation
hing a level nearly five times today's level.

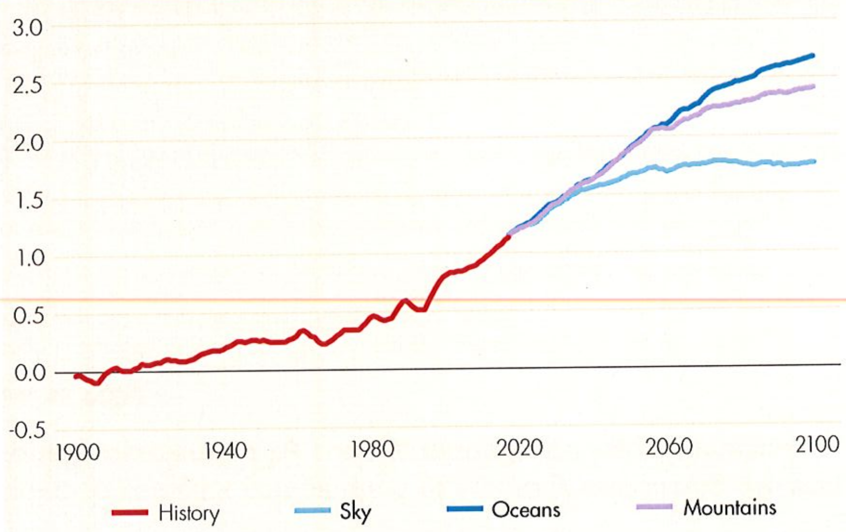
energy sources grow up to fifty-fold, with primary energy from renewables eclipsing
fuels in the 2050s.

10,000 large carbon capture and storage facilities are built, compared to fewer than
operation in 2020.

zero deforestation is achieved. In addition, an area the size of Brazil being reforested
the possibility of limiting warming to 1.5°C, the ultimate ambition of the Paris Agreement.



:CENARIOS COMPARED – GLOBAL AVERAGE SURFACE TEMPERATURE RISE



'he MIT Joint Program on the Science and Policy of Global Change modelled the climate impacts
in comparison with those of **Mountains** and **Oceans**. All series are five-year moving averages.

: MIT

: new technologies at mass scale
overnment policy environments that
ncentivise investment and innovation.
e factor will suffice to achieve the
. Instead, **Sky** relies on a complex
tion of mutually reinforcing drivers
pidly accelerated by society, markets,
ernments.

climate challenges arise from the
umulation of greenhouse gases in the
ere, there are an infinite number of
pathways for the annual reduction of
; over the coming decades that can
in outcome consistent with the Paris
. Of course, some of these pathways
i more plausible than others – you
expect that the global economy
completely re-wired overnight.

Sky begins with the current structure of economic sectors and government policies and the capacity for change that exists now. It then assumes very aggressive, but plausible, capacity-building and ratcheting of policy commitments through the first two five-year review cycles embodied in the Paris agreement. Beyond that time-frame, there are naturally rather greater uncertainties about how policies and technology may be developed and implemented globally. So, the scenario progressively becomes driven simply by the ambitious goal to achieve net-zero emissions by 2070, taking full account of the characteristics of scale, technological substitution, and investment in the various sectors of different national economies. Such a goal-driven scenario is sometimes referred to as "normative."

By adopting an approach grounded in the current reality of the energy system but then combined with a specific long-term goal, we intend **Sky** to be both an ambitious scenario and a realistic tool for practical considerations today.

Additionally, we are publishing extensive quantitative data sets for the **Sky** scenario, so that others can inspect and make more use of this inf[illegible]ation themselves.

The Paris Agreement has sent a signal
the world; climate change is a serious
that governments are determined to ac
By 2070, there is the potential for a ve
different energy system to emerge. It c
system that brings modern energy to a
world without delivering a climate leg
society cannot readily adapt to. That i
essence of the **Sky** scenario.

Link to **quantitative data sets**

CHAPTER 2

CHALLENGES FOR A 21ST CENTURY SCENARIO

:HALLENGES FOR A
· CENTURY SCENARIO

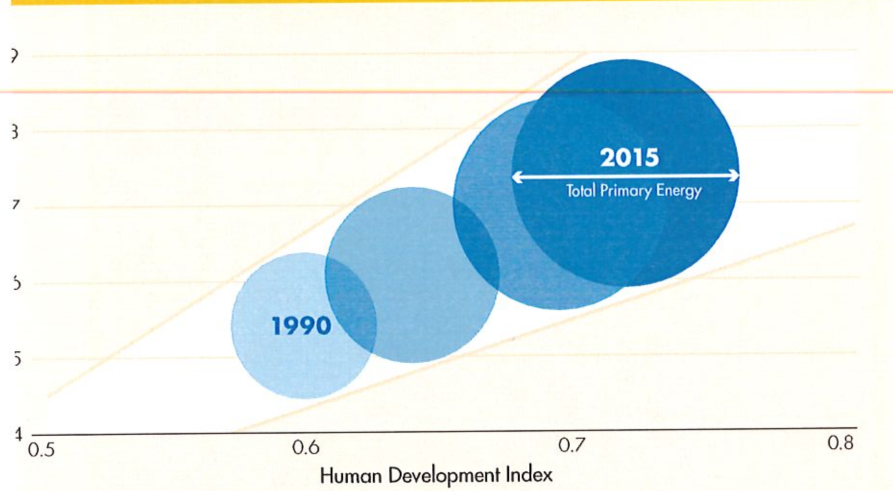
:nge: Energy demand is rising

enables the whole economy to function. It is needed and used here – in homes, factories, shops, schools, personal transport, freight, on, water systems, agriculture, and construction. It is a vital hidden ent in manufacturing and delivering almost all the products and services ı society takes for granted.

the course of the 20th century, ıergy demand increased ten-fold ation more than tripled, economic ınd development surged, extended became commonplace, and a wide new energy services appeared, from ion at the beginning of the century elated services at its end. But in the f the UN Sustainable Development everal billion people are still pursuing life through much-needed access to clean water, sanitation, nutrition, health care, and education. Energy is a key enabler for these basic needs.

On a per capita annual basis, the range of primary energy use today is from 20 gigajoules (GJ) in a country such as Kenya, to about 300 GJ in the US. The global average currently stands at nearly 80 GJ but is expected to rise as near universal access to modern energy services is achieved during this century.

) ENERGY DEMAND RISES WITH POPULATION AND DEVELOPMENT



: Shell analysis, IEA, UN

New energy services will feature in the 21st century as well, from extensive use of artificial environments in which people live and work in comfort to trillions of connected devices within the "internet of things." As an early example, the connections people make through international travel have already doubled in the first two decades of this century (measured in terms of international air travel arrivals). Population growth, much-needed development, new energy services, and the extended use of existing services will all contribute to energy demand growth.

Challenge: Efficiency can have unexpected consequences

Without limiting the availability of enei services, energy demand growth can potentially be slowed through rapid improvement in the efficiency of such s While this will inevitably happen it cai be a double-edged sword. On the on hand, increased efficiency has been c the economic growth engines of the 2 century, with the manufacturing cost ai energy consumption of appliances suc air conditioners falling consistently ove decades. But on the other hand, these costs have also led to increasing uptal by consumers.

"

In 2016, vehicle ownershi North America and Euro varied from 500 to 800 1000 people. China was per 1000 people, with In 42 per 1000, and inevita set to grow.

ıple, the most recent energy service rge efficiency gains is lighting, with idly replacing incandescent, halogen, escent bulbs. But there is now clear : of growth in lighting services as a en in cities where lighting saturation ıumed to have been reached. ıg is being transformed with LEDs, rom street displays to giant billboards.

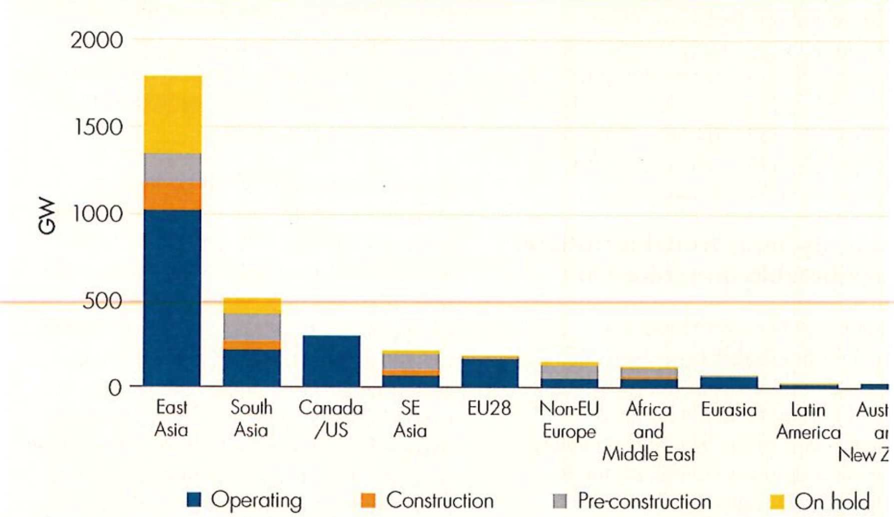
ıge: Coal remains popular

ıe rise of CO_2 in the atmosphere will ıoving away from fossil fuels to other ɔf energy as well as utilising CCS. energy sources will be challenged d fast enough to meet both rapid growth and the need to back out g emitting sources quickly enough. ·d high demand growth can upward pressure on energy ʼhich, in turn, could encourage ːtraction of coal, oil, and gas, ourage the transformation or tion of existing infrastructure.

Although the world is beginning to act, substantive progress towards the Paris goal will be challenging, partly because of coal. As renewables and natural gas increasingly dominate the energy sector in developed countries, bringing down emissions, coal use is increasing in some economies as new generation capacity is required for development. Vietnam is one such economy, with several large coal-fired power stations under construction in 2018.

A stark reality of the early 21st century is the lack of a clear development pathway for an emerging economy that doesn't include coal. Coal is a relatively easy resource to tap into and make use of. It requires little technology to get going but offers a great deal, including electricity, heating, industry,

COAL ELECTRICITY GENERATION CAPACITY



Note: Coal remains popular. New projects outside China could potentially exceed those under constr in the country.

Source: Global Coal Plant Tracker, January 2017, endcoal.org

and, very importantly, smelting to make iron. Although solar PV and wind offer clean, distributed electricity, benefiting households, electricity alone is currently insufficient for rapid urbanisation and industrialisation, including the construction of cities and the manufacture of products such as automobiles and appliances.

Challenge: Some parts of the energy system are "stubborn"

Not all economies will reach net-zero emissions at the same time. The EU or North America may need to consider this as an objective for the 2050s, in part to balance countries that arrive at this point much later in the century. As a progressive country within a progressive region, Sweden has already set its eyes on 2045. But net-zero emissions in almost any industrial economy in the 2(; is a tough ask. The apparent lack of low-carbon solutions for aviation, shipping, cement manufacture, some chemicals processes, smelting, glass manufacture others means that significant sectors of industrial economy won't trend rapidly zero emissions. Even the power sector still need support from conventional th generation in 2050.

Challenge: Some technologies are "stalled"

Some promising technologies are curr stalled, with hydrogen, perhaps, being notable example. Coming into this cer was seen as the future fuel in road trans hydrogen has now been eclipsed by b electric vehicle developments. More rec hydrogen has been proposed as a pc solution for industrial processes requirir intense heat, the metallurgical sector (v coal is the staple), home heating, and transport, where battery storage is sev limited owing to weight.

ɔector where progress has been
an originally anticipated is biofuels
gy, which has the potential to
essential, high-energy density, low-
ootprint fuels for certain transport
ons. Biofuel production could also be
ed as a route to negative emissions,
n the US today, where CCS has
ached to a bio-ethanol plant.

ıge: Systems transformations predictable and take time

varming in line with the Paris
ent means achieving net-zero
s by 2070, just over 50 years
. In energy transition terms, a
is the blink of an eye, and a century
ically see just a handful of major
ations, although not all follow
d pathways.

As the 20th century arrived, an electric car was the preferred choice on American roads, but by 1920 the world was in the middle of the Ford Model T combustion engine era. Four billion cars later, the essential technology remains largely the same, yet with electric mobility emerging again.

Even electricity itself, which continues to transform our world, has not been a fast-paced energy technology. The first electricity grid appeared in New York in September 1882, over 135 years ago. Although the technology has spread globally and appears ubiquitous, it makes up less than 20% of final energy use today; so, 80% of the energy we use now isn't electricity but fossil and bioenergy hydrocarbons. Over the course of the last few decades, electrification of final energy has moved relatively slowly, at around 2%-points per decade – for example, it was about 17% in 2005 and 19% in 2015.

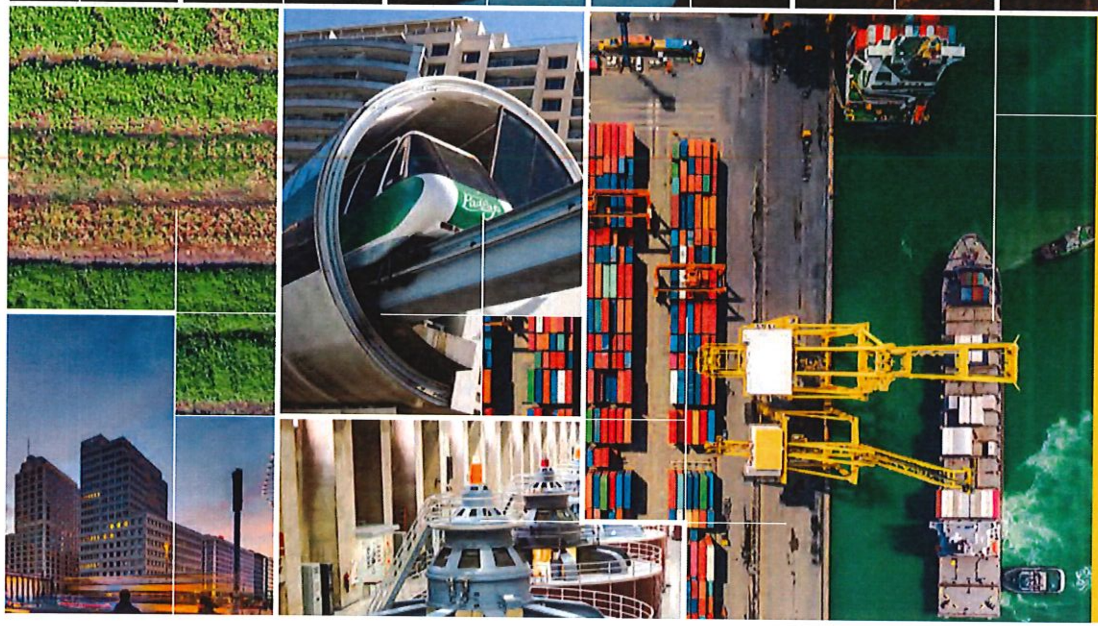
By the 1960s a nuclear power revolution seemed possible, but it had stalled completely by the 1990s. Similarly, in the 1960s, solar PV began to appear in highly specialist applications, but it has taken 50 years to pass 1% of global electricity production.

> **The photovoltaic (PV) effect was discovered in 1839, then eventually deployed on satellites as solar PV from 1962. Four decades later, only two GW of capacity existed globally, but in the following fifteen years capacity increased two-hundred fold.**

One reason systems transformations take time is that the success of one transformation – from horses to the international combustion engine, for example – can impede the progress of the next. A legacy of successful development is the potential for lock-in of the resource on which the current system was built. This potential for lock-in stems from the resistance to stranding the original capital investments and losing the jobs that have been created.

Challenge: Given the time fra 2070, there can be no slippag

Achieving net-zero emissions in just 50
leaves no margin for interruption, stalle
technologies, delayed deployment, pc
indecision, or national back-tracking. I
it requires a rapid acceleration in all a
of an energy transition and particularly
policy frameworks that target emission
Success can be accomplished only thı
broad process that is embraced by so
led by governments, and lightly coord
by organisations including the UNFC
EU, ASEAN, and others.



CHAPTER 3
FROM MOUNTAINS AND OCEANS TO SKY

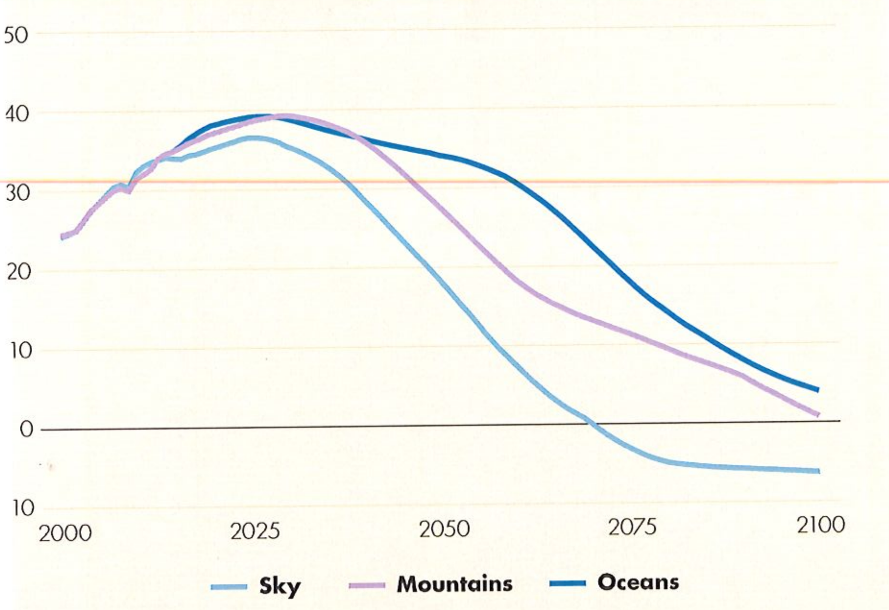
ROM MOUNTAINS
) OCEANS TO SKY

›riginal New Lens Scenarios, we explored two possible ways the 21st could unfold, taking several pressing global trends and issues and using ; "lenses" through which to view the world.

ns and **Oceans** provided a detailed of current socio-political trends and sible trajectories into the future, with ns more government-led with a top- ›proach and **Oceans** more bottom-up arket-driven outcome.

scenario brings further to the surface ging possibility of better multi-lateral ition to tackle climate and air-quality this regard, it combines the most progressive elements of both **Mountains** and **Oceans**. This collaborative approach has been seen in previous real-life incarnations, such as in the Montreal Protocol on ozone-depleting substances, but true long-term international co-operation and a willingness to combine national self-interest with the differing interests of other nations has generally eluded society as a lasting trend. Nevertheless, the Paris Agreement is built on such a model, albeit with a strong element of peer review and challenge.

;CENARIOS COMPARED – WORLD ENERGY-RELATED CO_2 EMISSIONS

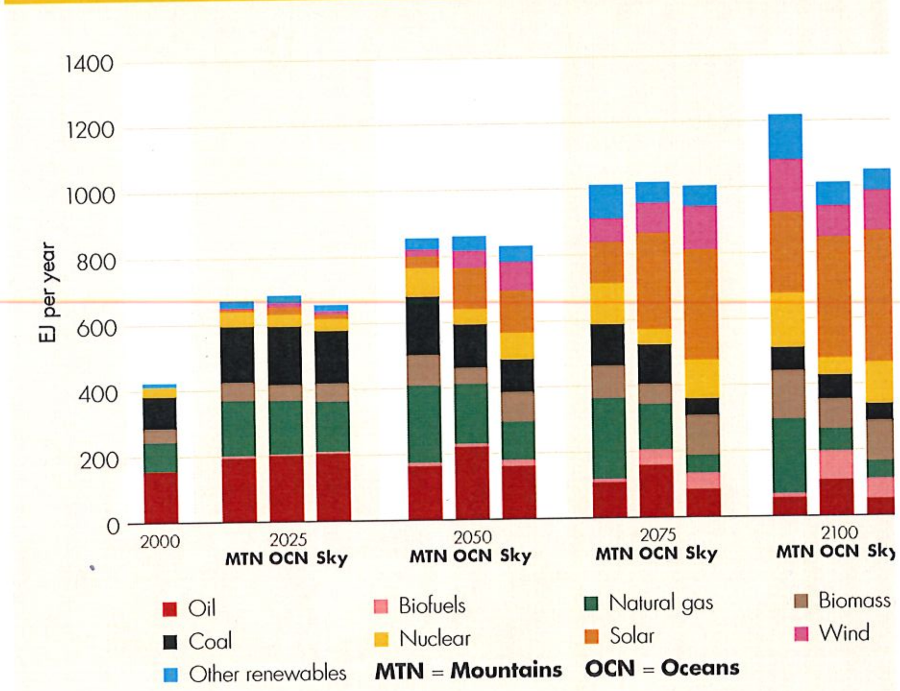


Shell analysis

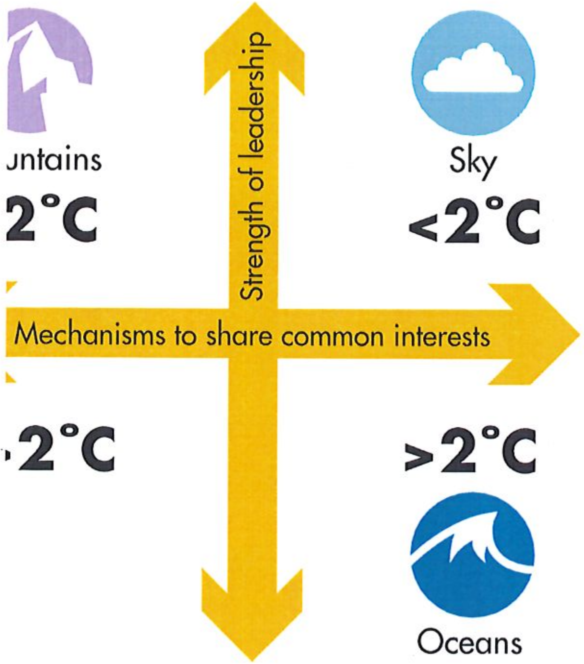
Leadership to create a shared vision was an essential element of the Paris Agreement, as demonstrated through bilateral agreements between several heads of government in the two years before the final negotiation. But so, too, was listening and responding to those most at risk from climate change, such as the Alliance of Small Island States (AOSIS) with its deep concerns in relation to sea level rise. Responding to these concerns, a "high ambition coalition" emerged in Paris and was responsible for the incorporation of a stretch goal within the Paris Agreement to limit warming to 1.5°C.

These developments introduce the noti framework for resolution of global issu which various scenarios could be posi That framework is not solely depender trends such as technological change, v features at an accelerated or even bre pace in almost any 21st century story, is born out of long-term self-interest anc way society listens and reacts to the is the day.

PRIMARY ENERGY BY SOURCE IN THE THREE SCENARIOS



Source: Shell analysis



ires both leadership and emerging ; from all sectors of society. The issue ə change is a global commons problem a solution that deals with the complexity e public and private interests.

magines a world where influence stretches vide, power is devolved, competing ıre accommodated, and commerce is king. ip is not strong, but an evolving recognition on interests is a feature of commerce. : potential is unleashed with technology ent and efficiency improvements driven ɔmmercial engine.

ɪst, **Mountains** is a world with status ver locked in and held tightly by those nfluential. Stability is highly prized, and ərful align interests to unlock resources ınd cautiously, not solely dictated by le market forces. Economic growth is ıt moderated, but centralised authority : prospect of city transformation, a ı in modes of transport, and widespread CS – features that are important for limiting missions.

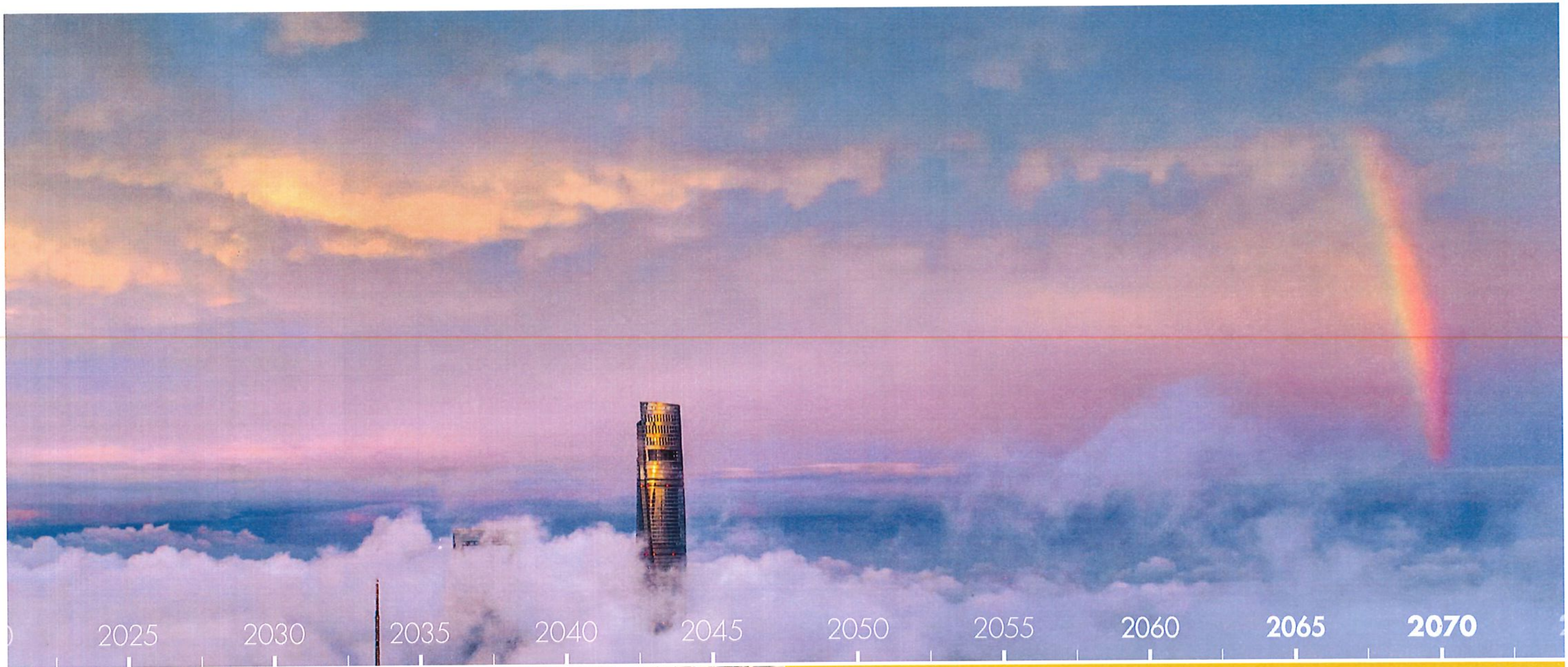
MOUNTAINS, OCEANS AND **SKY**: HOW DO THEY DIFFER IN APPROACH?

The modelling-and-development of the **Sky** scenario differs from the methoc applied in earlier Shell scenario work, such as for **Mountains** and **Ocean**: It also differs from the approach taken by most energy organisations that hı developed 2°C scenarios.

Mountains and **Oceans** both started life through a series of workshops that sought to identify key societal trends that had the potential to shape the landscape of the 21st century. From that work, narrative storylines emerged that formed the basis of the two scenarios. These storylines were then tested by energy modelling to fully explore the impact of the trends in each scenario on the energy system. That modelling included feedback and checks, such that a plausible and consistent scenario emerged where the narrative and the energy numbers stood solidly together. The scenarios were open-ended and not goal-seeking, so outcomes such as warming of the climate system emerged from the realpolitik of the scenarios and the energy choices made as a result.

In contrast, a narrow 2°C scenario establishes that level of warming as a given target from the outset, irrespective of the prevailing political and social conditions at any point in time. An energy pathway and storyline then develop as the outcome, both of whic need to challenge plausibility to meet set on warming. This approach to scei building is known as "normative."

As noted in the introduction, **Sky** takes hybrid approach aimed at being help those in society making decisions todc From 2018 to around 2030, there is c recognition that the potential for dramc short-term change in the energy systerr is limited, given the installed base of capital across the economy and availc technologies, even as aggressive new are introduced. But the period is also ı to include significant capacity-building technology cost reductions, following ı five-year nationally determined contrib (NDC) cycles of the Paris Agreement, that after 2030, deployment can proc an accelerated pace to ensure a resul below 2°C.



CHAPTER 4
A SCENARIO FOR SUCCESS – SKY

gins with the actions taken in the first decade of the Paris Agreement. ıments respond positively to the rapid cycle of assessment, review, and ɜment of national contributions, as set up under the Paris Agreement. the 2023 stocktake, there is wide resubmission of national contributions, ɜ notable change by China to a falling emissions pledge. In **Sky**, by the ɪtocktake, all contributions have been radically improved, with India now ng an emissions plateau in the 2030s.

e 2020s in **Sky**, emissions reduction is relatively slow while capacity ut beginning in 2030, the speed ɪrmation accelerates rapidly as key ɪility challenges of the 21st century be met.

Success: Energy for all

In **Sky**, the global population grows from 7.5 billion in 2017 to 10 billion by 2070, after which it stabilises. Energy demand also rises throughout the century, with a near plateau from 2080. Importantly, per capita usage remains relatively low in **Sky** because of unprecedented efficiency gains for energy services – an approximate tripling in efficiency is seen over the course of the century. As a result, per capita primary energy demand converges near 100 GJ per year – far below the numbers seen today in industrialised economies but nevertheless a level that provides the broad range of energy services required for a better life. As a reference, a modern energy-efficient refrigerator will consume just over one GJ per year.

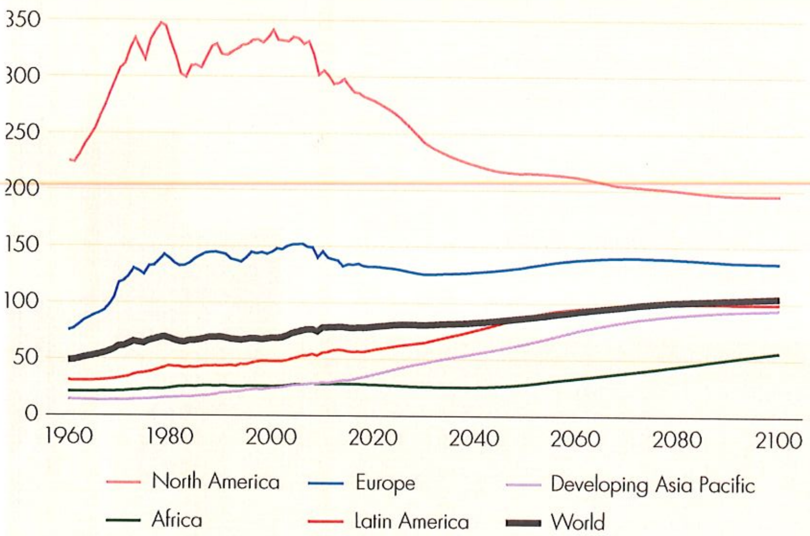
With the global population at 10 billion late in the century and per capita energy use rising, the energy system in **Sky** is approximately double its 2010 size.

Success: Dealing with coal

At COP23 in 2017, 25 countries and formed the Powering Past Coal Allianc pledging to phase out existing traditioı power in their jurisdictions. In the next years, in **Sky**, a significant number of ‹ countries join the Alliance with the resu coal for power generation diminishes in of the world. In Vietnam and even in Inc coal for power construction ends before By the 2030s, additional solar and wir all incremental electricity demand.

China's push to accelerate the phase-o coal in **Sky** means global peak coal dı is now behind us, with rapid decline al although coal remains important in sorr

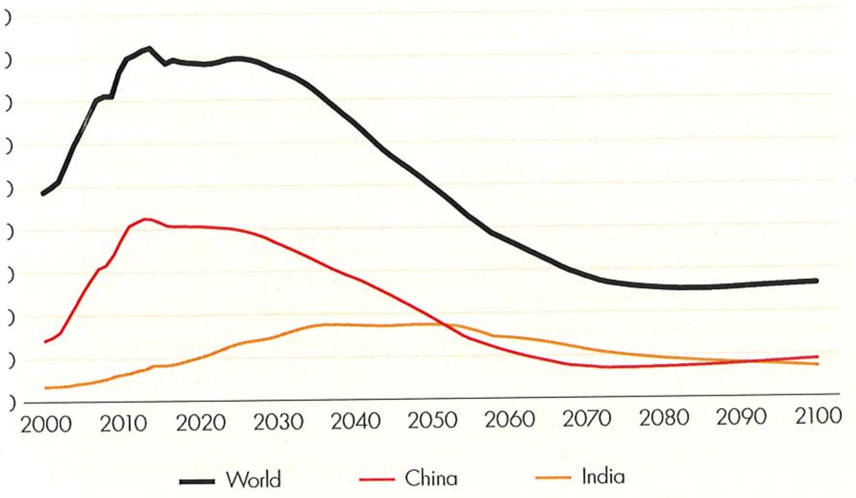
ER LIFE FOR ALL



ɔday, a better life for all can be achieved for an average of 100 GJ per capita.
the century, efficiency gains mean that a better life can be achieved at still lower figures.
Shell analysis, IEA (historical data)

In Sky, absolute CO_2 emissions peak before 2040 in India, by then the most populated country on earth.

:OAL USE IS BEHIND US IN **SKY**, WITH TOTAL CONSUMPTION FALLING RAPIDLY THE EARLY 2030s ONWARDS



Shell analysis, IEA (historical data)

. and metallurgical coal continues as a put for smelting. By 2070, coal's share primary energy falls to around 6%, m 25% in 2020.

;: Transformation of stubborn ılled technologies

ı decade following the Paris :nt, energy system CO_2 emissions are ›cked in by existing technologies, ·ock, and societal resistance to But by 2030 in **Sky**, the system is triggered in the 2020s by significant s in energy technologies and scale acture leading to price falls for rs and businesses. This is facilitated ·ed government intervention in and development and the important nmercialisation phase, with major battery storage technology, CCS, ɔnced biofuels.

Success: Governments step up the pace

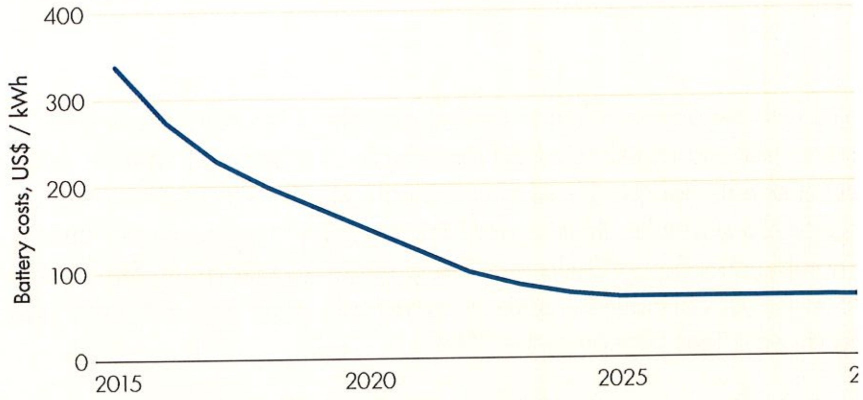
In **Sky**, governments around the world implement legislative frameworks to drive efficiency and rapidly reduce CO_2 emissions, both through forcing out older energy technologies and through promoting competition to deploy new technologies as they reach cost effectiveness.

For example, at the national and sub-national level, governments speed up the energy transition by adapting power markets to new renewable technologies and putting a meaningful price or constraint on carbon emissions from conventional thermal generation. Legislation in many jurisdictions forces grids towards 100% renewable energy by the 2040s.

Appliances, commercial and residential buildings, and personal transport are all targeted with aggressive efficiency or emission standards. The creation of low-emission zones by city authorities forces older vehicles off the road, and in many cities electric vehicles become the natural replacement due to their convenience and the wide availability of recharging points. Scrappage incentives speed up the replacement of out-dated, less efficient equipment in homes and offices. But the most significant emissions-targeted action taken by governments around the world is the adoption of effective implicit or explicit carbon-pricing mechanisms.

Since Paris, government-led carbon-pricing approaches have been gaining traction. At the 2017 OnePlanet Summit, several countries and states within the Americas committed to expand their use of these mechanisms. During the same year, C announced the launch of its nationwid emissions trading system, starting with power sector. And by the beginning c 2018, California, Quebec, and Ontar were operating under linked emissions trading systems.

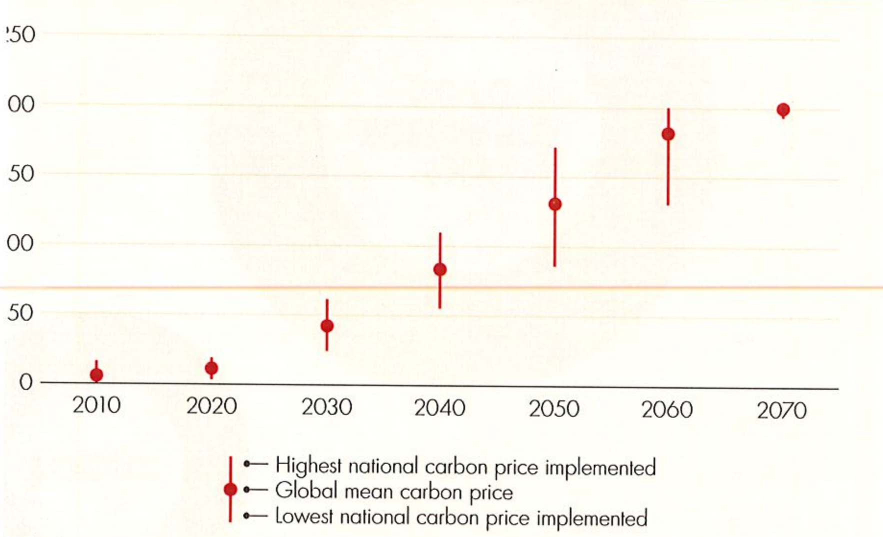
BATTERY COSTS FALL RAPIDLY IN **SKY**, IN PART DUE TO GOVERNMENT FUNDING OF NEW TECHNOLOGIES



Source: Shell analysis, Bloomberg New Energy Finance (historical data)

> **In Sky, solar PV maintains strong average growth rates of 20% per year, exceeding 6500 GW installed capacity by 2035. This will cover an area of 100,000 km², equivalent to an area the size of South Korea. From then on to 2070, nearly 1000 GW will have to be added every year, when solar PV's global footprint approaches the area of Spain.**

:NMENTS RAPIDLY ADOPT CARBON-PRICING MECHANISMS THROUGHOUT THE
) IN THE 2020s; COMPLETE HARMONISATION IS ACHIEVED BY 2070



:: Shell analysis

overnment-led carbon pricing
as a suite of taxes, levies, and
ıechanisms. Surprisingly quickly, a
understanding is reached between
ents as to the appropriate level of
of emissions.

) in Sky, government-led carbon
, firmly established throughout the
nd China, with Russia and India
he second wave of entrants to carbon
Global implementation of carbon
y governments is complete by the
0s, with all systems then achieving
e limit to deter emissions.

arbon pricing has two other
ıt consequences. First it speeds
doption of CCS for large emitters
ving the deployment of net-negative
gies like bioenergy with CCS.

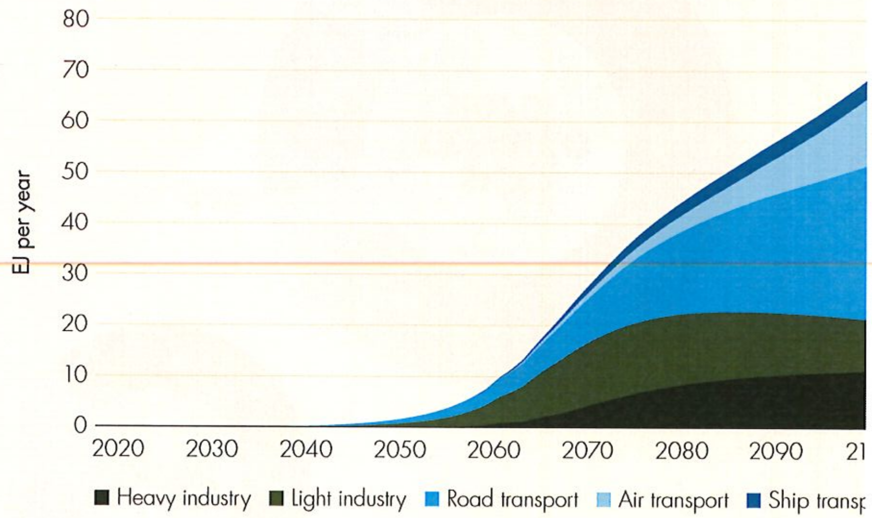
Second, carbon pricing encourages emissions reduction across the whole economy, especially through improving energy efficiency, thus generating significant shifts in consumer and producer behaviour.

Success: New energy systems emerge

Onshore and offshore hydrogen electrolysis systems also begin to emerge around the world in **Sky**. Initially, they make use of the growing off-peak surplus of electricity from renewable sources, but later become fully integrated base-load systems. As a result, after 2040, hydrogen emerges as a material energy carrier, steadily growing to account for 10% of global final energy consumption by the end of century.

As oil and gas use falls over time in **Sky**, redundant facilities are repurposed for hydrogen gas storage and transport. Indeed, the growing LNG supply in t[illegible] early decades

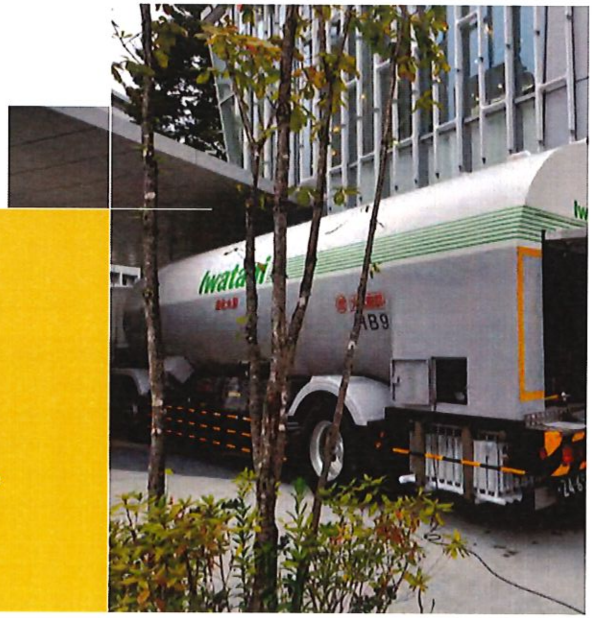
IN **SKY**, HYDROGEN EMERGES AS A MATERIAL ENERGY CARRIER AFTER 2040, PRIMARILY FOR INDUSTRY AND TRANSPORT



Note: By 2100, hydrogen supplies a quarter of all transport energy demand and over 10% of industrial energy

Source: Shell analysis

"Hydrogen grows as an energy carrier from 2040 in Sky, with 800 million tonnes per year global capacity by 2070 – more than double the current global LPG m[illegible]et.



ntury has enabled hydrogen to gain
d and develop scale. An immense
of electricity networks and hydrogen
ensures secure and affordable
/ and hydrogen supply, which
; switching across sectors, particularly
ɔrt and industry.

ıgh aviation and shipping continue
ı crude oil for the first decades of
synthesised from biomass begins
ıore and more of the market share.
mes that this is in the form of liquid
given its greatest flexibility, but if
ersion to methane proves the more
ıl, then this equally could be in the
form of compressed or liquefied bio-gas for ship, rail, and road uses. In the latter stages of the transition, hydrogen emerges as a new energy carrier, particularly for aviation.

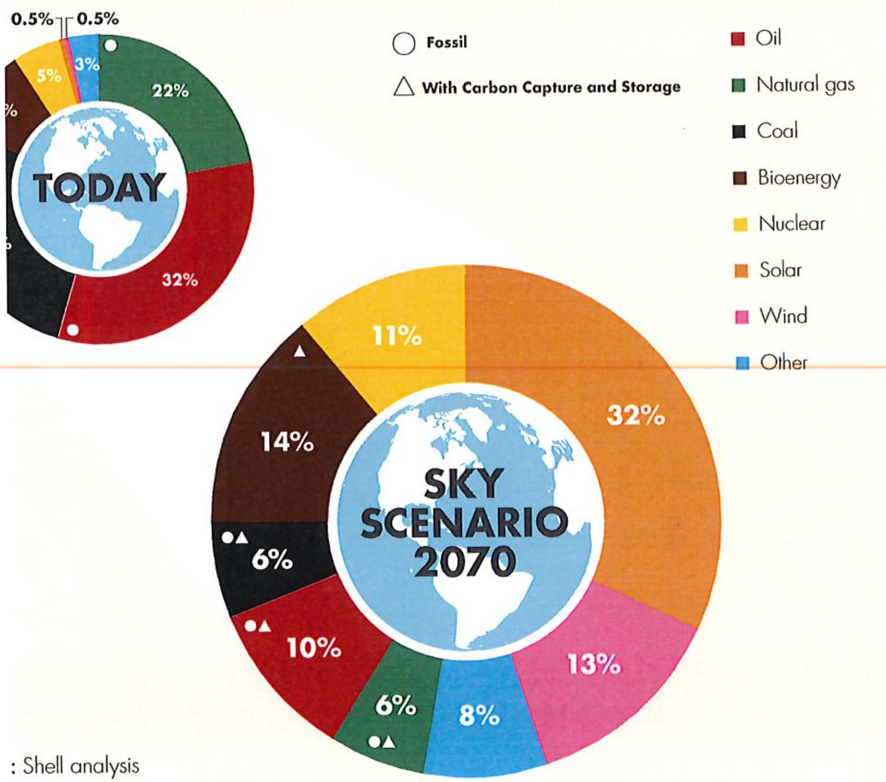
Success: Paris works

In **Sky**, the Paris Agreement succeeds, driven by government implementation of targeted energy policy at every level in parallel with aggressive action across the global economy, including the energy sector.

These and similar actions multiply rapidly. At first, government leadership is responsible for the speed of change, but increasingly, peer pressure provides the push in response to the transparency framework embedded in the Paris Agreement. New technologies become increasingly cost-competitive by themselves as mass deployment increases. The five-year ratchet mechanism works in the **Sky** scenario.

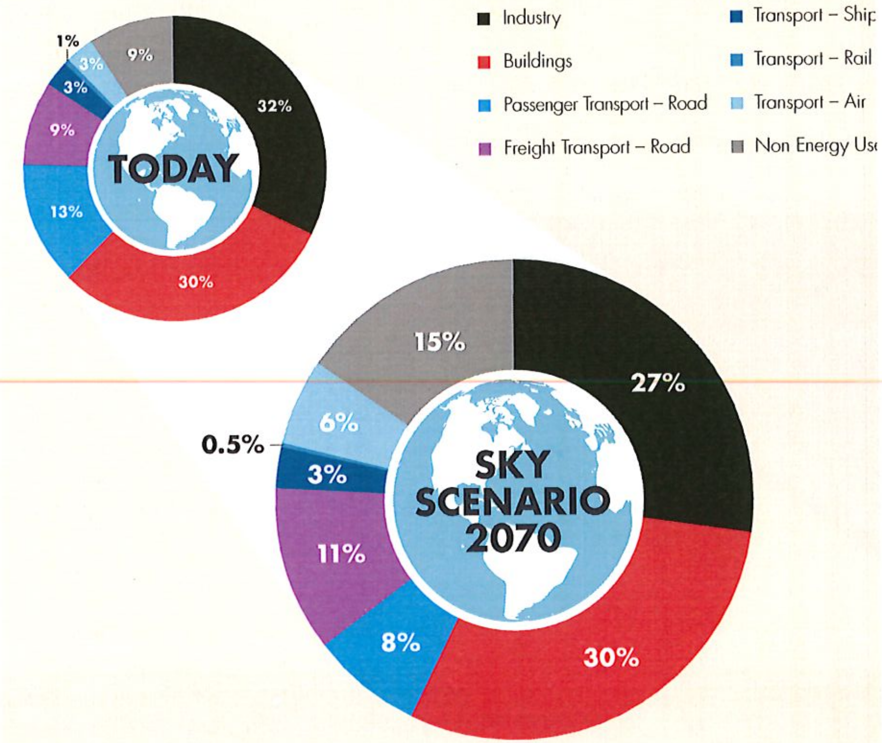
Not all countries have reached net-zero emissions by 2070. But beginning in 2020, progressive countries follow Sweden's earlier legal commitment to reach net-zero emissions by 2045. Along with Brazil and other big economies, most European countries reach net-zero by 2060, with some seeing continued falls such that their economy-wide emissions become negative – in other
drawing down CO_2 from the atmosph
This is achieved by combining the use
biomass for energy with CCS. These c
are then able to offer negative emissic
transfers to those countries still in positi
territory, thereby achieving the global
called for under the Paris Agreement.

ET-ZERO EMISSIONS WORLD IN 2070, SOLAR, BIOENERGY, AND WIND DOMINATE
/ABLES SUPPLY WHILST OIL REMAINS THE LARGEST FOSSIL ENERGY SOURCE

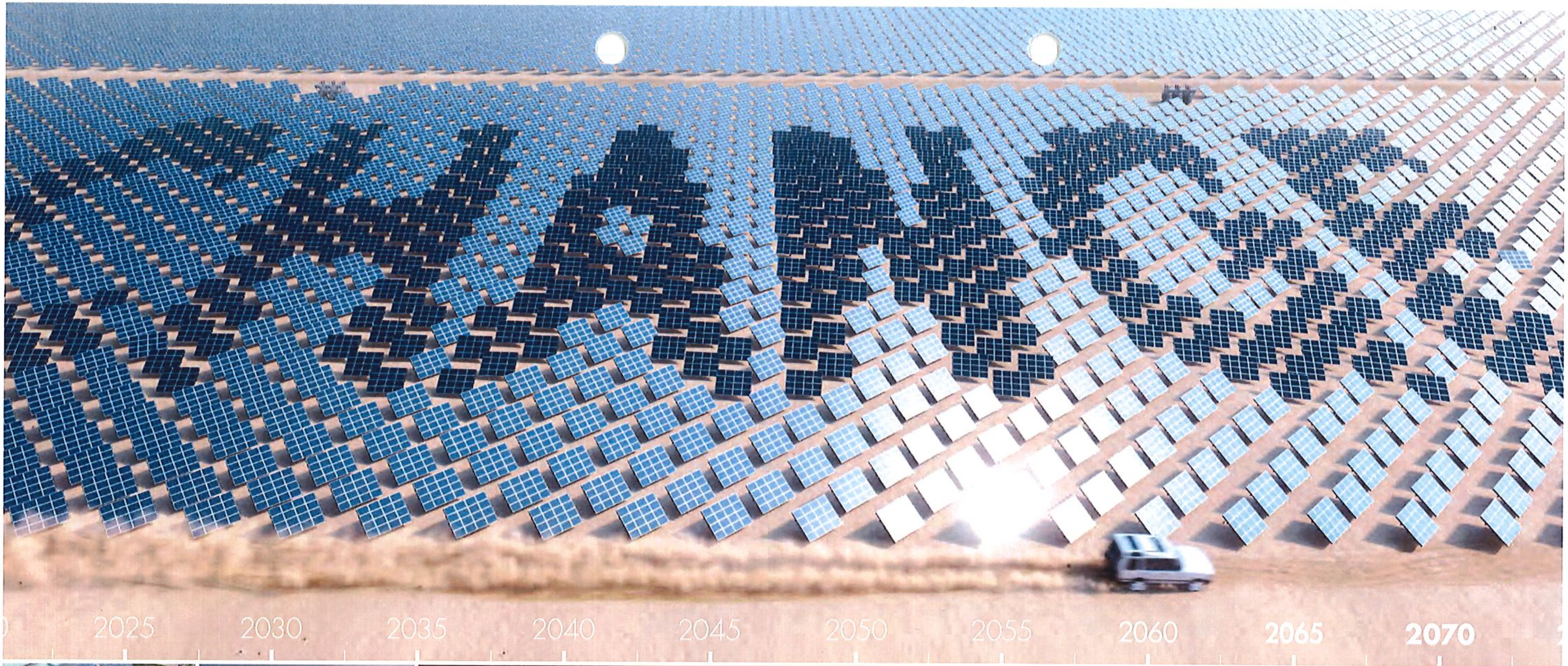


: Shell analysis

WORLD TOTAL FINAL ENERGY CONSUMPTION BY SECTOR IN **SKY**



Source: Shell analysis



CHAPTER 5
SECTOR TRANSFORMATIONS

ECTOR TRANSFORMATIONS

the route to net-zero emissions in 2070 involves change at every level of
nomy and energy system, from urban configuration to consumer demand
gy to the breakthroughs in technology required to deliver viable and cost-
e alternatives to fossil fuels. And in the world of **Sky**, transformation of the
system to produce fewer greenhouse gases is matched by transformations
sectors that produce the remaining one-third of greenhouse gas emissions.

ne most important energy system
Sky is electrification – the increasing
nent of fossil fuels (such as natural
ooking and gasoline for mobility)
icity.

essful transport revolution

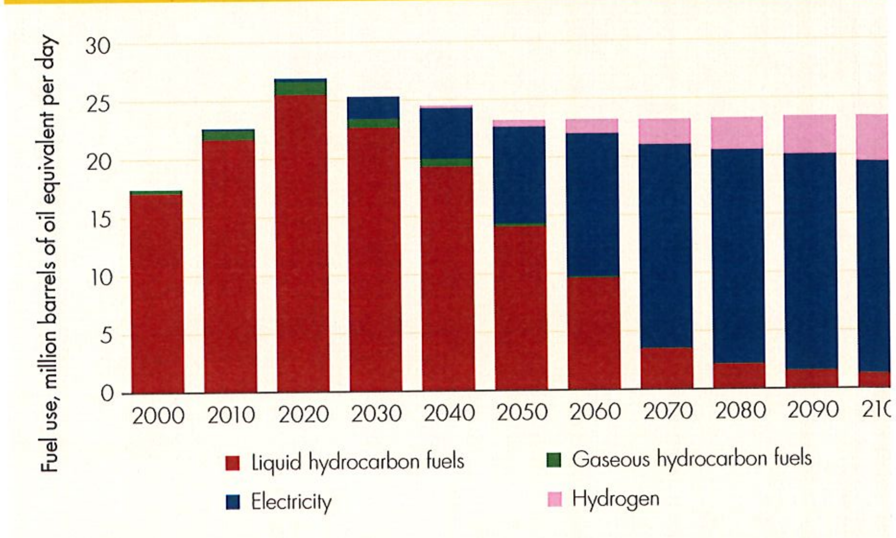
), the foundation has been created
olutionary transformation of the
system. The global Clean Energy
al, which emerged in 2009 after
enhagen Climate Conference to
ge the transition to a global clean
energy economy, had already adopted an Electric Vehicle Initiative as one of its early actions, with the target of 20 million electric vehicles deployed globally by 2020 and 30% new vehicle sales by 2030. And the UK had pledged to phase out the sale of internal combustion engine passenger cars by 2040.

In **Sky**, this transformation occurs more rapidly than many expect; as early as 2030, more than half of global car sales are electric, extending to all passenger cars by 2050. One reason is that in some prosperous large cities, workers enjoy the freedom and

"

In Sky, passenger electric vehicles reach cost parity with combustion engine cars by 2025. By 2035, 100% of new car sales are electric in the EU, US, and China, with other countries and regions close behind.

THE FUEL MIX FOR PASSENGER VEHICLES SHIFTS RAPIDLY IN **SKY**, WITH ELECTRICIT
DOMINATING BY 2070 AND LIQUID FUELS NEARLY HALVING FROM 2020 TO 2050



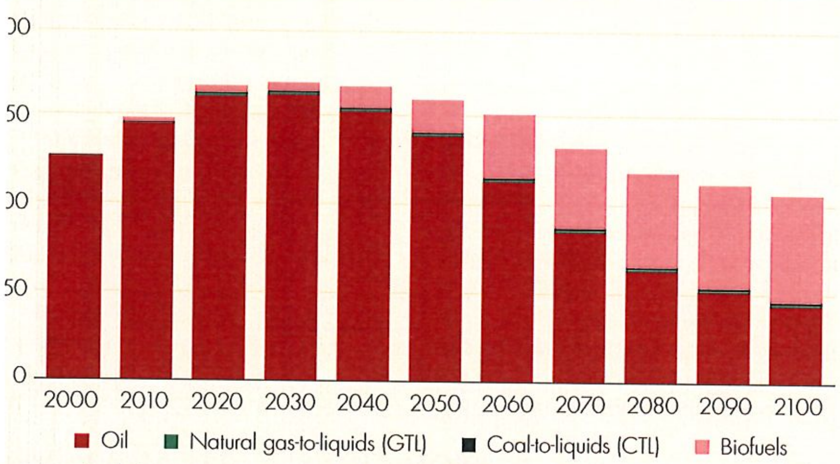
Source: Shell analysis

convenience that the fleets of autonomous electric vehicles provide. Another reason for the rapid increase of electric vehicles has to do with the exciting new options being offered. For example, in **Sky**, a standardised chassis design emerges in combination with battery or fuel-cell (FCEV) architecture, being shipped in almost flatpack form to local design companies for bespoke body fabrication using 3D printing techniques. And a specialised CarOS (Operating System) evolves, including battery management and autonomous operation, supplied as a single universal interface box.

In this way, electric vehicle penetratior
accelerates on the back of a new
manufacturing approach and custome
proposition that offers complete custon
a welcome reward for the loss of diffe
engine performance. The change is a:
profound as the arrival of the assembl

Across all forms of transport, biofuels p
a critical role in the energy transition ir
Sky. With continued reliance on liquid
as the high energy density fuel of choi
but set against the need to reduce CC
emissions, biofuel use expands rapidly
While first generation fuels such as su
cane ethanol continue to mid-century b

ICED BIOFUELS GROW RAPIDLY IN **SKY**, MEETING AN ONGOING NEED FOR HYDROCARBON FUEL.



y 2100, biofuels production has reached some 30 million barrels of oil equivalent per day.
Shell analysis

ng, the impetus comes from new pathways that produce drop-in nt fuels for aviation, road freight, and These fuels can be derived from a nge of bio-feedstocks, reducing the ncy on food crops.

e passenger vehicle transformation is omplete by 2070. Liquid hydrocarbon umption almost halves between d 2050 and falls by 90% by 2070 in the sector. And even though road freight holds on to diesel into the 2050s, because of the need for a high-energy-density fuel, this sector also experiences its own transformation, split along biodiesel, hydrogen, and electrification lines.

estic refrigerator efficiency led since 1970. To offer a fe for all but also manage demand, Sky matches these s across the economy.

The built environment

Changes in the built environment, covering both homes and commercial properties, evolve over decades, but the foundations are established in the 2020s. During this period, governments implement radical changes in building codes, set high efficiency standards for appliances, establish new infrastructure for district and regional heating needs, and establish practices that encourage attractive compact urban development.

The efficiency drive is so effective that final energy demand for residential services, which include heating, cooking, lighting, and appliance use, remains steady at around 90 EJ for all the century, even as most of the growing global population gain access to these amenities.

Electrification of the building stock proceeds rapidly, with local use of natural gas declining progressively from 2030. By 2070 in North America and much of Europe, natural gas is no longer used for residential heating and cooking.

Industrial transformation

The shift in industry required for net-zero emissions follows a more incremental path, largely driven by the progressive implementation of government carbon-pricing systems and the ratcheting up of the resultant price that occurs as governments respond to the Paris Agreement. The transformation is profound and follows three distinct routes:

- Efficiency improves continuously, with most industrial processes approaching thermodynamic and mechanical efficiency limits by the 2050s.
- Some processes shift towards electricity, particularly for light industry, where electricity use doubles from 2020 to 2040. Hydrogen also emerges as an important fuel for light industry by 2050 as natural gas use declines. But a similar change for heavy industry doesn't emerge until after 2050, with hydrogen, biomass, and electricity substituting for natural gas and some coal use.
- Coal remains important in the metal sector and some other processes ric through the century, but with govern implemented carbon prices rising, C emerges as the solution.

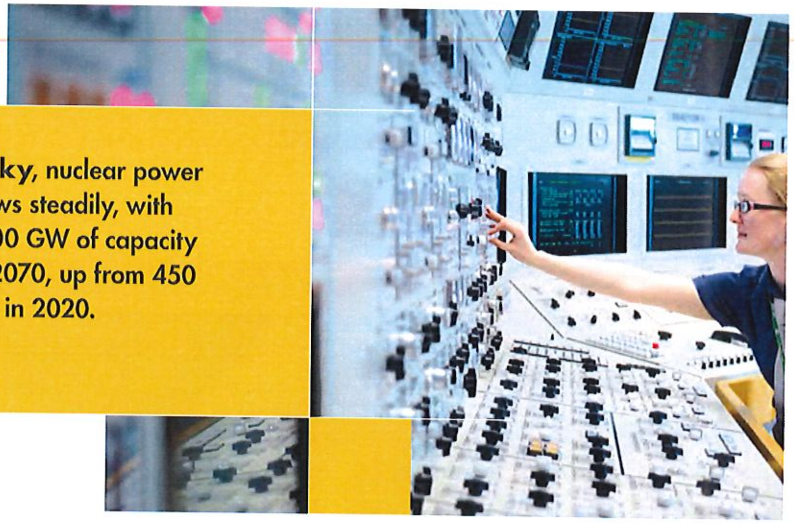
Industry also benefits from an increase on the circular economy, which sees l scale recycling expand throughout the to the extent that some resource extrac declines as a result.

An electric world

As electricity makes its way rapidly int transportation, home heating and coo and industrial processes, its role in the system grows. By the 2070s, electricit exceeds 50% of end-use energy consu compared with less than 20% in the 2

With renewables penetration increasir issues associated with renewable inter and grid infrastructure receive policy c Utility-scale and distributed electricity b increasingly compete head-to-head wi conventional thermal generation, leadi electricity prices in some markets to fa the variable cost of less efficient coal c plants, thus hastening their decommissi

"In Sky, nuclear power grows steadily, with 1,400 GW of capacity by 2070, up from 450 GW in 2020.

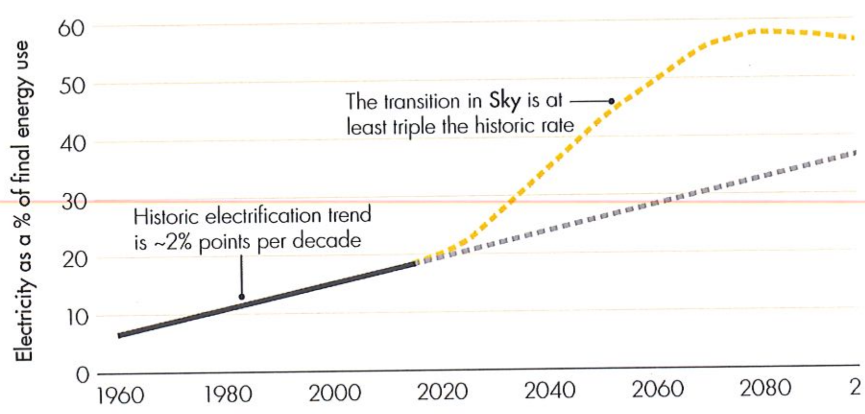


TRICITY IN THE 21ST CENTURY

lobal electricity demand stands
22,000 terrawatt hours (TWh)
In **Sky** it rises to around100,000
year during the second half of
ry, or the addition of about 1,400
generation per year from now on.
rence, when complete, the 3.3
kley Point nuclear power station
nstructed in the UK will add about
, so this pace of development is
nt to some 50 giant power stations
each year, or one additional such
er week. Global generation from
d solar was around 1,300 TWh in
ith about 200 TWh added from

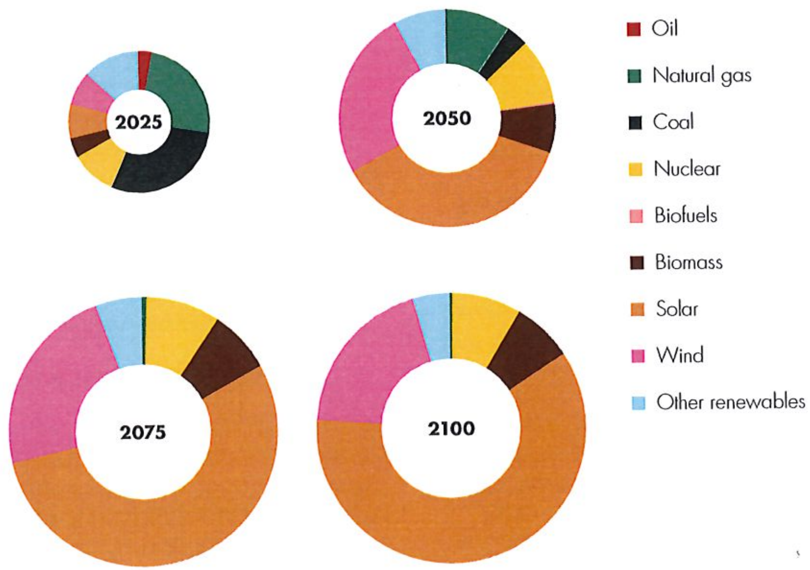
2015 to 2016 against total added electricity generation of some 600 TWh. So, new solar and wind are not yet close to meeting additional generation demand. Although both are rising quickly, thermal power stations will continue to be needed to at least mid-century. This also means that emissions from electricity generation globally will only fall in the medium term to the extent that natural gas and nuclear can displace coal.

CURRENT ELECTRIFICATION TRENDS ARE NOT SUFFICIENT FOR SKY



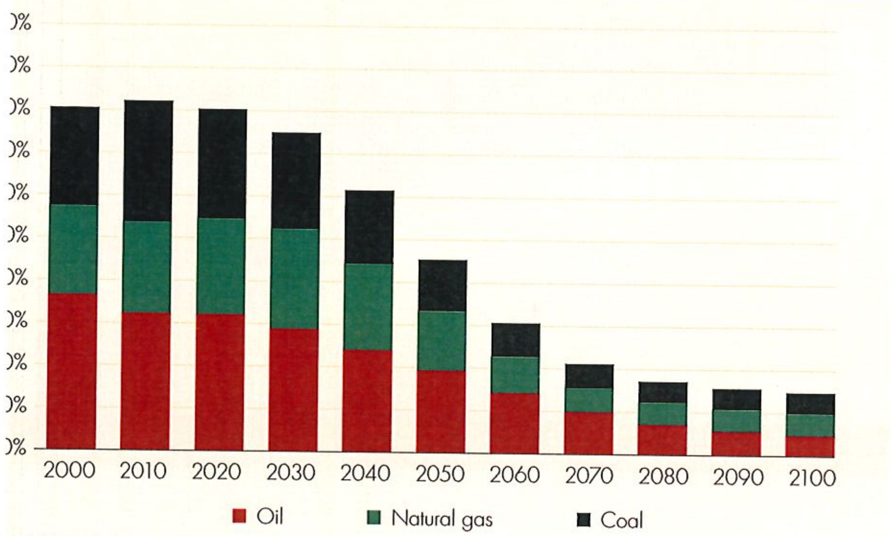
Source: Shell analysis, IEA (historical data)

THE ELECTRICITY MIX SHIFTS HEAVILY TO SOLAR THROUGH THE CENTURY



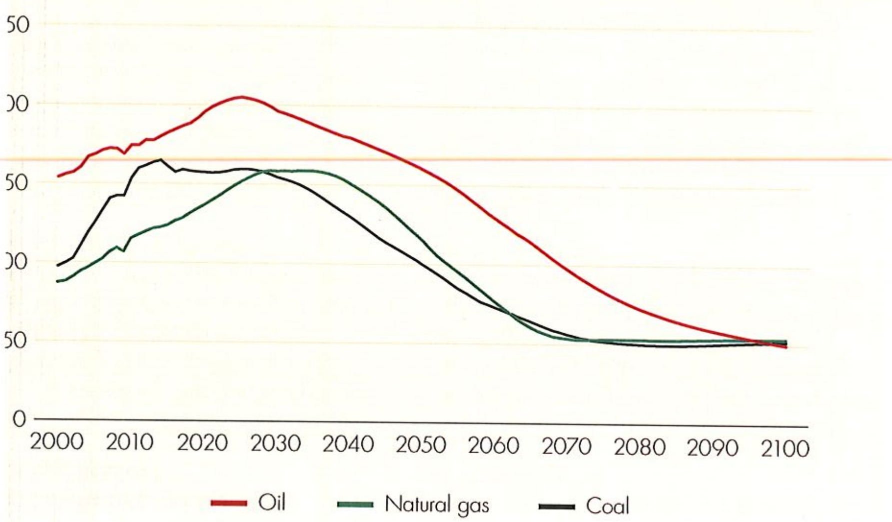
Note: The dia er of the pie chart represents the total electricity demand.
Source: Shell analysis

', BY MID-CENTURY FOSSIL ENERGY FINALLY RELINQUISHES ITS MAJORITY SHARE GLOBAL ENERGY SYSTEM



: Shell analysis

', PEAK COAL DEMAND IS ALREADY BEHIND US, PEAK OIL DEMAND FOLLOWS IN 20s, AND AFTER A PLATEAU, GAS DEMAND FALLS RAPIDLY FROM 2040



: Shell analysis

In **Sky**, electricity reliability issues are largely managed through a combination of improved market design (for example, capacity markets), grid integration (for example, cross-border integration in Europe), demand-side management (for example, smart grids), and deployment of cost-effective heat, battery, and hydrogen storage. Falling capital costs ensure that the renewables build-out is affordable, being well within historical spending on the new energy system as a share of global GDP.

By the 2070s, the power generation sector has progressed through two radical transformations. The first is one of scale, with electricity approaching a five-fold increase over 2017 levels. The composition of sources has also changed, with fossil fuels effectively absent from the sector and solar meeting over half of global electricity needs in 2070 and still increasing. A new addition to the sector is generation from biomass combustion, which is linked with CCS to offer an important carbon sink.

A new energy system

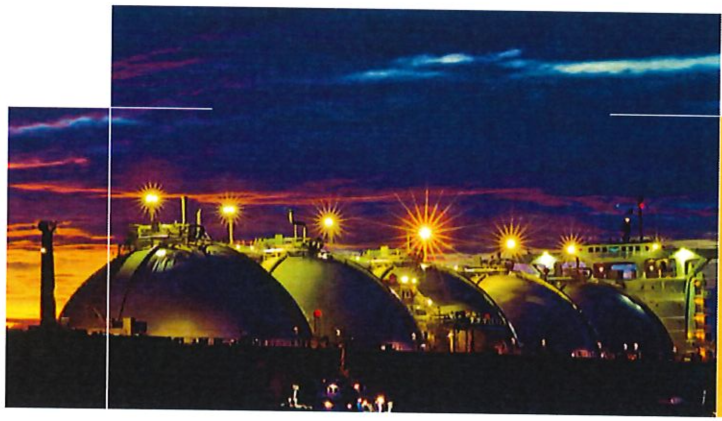
In **Sky**, the first clear signs of the transition emerge in the 2020s, with oil demand stagnating, coal declining, natural gas growing as it replaces coal, and solar closing in on nuclear as the largest non-fossil part of the energy system.

By 2070, oil production remains at so 50-60 million barrels per day due to the broad swathe of services that it stil supplies. Non-road transport continues make significant use of liquid hydrocar fuels, with overall growth through to 2(Biofuels supplement the liquid fuel mix, with hydrogen playing an increasing r after 2050.

Natural gas, both as pipeline gas and plays an important early role in supplar coal in power generation and backing renewable energy intermittency as wind solar grow in the power sector. But as PV expands rapidly, as battery costs fa as the high cost of carbon emissions bi even natural gas succumbs to the transi It is the last fossil fuel to peak, with den falling rapidly after 2040. By 2055, na gas use for power generation is back t levels globally.

By the middle of the century the energ is starting to look very different, with sc emerging as the dominant primary ene supply source by around 2055.

Energy system CO_2 emissions peak in mid-2020s at around 35 gigatonnes (after which a continuous decline sets i



Global natural gas c reaches a plateau by in Sky at 4,600 billi cubic metres per yea (bcma) – up from 3,: bcma in 2017.

ɡreenhouse gases and ıergy sectors

es at net-zero CO_2 emissions for the ıergy system by 2070, although with distribution among different sectors ıtries. That covers all the carbon d within the coal, oil, and gas used ıy, but excludes feedstock for non-ıroducts, such as plastics.

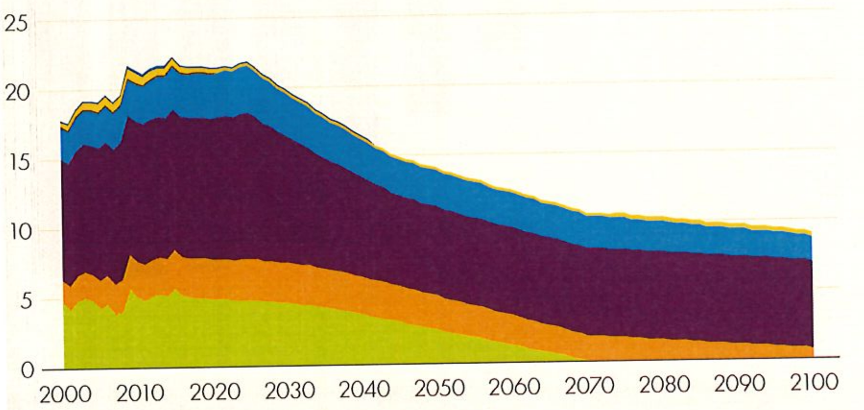
ɪrous other human activities have the trace gas composition ıosphere, which have also ed to warming the climate system. manufacture is one example, where ıation of limestone releases CO_2.

cultural system has added to the in the atmosphere due primarily to vestock and rice growing. Land-use over the course of several centuries, deforestation and agricultural tion of soil, has also lowered the arrying capacity of the land-based biosphere, which, in turn, has added to atmospheric CO_2.

In the modern era, all these activities have accelerated, and new long-lived trace gases have appeared, some with extraordinary warming potentials. Sulphur hexafluoride, common in gas-insulated transformers, is one example, with a warming potential 24,000 times that of CO_2.

In the **Sky** scenario, significant changes are made in all the greenhouse-gas producing sectors. While all the items in the accompanying table represent best practice currently in some locations, the **Sky** pathway dictates universal uptake by about 2030, but with some recognised slippage in the least developed economies. For short-lived gases such as methane, the requirement is significantly reduced emissions, rather than net-zero, as these gases break down in the atmosphere over a few years.

NERGY SYSTEM GREENHOUSE GASES ALSO DECLINE SHARPLY IN **SKY**

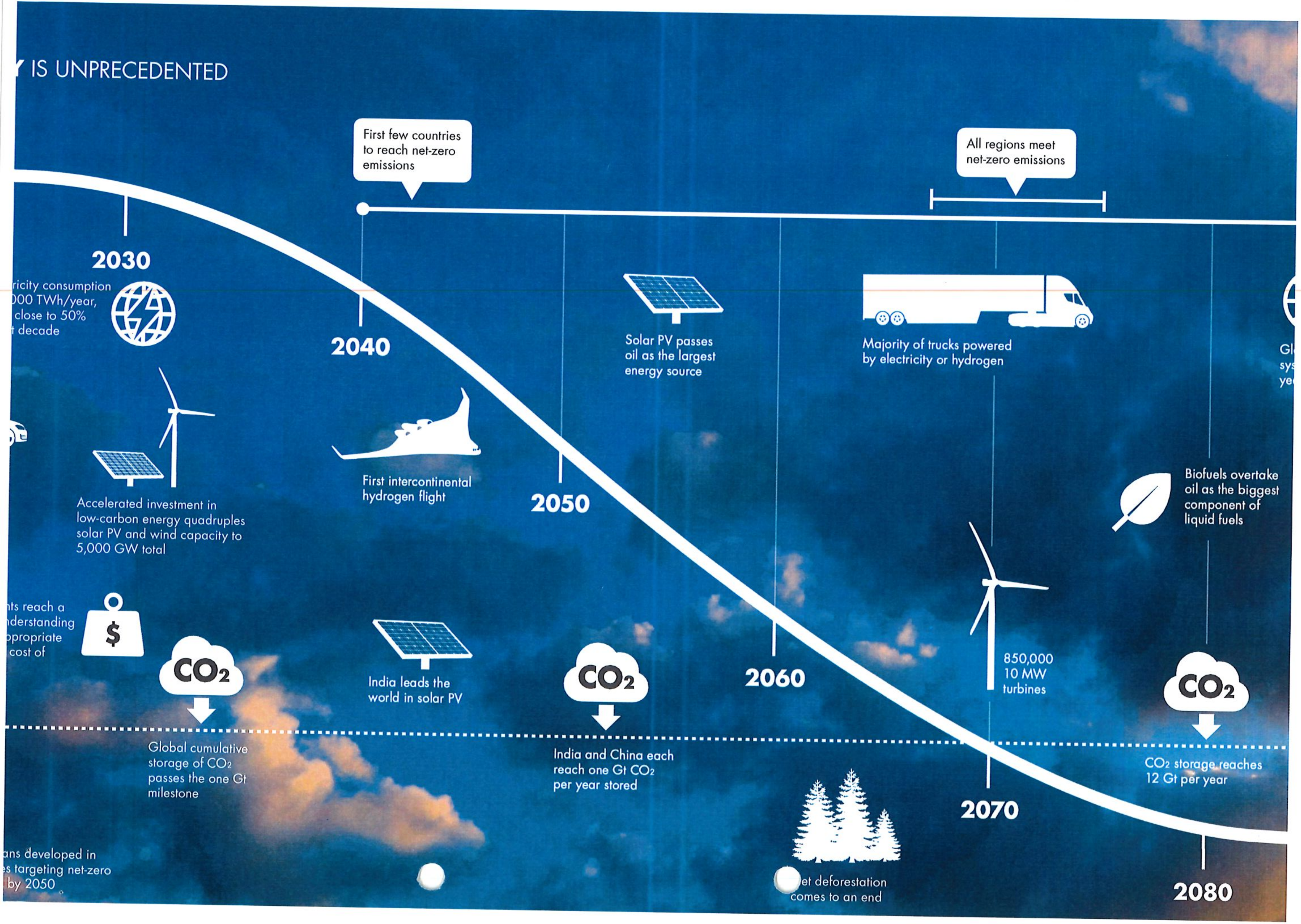


ırbon dioxide (land-use change) ■ Carbon dioxide (process emissions, e.g., cement)
ethane ■ Nitrous oxide ■ Perflurocarbons ■ Hydroflurocarbons ■ Sulphur hexafluoride

ɜ: Shell analysis, MIT

Although the emphasis in **Sky** has been on energy system CO_2 emissions, a view on all a: greenhouse gas emissions is needed to complete the scenario and understand the potentic surface temperature. That view has been developed based on full implementation of all th in the table.

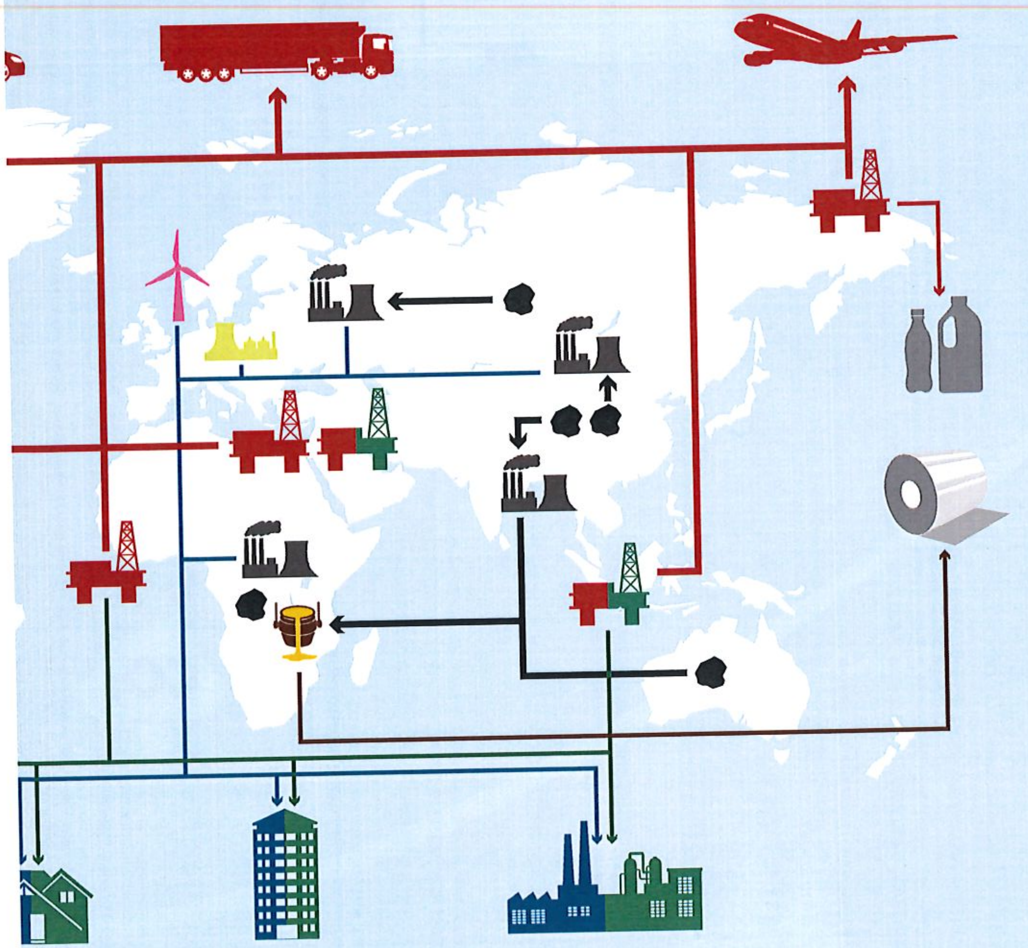
GAS	SECTOR	ACTION REQUIRED BY **SKY**
Carbon dioxide	Cement	■ Progressive substitution away from cement in buildir ■ Some substitution away from limestone as a feedstc e.g., using fly-ash ■ Using carbon capture and storage (CCS)
	Industrial (process emissions)	■ Using CCS
	Agriculture	■ Eliminating deforestation for land gain ■ Implementing soil carbon programmes, e.g., no-till farming, land-use rotation
	Urbanisation and development	■ Creating green cities through extensive tree plantinc ■ Maintaining green belts within and around cities ■ Avoiding city spread through higher density living ■ Addressing traditional biomass usage through mod access to energy programmes
Methane	Coal mining	■ Reducing coal consumption ■ Implementing best practice for methane drainage and use in coal mines (e.g., UNECE Guidance) ■ Managing abandoned mines
	Oil and gas industry	■ Reducing oil and gas consumption ■ Oil and gas industry leaders implementing best-pra from the 2020s, and all world production meeting best-practice by 2050
	Cattle farming	■ Offering alternative products to consumers ■ Changing cattle diets to minimise methane
	Rice growing	■ Reducing forced flooding in rice paddies
	Urbanisation and development	■ Capturing methane from landfill
Nitrous oxide	Agriculture	■ Implementing nitrogen fertiliser management, i.e., application rate, formulation (fertiliser type), timing of application, placement
	Industrial processes	■ Implementing catalytic decomposition and thermal destruction techniques
Fluorinated gases	Various (e.g., IT industry, rigeration, transformers)	■ Progressive substitution away from PFC, HFC, and ■ Using best practice management ■ Introducing recovery programmes for retired equipmen (e.g., refrigerators, transformers)



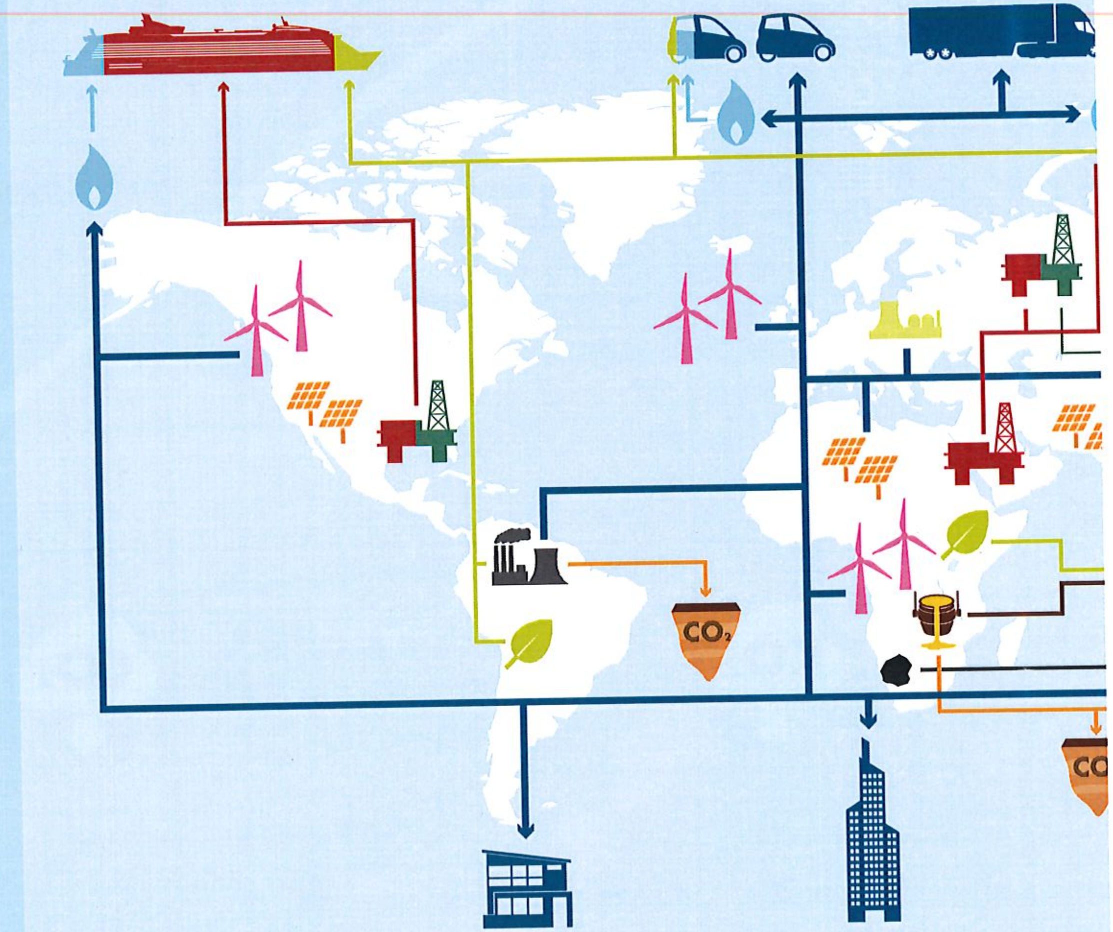
Y IS UNPRECEDENTED
First few countries to reach net-zero emissions
All regions meet net-zero emissions
2030
ricity consumption
000 TWh/year,
close to 50%
t decade
2040
Solar PV passes oil as the largest energy source
Majority of trucks powered by electricity or hydrogen
Gl
sys
ye
First intercontinental hydrogen flight
Accelerated investment in low-carbon energy quadruples solar PV and wind capacity to 5,000 GW total
2050
Biofuels overtake oil as the biggest component of liquid fuels
nts reach a
nderstanding
ppropriate
cost of
$
CO_2
India leads the world in solar PV
CO_2
2060
850,000
10 MW
turbines
CO_2
Global cumulative storage of CO_2 passes the one Gt milestone
India and China each reach one Gt CO_2 per year stored
CO_2 storage reaches 12 Gt per year
2070
ans developed in
s targeting net-zero
by 2050
et deforestation comes to an end
2080

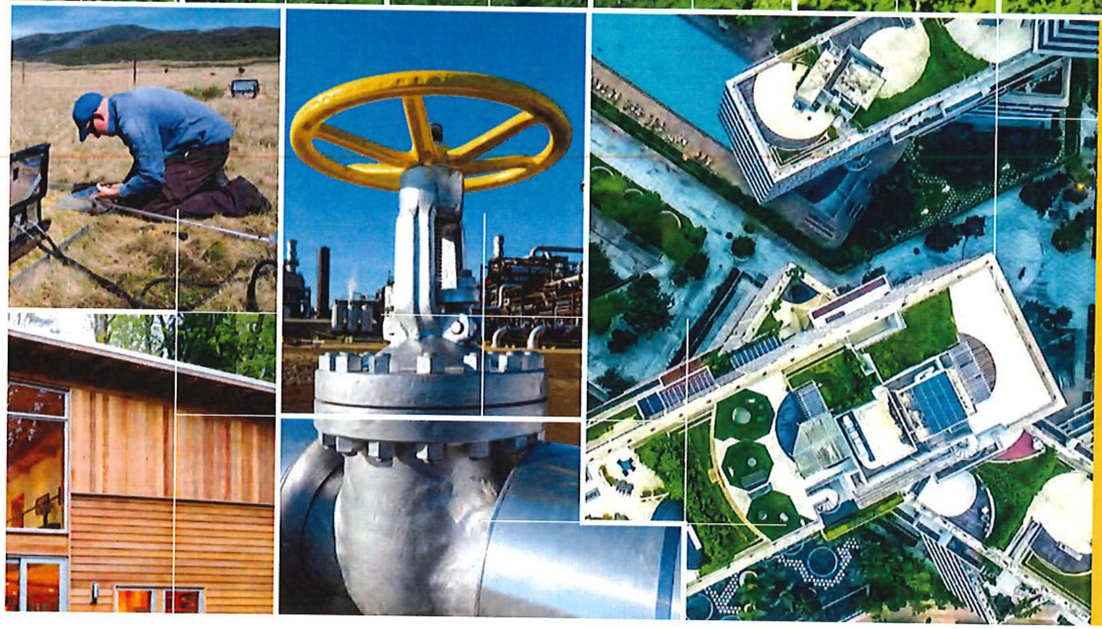
y. For most of the global
t individually by collecting
commencing. Candles for
handler, who used various
lighting was supplied

by town gas, kerosene lamps, and for a rapidly increasing number of people, electricity. While there remain a disturbing number of people with little to no energy access today, much of the global population make regular use of petroleum products, natural gas, and electricity. But what could that look like in the latter part of this century as we reach for net-zero emissions? In **Sky**, an electricity-based energy system supplants the largely fossil fuel-based system of today.



SKY IN 2070 – AN ELECTRICITY-BASED ENERGY SYSTEM





CHAPTER 6

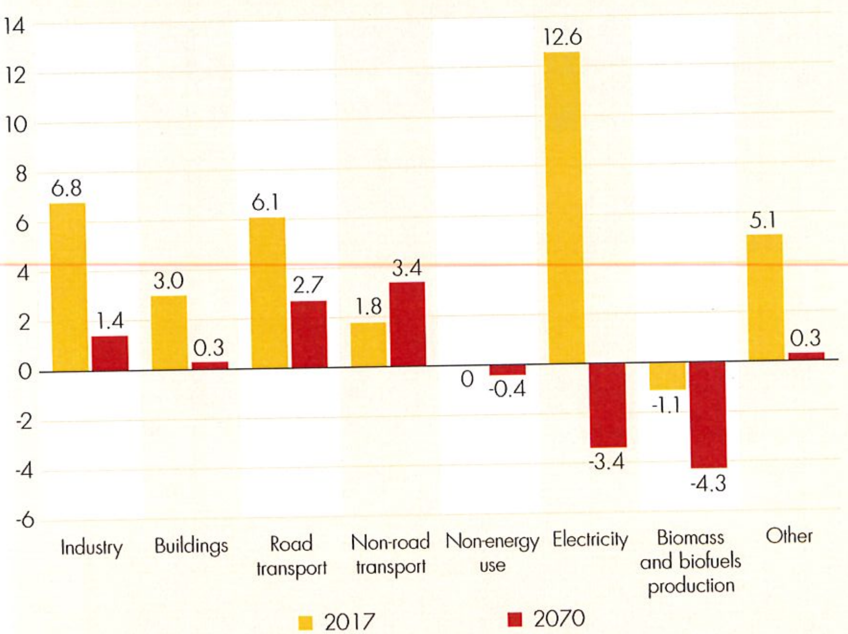
ACHIEVING THE BALANCE

ACHIEVING THE BALANCE

...ing emissions

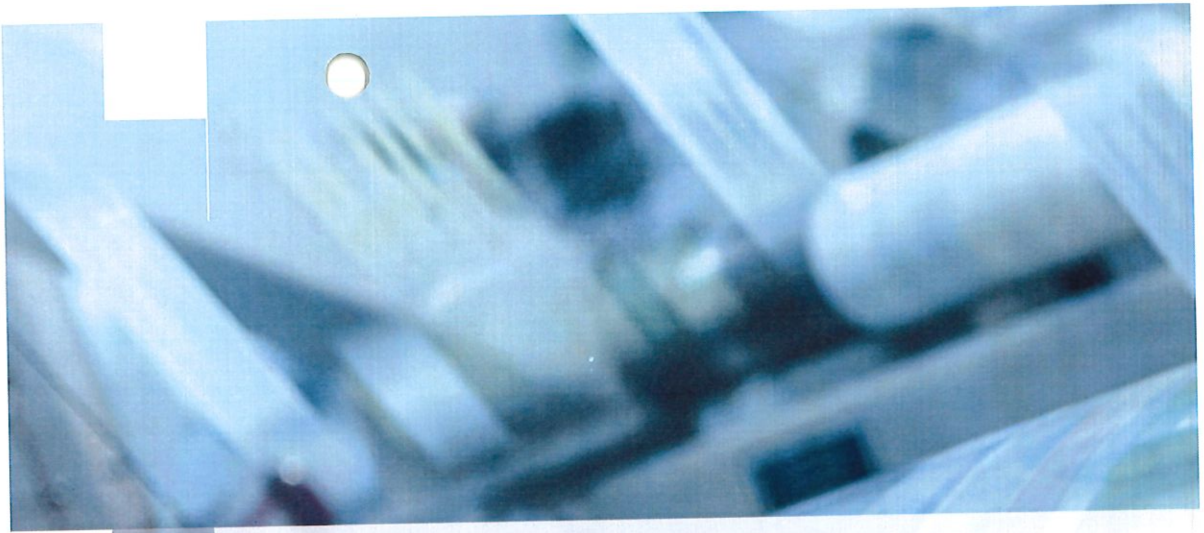
...fossil fuel use declines sharply after 2030 – but it cannot be eliminated
...ctors to the extent that warming is limited to well below 2°C. Even with a
...uite of technologies available and a 50-year timeframe for deployment,
...echnologies and energy services can be swapped out for non-emitting
...ives at the necessary pace. Indeed, in so-called "hard-to-abate" sectors,
...al alternatives have yet to be developed, and innovation rather than
...nent is still the current order of the day.

THE ENERGY SYSTEM CO_2 EMISSIONS IN **SKY** TRANSFORM TO NET-ZERO BY 2070



...Other" represents other energy-sector activities, such as the transport and refining of fossil energy,
...sed heat generation, and in the future, hydrogen production.

...: Shell analysis



REMOVING CARBON THROUGH USE

Carbon capture and use (CCU) operates very differently from CCS (permanent geological storage). There are examples of capture and use in practice today, such as the conversion of CO_2 to certain chemicals (for example, urea, the basis for fertilisers) and the production of plastics such as polycarbonates. These processes all require CO_2 as a feedstock, but are not necessarily designed to store it permanently. If the carbon is returned to the atmosphere, such as through the degradation or incineration of the product that is made, then the net impact of the process may be zero in terms of atmospheric CO_2 levels.

In a future energy system, there are two ways in which CCU could become effective:

- CCU might be focused on manufacturing synthetic hydrocarbon fuels, which could displace the need for fossil hydrocarbons. However, the synthetic fuels industry would need substantial technological innovation and then would need to scale very significantly before it could have a material impact, so this route is unlikely to be a significant contributor over the timescale addressed in **Sky**. Synthetic fuels are... a sink in themselves, since once the... made and used, the CO_2 is returne... the atmosphere.
- CCU could be applied to the manu... of certain goods – for example, buil... materials or plastics. But to act as a... mitigation mechanism akin to CCS,... must lead to more-or-less permanent... storage. The total stock of the produ... be maintained for a very long time (... a century or more) for CCU to appr... CCS equivalence. In **Sky**, fossil fuel... bio-feedstocks are used to make suc... products, acting as an effective carb...

This situation means that assigning a m... value to CCU plays a critical role. Doi... for CCS is a relatively simple task – ea... tonne stored can be counted as perm... mitigation and will contribute to the ov... task of reaching net-zero emissions. Th... cannot be said for CCU. While carbo... be embedded in urea or polycarbona... there is no established protocol to defi... as permanent mitigation. Work remair... done in this field.

every facet of the current energy
ɔs either changed or is in transition
remaining fossil fuel use leads to
; of some 15 Gt CO_2 per year,
to 11 Gt by 2100. This is about one
ɔday. For this reason, emission sinks
oving CO_2 from the atmosphere)
ı most long-term, low-emission energy
;, including **Sky**.

Agreement recognises this reality
:alls for a balance between
; by sources and removals by sinks of
ıse gases. Importantly, the Agreement
es that even after significant mitigation
ough substitution, greenhouse gas
; will continue, meaning that sinks will
tial at some level.

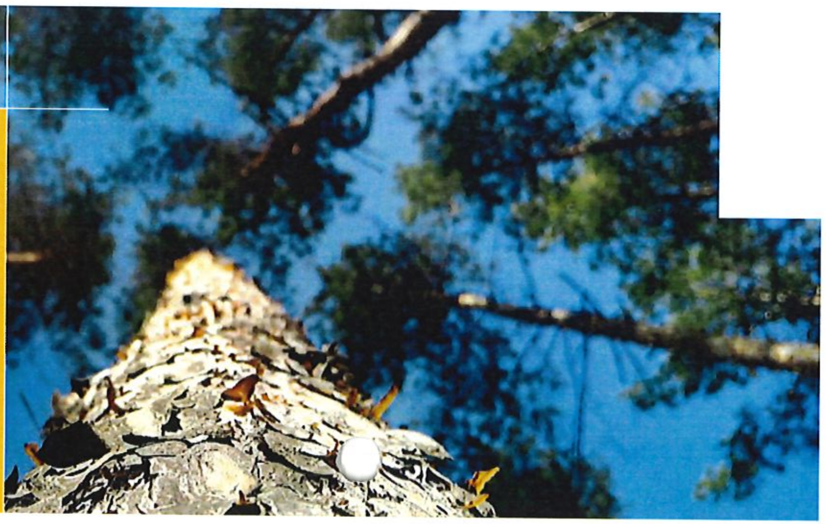
ing mechanisms in the ' system

ıe energy sector, **Sky** utilises three
sms that either prevent the release of
emove CO_2 from the atmosphere.
he mechanisms handle one trillion
CO_2 over the course of the century.

1. Conventional CCS applied in large point-source emitting facilities such as cement plants or iron ore smelters. The CO_2 is geologically stored, typically two to three kilometres below the surface. CCS technology is applied at scale in several facilities around the world today.
2. Conventional CCS applied in power plants operating with a sustainably produced biomass feedstock. In totality, this mechanism results in net removal of CO_2 from the atmosphere.
3. The production of various products, such as plastics, from fossil fuels or a biomass feedstock. These materials are then used by society and can deliver effective storage of carbon rather than releasing it to the atmosphere as CO_2. When the carbon is derived from biomass, this mechanism also results in net removal of CO_2 from the atmosphere.

The issue of greenhouse gas emissions extends beyond energy use, and there is also interplay between the energy system and natural systems, for example, when using bioenergy. **Sky** recognises this and the scope that exists for actions in one system to help the other and vice versa.

In Sky, changes in land-use and an end to deforestation are critical to the overall outcome. But large-scale reforestation can be a game changer, with the potential to push even further to the ambitious 1.5°C goal of the Paris Agreement.



Nature-based solutions: Reforestation, restoration, and avoided deforestation

Land-use change throughout the world over the last century (but extending back hundreds of years) has contributed to the rise in atmospheric CO_2 and continues to do so. The Global Carbon Project has estimated that land-use changes have resulted in five Gt CO_2 per year being emitted for each of the last 20 years. If these changes can be stopped, many degraded ecosystems can be restored. The Nature Conservancy has estimated that around 500 Gt CO_2 in total can be drawn down from the atmosphere at costs today below US$100/tonne CO_2 and sustainably stored by improved soils and extended forest cover.

The fourth mechanism introduced into the scenario is one that is widely understood and much used today – reforestation, restoration of degraded land, and avoided deforestation. Without tackling these areas alongside the energy system, overall net-zero emissions cannot be achieved. **Sky** assumes significant land-related actions to bring the land-use and agricultural systems back into balance and ensure that by 2070 net deforestation has reached zero.

Further, very large-scale reforestation could accompany this, offering the opportunity to remove additional carbon from the atmosphere and thereby approaching the stretch goal of the Paris Agreement – to limit the rise of the global average surface temperature to just 1.5°C.

The scale of change required in the land-use sector will require action by governments, both domestically and through international cooperative mechanisms, such as those included within the Paris Agreement.

The design, implementation, and use c
these mechanisms can trigger private :
involvement, which in turn could accel
the necessary activities.

Early action is important in this area gi
the decadal process of restoration anc
reforestation. Therefore, in **Sky**, these r
focused practices play an important rc
alongside the transformation of energy
across the economy. Indeed, in the cc
decades, some of the initial impetus fc
developments can come through indus
support and utilisation of certified acti\
and traded certificates to compensate
hard-to-mitigate energy-related emissio
CORSIA (Carbon Offsetting and Redu
Scheme for International Aviation), the
agreed by the aviation industry in 201
counter the rising emissions in that sec
a good example – nature-based soluti
feature within their proposed offset cat
Over time, however, in **Sky**, systems sı
CORSIA shift towards one of the three
capture categories above for offset pu

By 2070 the goal of net-zero emission
achieved within the energy system, an
interplay between energy and natural
continues. As illustrated, the energy sy:
balance is reached through combininç
use and geological CO_2 storage with
feedstocks to balance remaining fossil
emissions still going to the atmosphere

Through a broader swathe of actions ı
all sectors, including steps taken to bri
deforestation to zero and to begin the
of land restoration, the overall Paris Aç
goal of balancing remaining anthropo
greenhouse gas emissions with sinks ir
second half of the century is achieved

]RE-BASED SOLUTIONS: EXTENDING AMBITION)UGH RESTORATION OF NATURE

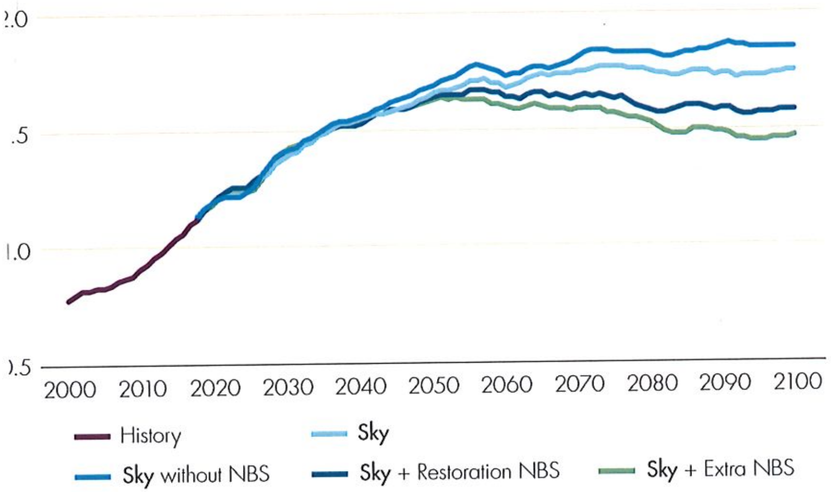
e case for **Sky** assumes that CO_2 ; from land-use change fall to zero by line with the energy system reaching emissions at the same time. But the n of ecosystems, including large-scale ion, can play a critical additional ducing a net draw-down of CO_2 atmosphere and therefore offering a to the ambitious 1.5°C outcome.

barriers can be overcome, such as ct on agricultural communities, these ised solutions (NBS) can help to k warming because scale-up can derably faster than transformation of echnologies.

from institutions such as MIT, the is Center at Woods Hole, and ure Conservancy has indicated idditional drawdown beyond **Sky** of 10 Gt CO_2 per year is feasible through reforestation, although the scale of the task is very large. Some 700 million hectares of land would be required over the century, an area approaching that of Brazil.

We have run two sensitivities on the **Sky** scenario, in consultation with The Nature Conservancy (TNC) and MIT. The first sensitivity involves accelerated avoidance of deforestation and the introduction of a similar scale of restoration. We have called this "**Sky** + Restoration NBS". This adds five Gt CO_2 per year drawdown to **Sky**. The second sensitivity, "**Sky** + Extra NBS", is required to limit warming to 1.5°C and assumes many cost and social barriers can be overcome more successfully so that an additional drawdown rate of 10 Gt CO_2 per year (i.e., 15 Gt per year in total) can be reached.

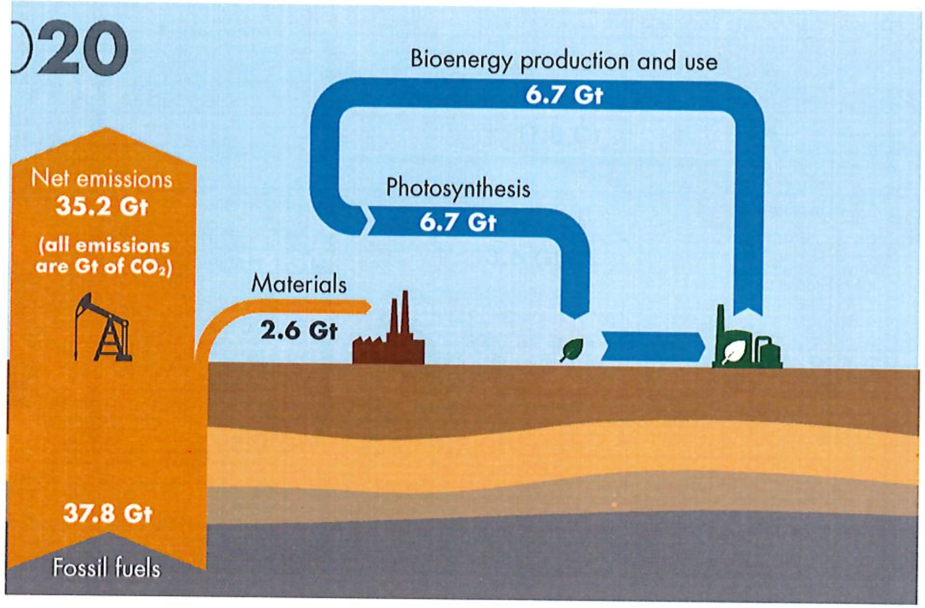
DING AMBITION IN **SKY**



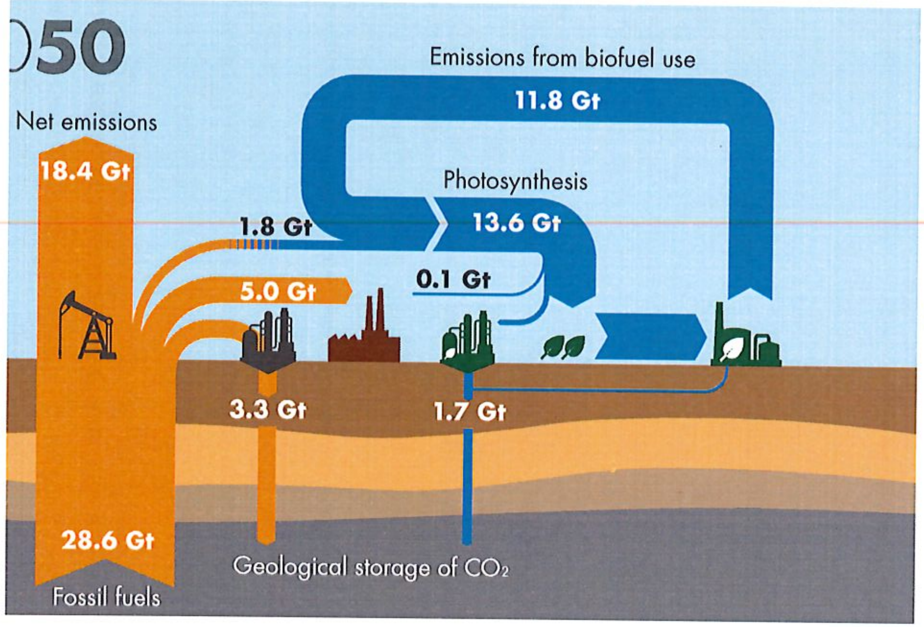
Shell analysis, MIT

:VOLVING ENERGY SYSTEM CO_2 BALANCE SHEET IN SKY

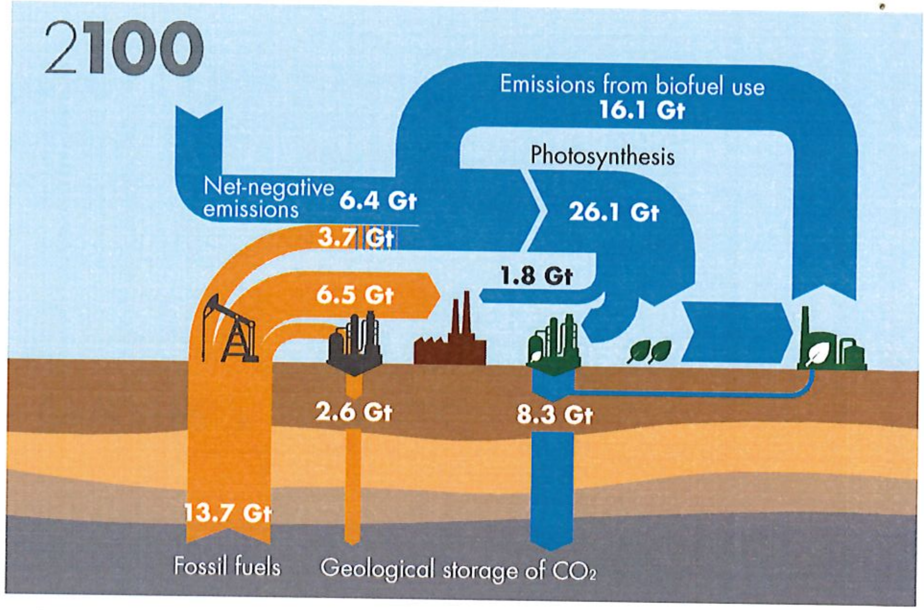
:l production | CCS | Biofuel production | Bioenergy with CCS | Carbon in products | Growi mass



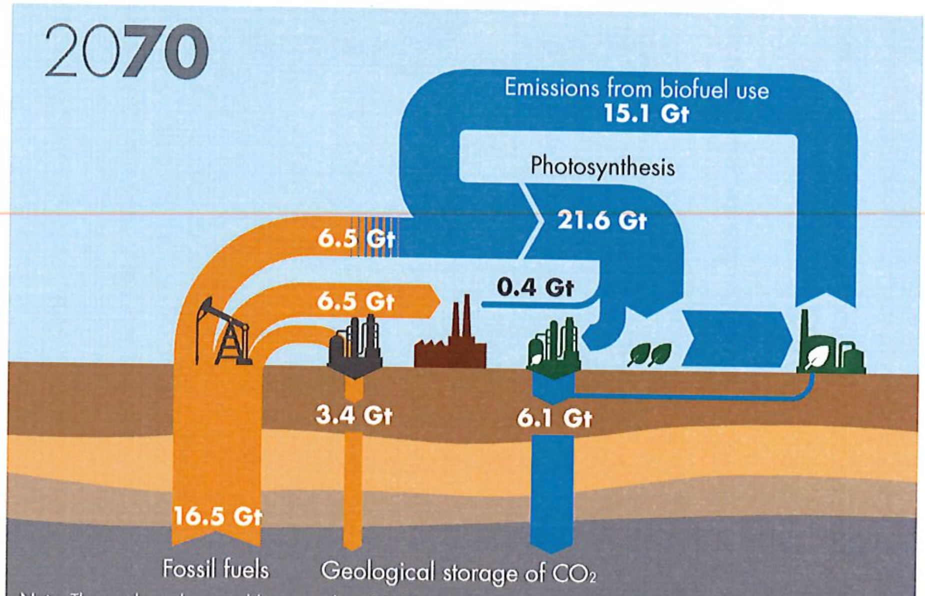
ıost carbon in fossil energy production is burned and emitted to the atmosphere, : CO_2 absorbed by wood and other plants used for energy is also returned to sphere.



ı 2050, the storage of CO_2 is rapidly scaling up. There are equal contributions from ›dded carbon in materials production and CCS. Fossil energy CCS leads the way

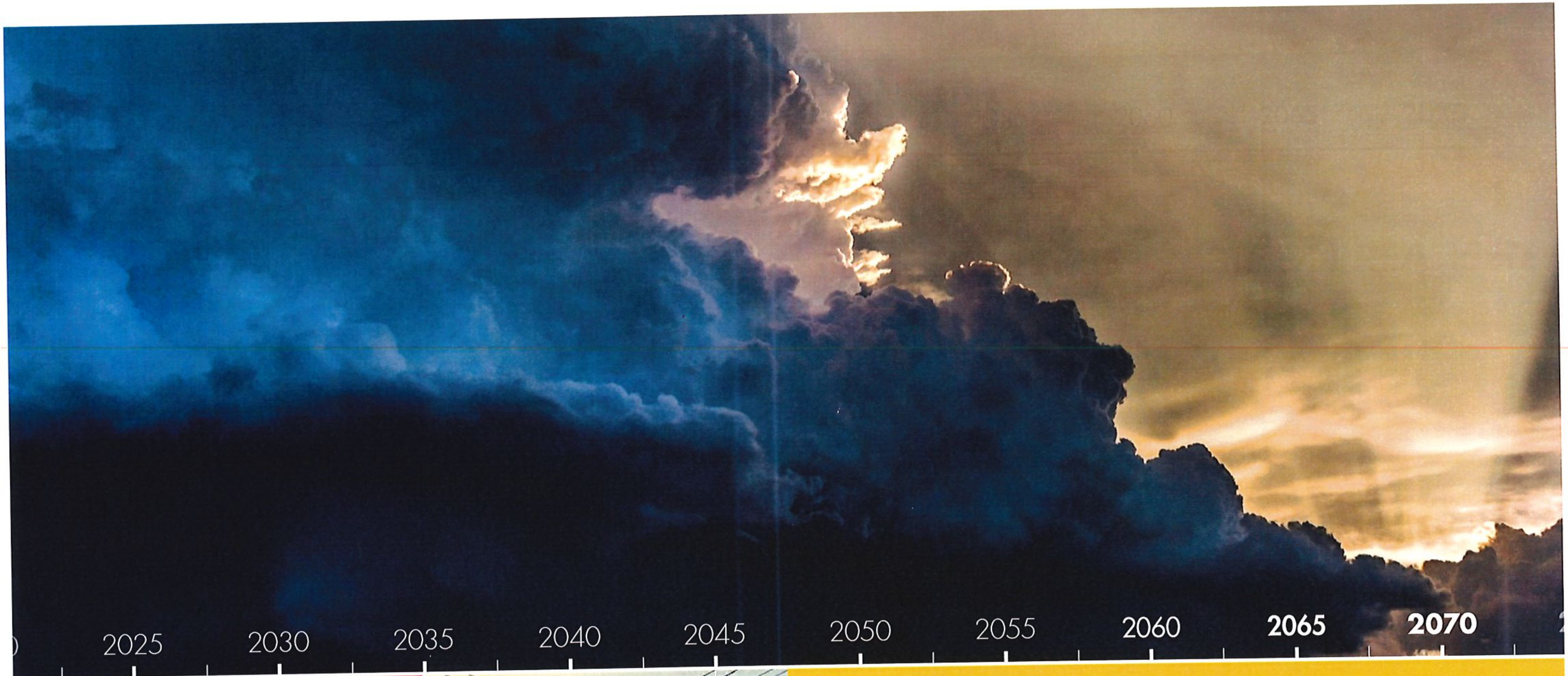


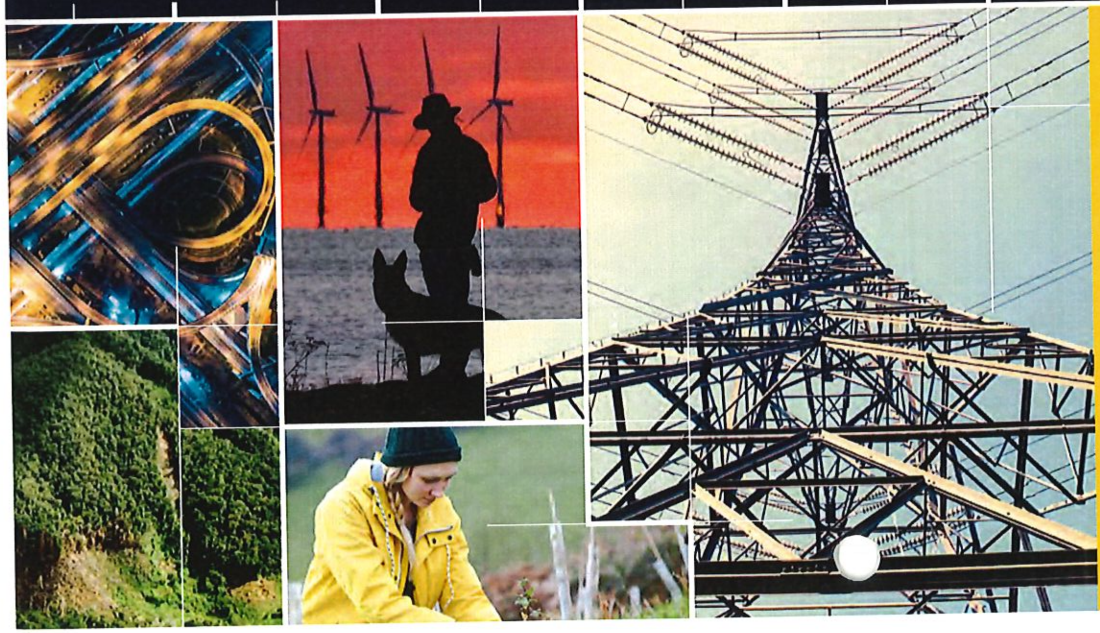
In **Sky**, at 2100, the bioenergy system has reached its resource base limit and is twice the size of the fossil energy system in CO_2 terms. The active management of CO_2 means that the total energy system is providing a drawdown of CO_2 from the atmosphere.



Note: The numbers do not add up exactly in 2070 owing to rounding up of data.

In **Sky**, in 2070, the energy system has achieved net-zero emissions. Fossil energy production less than half today's level. Alongside direct CCS and the use of carbon for materials, the rer





CHAPTER 7
THE PARIS AMBITION REALISED

⊣E PARIS AMBITION REALISED

beyond 2070, carbon capture levels off at around 12 Gt per year,
ıil fuel use continues to decline. This takes the overall energy system into
e emission territory, which draws down on accumulated carbon within the
ıre. As a result, warming peaks during the 2070s and levels out through
ance of the century.

, warming of the climate system
› around 1.75°C according to
dent expert analysis of the energy-
missions trajectory described by
ddition, a meaningful legacy
emoval industry offers the 22nd-
ociety the opportunity for further
estoration.

on to the actions covering the energy
utlined in **Sky**, significant reforestation
nd restoration of natural ecosystems,
wetlands, offer the possibility of
varming to 1.5°C, the ultimate
of the Paris Agreement.

Of course, the big challenge is whether there is the political will and, underlying this, the societal will to put in place and maintain the frameworks that are necessary to address this awe-inspiring task – re-wiring the whole global economy in just the next 50 years.

The Sky scenario outlines what we believe to be a technologically, industrially, and economically possible route forward. This should give us all some hope – and perhaps some inspiration. In more practical terms, perhaps this analysis can provide useful pointers to areas where focused attention could produce the best results.

The **future** depends on what we do in the **present.**

Mahatma Gandhi

Acknowledgements

We wish to thank the many people consulted externally in the development of **Sky**.

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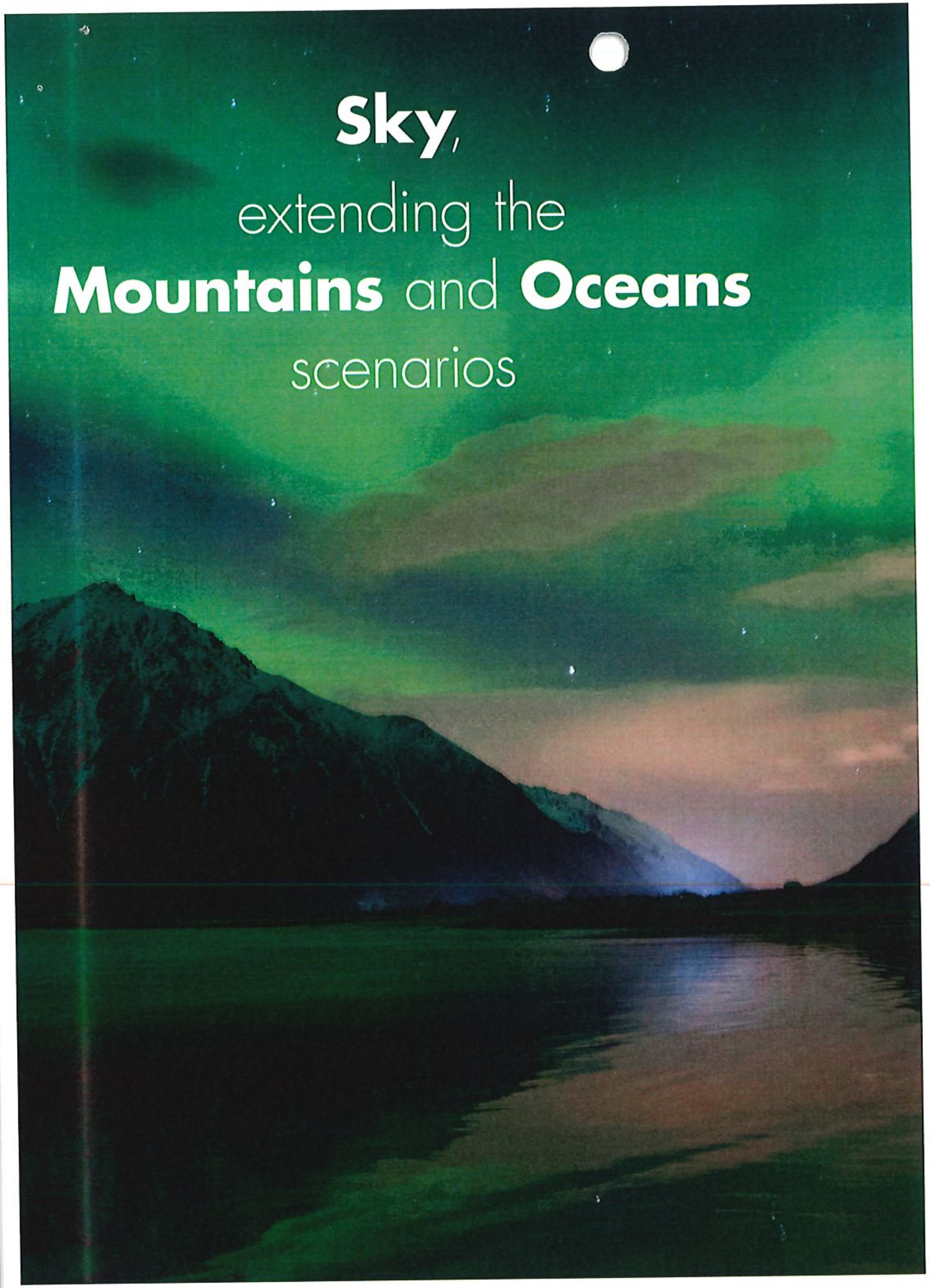
We would like to recognise the Massachusetts Institute of Technology (MIT) Joint Program on the Science and Policy of Global Change for assessing the climate impacts of **Sky** and contrasting it with **Mountains** and **Oceans**.

For the **Sky** scenario, MIT modelled the impact using their Integrated Global System Modelling (IGSM) framework. Shell has donated US$100,000 to the Joint Program in recognition of the effort. MIT will publish a Joint Programme Report on the work it has don

This work is partially based on historical data from the International Energy Agency's (IEA) World Extended Energy Balances © OECD/IEA 2017. The work has been prepared by Shell International B.V. and does not necessarily reflect the views of the IEA.

Please visit www.shell.com/skyscenario for additional data tables and further background information.



GLOSSARY

Energy Units

bcma	billion cubic metre per year
GJ	gigajoule (10^9 joule). The joule, J, is a unit of energy; 4.2 J are needed to heat one gram of water by 1°C.
EJ	exajoule (10^{18} joule)
kWh	kilowatt-hour (There are 3600 J per Wh). The unit Wh is commonly usec electricity generation, and J for energy more broadly.
TWh	terawatt-hour (10^{12} watt-hour, or one trillion watt-hours). A one GW pow station operating for 300 days per year will produce about seven TWh.
GW	gigawatt (10^9 watt, one billion watts). A one GW power station is the t size for a modern coal, gas, or nuclear installation.
Gt	gigatonne (10^9 tonne)

Other Terms

BECCS	bioenergy with carbon capture and storage
CCS	carbon capture and storage
CCU	carbon capture and use
EV	electric vehicle, defined as either a battery electric vehicle or a plug-in h electric vehicle
FCEV	fuel-cell electric vehicle
LPG	liquefied petroleum gas
NBS	nature-based solutions; the use of avoided deforestation, reforestation, a other restoration of natural ecosystems
NDC	nationally determined contribution; the actions countries take to reduce greenhouse gas emissions under the Paris Agreement
NZE	net-zero emissions, i.e., a balance between anthropogenic emissions by and removals by sinks of greenhouse gases
primary energy	the supply of energy sources including oil, natural gas, coal, bioenergy, energy, and renewables. Primary energy is energy drawn from nature, ir first usable form.
final energy	the demand for energy carriers, such as electricity or liquid fuels, by final consumers, such as industry, households and transport, for all their energy When natural gas is used for home heating, it is counted as final energy; is used to generate electricity in a power station it is counted as primary e
solar PV	solar photovoltaic panels used for electricity generation

.L DISCLAIMER

let contains data from Shell's new **Sky** Unlike Shell's previously published s and **Oceans** exploratory scenarios, the ario is targeted through the assumption ty reaches the Paris Agreement's goal g global average temperatures to well C. Unlike Shell's **Mountains** and **Oceans** which unfolded in an open-ended d upon plausible assumptions and tions, the **Sky** Scenario was specifically to reach the Paris Agreement's goal in a / possible manner. These scenarios are a ongoing process used in Shell for over to challenge executives' perspectives ure business environment. They are to stretch management to consider ts that may only be remotely possible. , therefore, are not intended to be s of likely future events or outcomes and hould not rely on them when making an t decision with regard to Royal Dutch Shell ies.

lly, it is important to note that sting portfolio has been decades in ent. While we believe our portfolio is ider a wide range of outlooks, including 450 scenario (World Energy Outlook includes assets across a spectrum of ensities including some with above- ntensity. While we seek to enhance our s' average energy intensity through both opment of new projects and divestments, no immediate plans to move to a net-zero portfolio over our investment horizon of ars. Although, we have no immediate move to a net-zero emissions portfolio, in r of 2017, we announced our ambition to r net carbon footprint in accordance with mplementation of the Paris Agreement's olding global average temperature low 2°C above pre-industrial levels. gly, assuming society aligns itself with the eement's goals, we aim to reduce our net otprint, which includes not only our direct ct carbon emissions, associated with the energy products which we sell, but ustomers' emissions from their use of the oducts that we sell, by 20% in 2035 and n 2050.

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