INEVITABLE POLICY RESPONSE

The Inevitable Policy Response: Forecast Policy Scenario

Preparing financial markets for climate-related policy and regulatory risks

Consortium partners

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The authors are solely responsible for any errors.

Glossary

- AgTech - Agriculture technology
- BECCS - Bioenergy with carbon capture and storage
- BNEF - Bloomberg New Energy Finance
- CAGR - Compound average growth rate
- CCS - Carbon capture and storage
- CDR - Carbon dioxide removal
- CH_4 - Methane
- CO_2 - Carbon dioxide
- CPS - Current Policies Scenario
- DAC - Direct air capture
- LT-DAC - Low temperature solid sorbent
- EV - Electric vehicle
- FPI - Food Price Index
- FPS - Forecast Policy Scenario
- GHG - Greenhouse gas
- ICE - Internal Combustion Engine
- IEA - International Energy Agency
- IPR - Inevitable Policy Response
- N_2O - Nitrous oxide
- NDC - Nationally determined contributions
- NEO - New Energy Outlook
- NETs - Negative emission technologies
- NPS - New Policies Scenario
- P1 - An IPCC 1.5°C scenario
- P2 - An IPCC 1.5°C scenario
- SDS - Sustainable Development Scenario
- STEPS - Stated Policies Scenario
- TCFD - Task Force on Climate-related Financial Disclosures
- ULEV - Ultra low emission vehicles
- WEO - World Energy Outlook

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Financial markets are underprepared for climate-related policy risks

A forceful policy response to climate change is not priced into today's markets.

Yet it is inevitable that governments will be forced to act more decisively than they have so far, leaving investor portfolios **exposed to significant risk.**

The longer the delay, the more disorderly, disruptive and abrupt the policy will inevitably be.

In anticipation, PRI, Vivid Economics and ETA are building a landmark forecast of the financial impact of this Inevitable Policy Response (IPR), including a Forecast Policy Scenario:

- How will it affect the economy?
- Which sectors are most at risk?
- Which asset classes will be impacted?

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Value-add of the IPR: **Forecast Policy Scenario (FPS)**

- **A high conviction policy-based forecast**, not a hypothetical scenario that optimises policy to meet a temperature constraint
- **Designed to be an alternative** to, for example, the IEA STEPS for business planning by corporations, investors and governments
- **Covers all regions of the world**, with specific policy forecasts for key countries and regions
- **Sets out the gap to 1.5°C** scenarios and how this might be filled by greater policy aspiration
- **Transparent**: on expectations for policy and deployment of key technologies, such as Negative Emission Technologies
- **Complete**: includes macroeconomic, energy system, and land use models linking crucial aspects of climate across the entire economy
- **Fully integrating land-use** to ensure the full system impacts of policies, and highlight the critical role of land use
- **Applicable to TCFD**: aligned forward-looking analyses

Later this year, the IPR will extend from macro and sector level results to portfolio and company level financial impacts to show investors the cost and impacts of this delayed, forceful and disruptive policy response forecast, and to make the case to ACT NOW and aspire to a more orderly transition to 1.5°C

We believe that any forecast will need to contain these elements. We welcome feedback on the forecasted policies and the results to enhance value-add and relevance on an ongoing basis.

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Growing awareness and momentum on climate issues makes a near-term, forceful policy response more likely

Extreme weather events

Impacts on security

The effects of a changing climate are **a national security issue.**

- US Dept. of Defense

Cheaper renewable energy

FINANCIAL TIMES

Europe 'watershed' as green energy set to overpower coal

JUNE 3, 2019

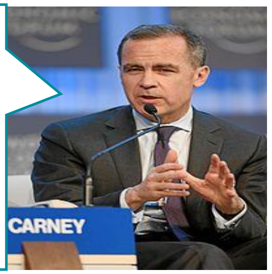
New climate research

Global warming report, an 'ear-splitting wake-up call' warns UN chief

Civil society action

Regulators warning on stability

The catastrophic effects of climate change are already visible around the world. We need collective leadership and action across countries, and we need to be ambitious.



Uninsurable World

Munich RE

"Climate change could make insurance too expensive for most people"

MOODY'S INVESTORS SERVICE

"Climate change risks outweigh opportunities for P&C (re)insurers"

Influence Shifting

FINANCIAL TIMES

GRAPHICS OPINION WORK & CAREERS LIFE & ARTS HOW TO SPEND IT

BHP UK investors urge halt to fossil fuel lobbying

The Sydney Morning Herald

Activist shareholders make history in anti-lobby resolution at Origin AGM

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Timing: Paris Ratchet process triggers a cumulating policy response into 2025

2020

Countries communicate their updated or 2nd round of climate pledges

2023

Global stocktake on climate, mitigation and finance

2025

Countries submit their 3rd round of climate pledges (NDCs)

2028

Second global stocktake

Policy announcements are expected to accelerate in 2023-2025

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Key policies we forecast are detailed in the IPR Policy Forecasts:

Coal phase-outs

- Early coal phase-out for first mover countries by 2030
- Steady retirement of coal-fired power generation after 2030 in lagging countries

ICE sales ban

- Early sales ban for first mover countries by 2035
- Other countries follow suit as automotive industry reaches tipping point

Carbon pricing

- US$40-80/t$CO_2$ prices by 2030 for first movers
- Global convergence accelerated by BCAs to ≥$100/t$CO_2$ by 2050

CCS and industry decarbonisation

- Limited CCS support in power
- Policy incentives primarily for industrial and bioenergy CCS
- Public support for demonstration, and then deployment of hydrogen clusters

Zero carbon power

- Significant ramp-up of renewable energy globally
- Policy support for nuclear capacity increase in a small set of countries, nuclear managed out elsewhere

Energy efficiency

- Increase in coverage and stringency of performance standards
- Utility obligation programs,
- Financial and behavioral incentives

Land use-based GHG removal

- Strong policy support for re/afforestation
- Stronger enforcement of zero deforestation
- Controlled expansion of bioenergy crops

Agriculture

- Technical support to increase agricultural productivity
- Increasing public investment in irrigation and AgTech
- Incremental behavioural incentives away from beef

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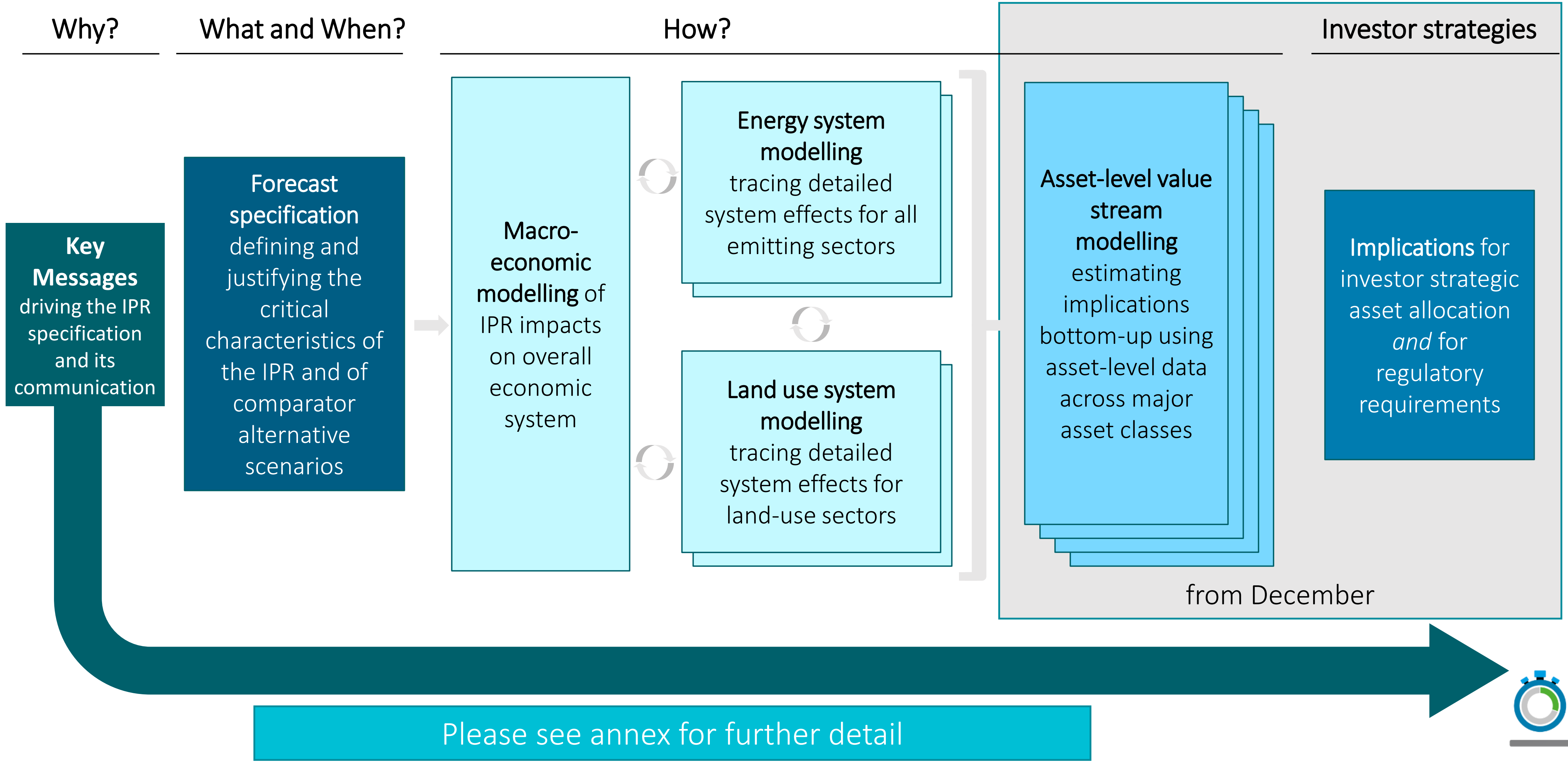
Enabling a green economy

'Just Transition' lens to ensure social and political feasibility

A fully-integrated modelling framework from policy to financial markets



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The Inevitable Policy Response (IPR) has three parts

2023-2050

The **Forecast Policy Scenario (FPS)** which lays out the policies and their impact expected from 2025 to 2050 based on IPR policy announcements 2023-2025

2050-2100

A **trend-constrained pathway** from 2050 to 2100 that reflects continued linear trends in energy, transport, industry and land-use, including the introduction of greenhouse gas removal options (such as nature-based solutions and BECCS) as known today

A **1.5°C Aspirational discussion** which looks at how this could accelerate further, particularly if there were a stronger policy push after 2035, and deeper deployment of greenhouse gas removal technologies past 2050

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Setting the context

The Forecast Policy Scenario (FPS) lays out the implemented policies for sectors and the economy from 2025 to 2050 based on the Inevitable Policy Response forecasts for the Paris ratchet process (2023-25).

Many well-established scenarios exist which we use to compare in our detailed analysis below.

Key 'reference' for comparison are those published by the IEA and the IPCC.

The International Energy Agency (IEA) produces three scenarios using the World Energy Model: **Stated Policies Scenario (STEPS), the Sustainable Development Scenario (SDS) and the Current Policies Scenario (CPS).**

- The STEPS includes policies which have already been stated and policies which are outlined under the Nationally Determined Contributions (NDC) made for the Paris Agreement. Many corporations reference this in discussions of their business planning and we believe markets are in effect priced on this.
- The SDS is a more ambitious scenario which is aligned to climate target of 'well below 2°C' according to the IEA.
- Our comparisons are based on World Energy Outlook 2019.

The IEA undertake energy modelling but do not consider the implication on land-use and the economy in an integrated way.

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Setting the context

The IPCC have collated many different modelling exercises which consider the integrated impacts of climate policy on the macroeconomics, energy-system, and land-use.

These modelling exercises are often based on scenarios which are constrained to a specific temperature target and therefore may include policies modelled which do not account for institutional and political readiness, technology readiness, or behavioural and societal momentum.

We investigate two representative 1.5° pathways:

- P1 is a scenario in which social and technological innovations reduce energy demand dramatically up to 2050. There is a rapid decarbonisation of the energy system and neither fossil fuels with CCS or BECCS are used.
- P2 is a scenario with a focus on sustainable consumption patterns and low-carbon technological innovations. There is limited societal acceptability for BECCS but with well-manage land systems.
- Both P3 and P4 scenarios deploy significant amounts of Negative Emissions Technologies (see page 95).

The IPR FPS provides a complete integrated scenario built upon realistic policy implementation to challenge investors to evaluate their own forecasts and to help strengthen the discussion on forecasts of policy action towards a Paris-aligned 'well below 2°C' outcome and prepare financial markets for climate-related policy risk.

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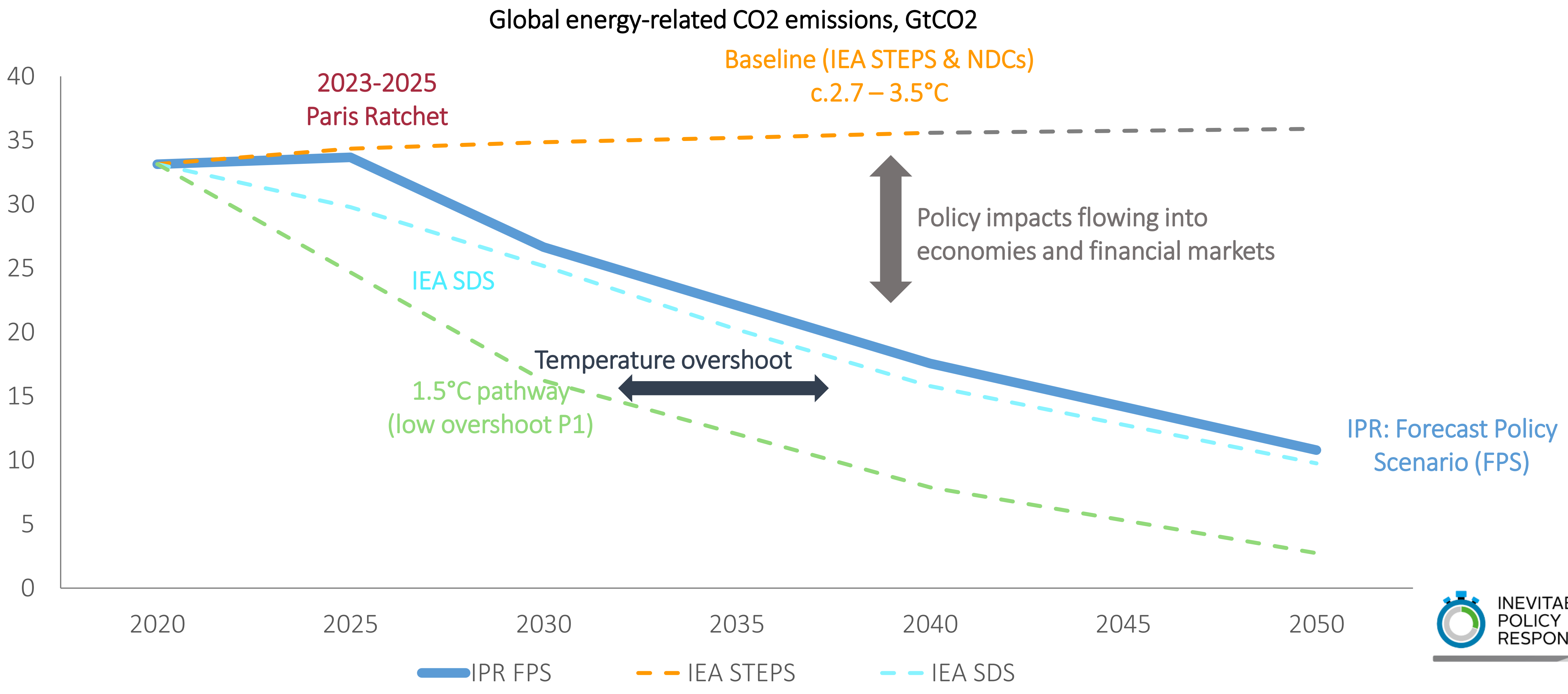
The IPR: Forecast Policy Scenario (FPS) facilitates discussion around a business planning case to fully value climate-related policy risk



Headline takeaways for investors

Deep and rapid changes in the energy system

- Oil to peak in 2026-28
- Thermal coal virtually non-existent by 2040
- Renewables generating approximately half of all electricity in 2030

Transport electrified inside 20 years

- ICE sales bans, supported by falling cost of EVs, drive rapid deployment of ultra-low emissions vehicles
- Making up almost 70% of passenger vehicles by 2040

Major changes in land use

- Deforestation virtually eliminated by 2030, with pressures on supply chains
- Large opportunities to invest in nature-based solutions

Rapid reductions in carbon emissions, but not enough to hit 1.5°C

- > 60% fall in global CO_2 emissions by 2050
- New innovative policy and industrial solutions, not yet proven or achieved at scale, are needed to achieve 1.5°C

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IPR FPS results in rapid emissions reductions towards reaching 2°C, but even greater action is required to meet a well below 2°C target*

Global GHG emissions in IPR FPS decline by 3.0% on average per year from 2025 to 2050 thanks to:

- Transformative decarbonisation of the power and transport systems
- Elimination of deforestation, and steady incorporation of nature-based solutions
- Maintaining and propagating the recent acceleration in energy efficiency
- Continued strong improvements in agricultural productivity

Nevertheless, IPR FPS expects slower progress than implied by existing 1.5°C and well-below 2°C 'constrained scenarios':

- There is a delay to policy action
- Industrial sector reductions less rapid due to less aggressive expectations for industrial demand reductions.
- Land-use sector reductions less rapid due to less aggressive expectations for radical dietary change, less disruptive changes in land-use, and resulting persistence of land-use emissions

The IPR FPS is significantly closer to the IEA SDS than the IEA STEPS by 2050, with combustion CO_2 emissions in 2050 25.1 $GtCO_2$ below STEPS and 1.0 $GtCO_2$ above SDS; however the pathway to decarbonisation differs significantly:

- IPR FPS expects rapid decarbonisation in power and transport, but does not expect as steep a contraction in energy demand, a rapid transformation of industry and the quick deployment of CCS underlying SDS
- IPR FPS sees negligible CCS in fossil fuel power
- IPR FPS more explicitly incorporates persistence of land-use emissions, which are not modelled in detail in SDS

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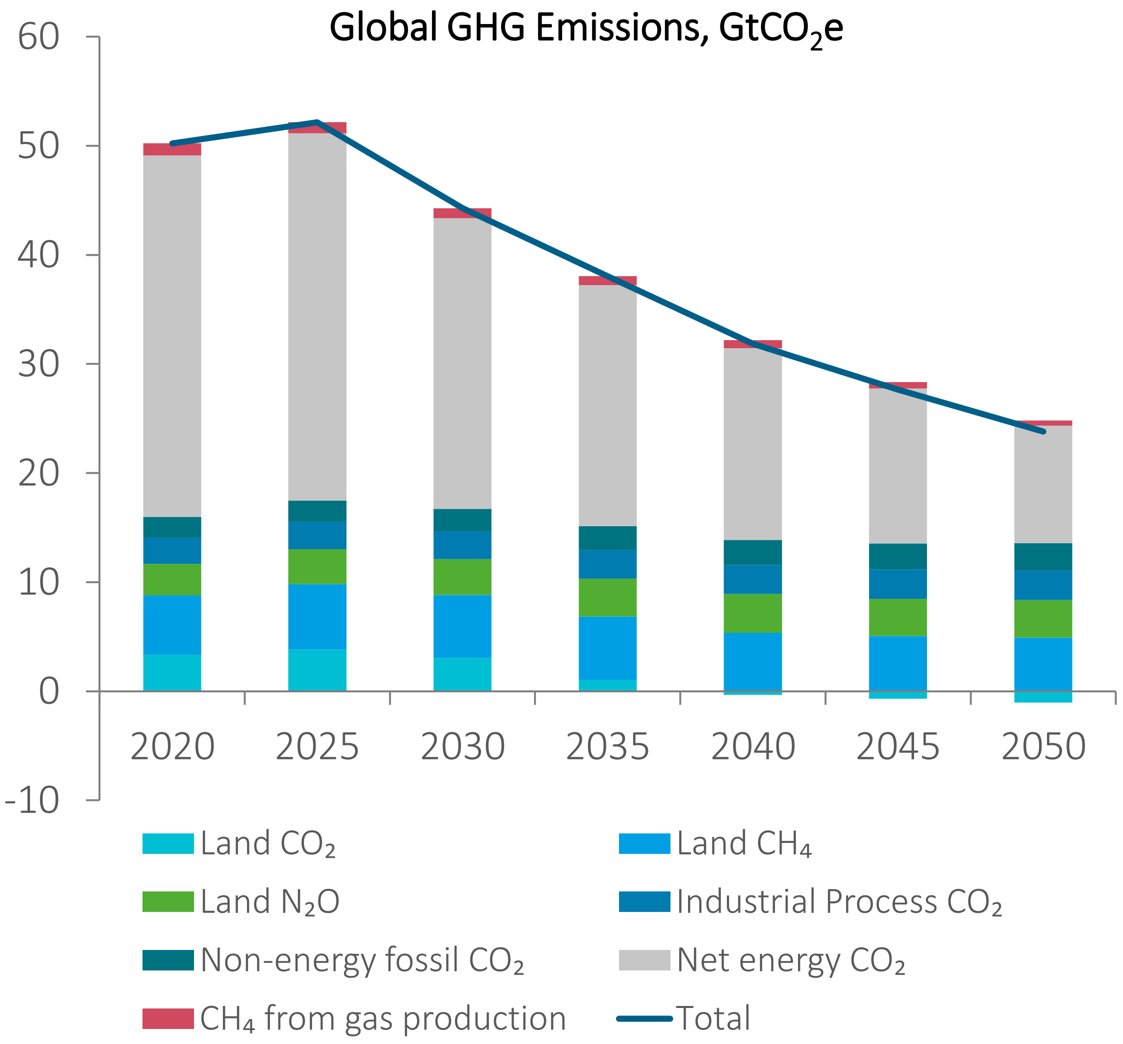
Note: The FPS was designed from the policy forecast, and not constructed to meet a specific temperature target. However, the accumulated GHG emissions of FPS to 2050 are consistent with and comparable to scenarios that label themselves as aligned to **2°C. Therefore, FPS can be used alongside (or in place of) 2°C scenarios for investors or corporates seeking to test the impact of a 2°C transition on their portfolios**

Global emissions fall rapidly



In the IPR FPS global emissions fall rapidly to 2050 following the IPR in 2023-2025

- Global CO_2 emissions fall by over 60%, while global GHG emissions fall by over 50%
- GHG emissions fall by around 3.0% annually from 2025 to 2050
- Energy-related CO_2 emissions decrease rapidly by around 4.4% annually from 2025 to 2050 which is comparable with 2°C aligned scenarios
- CO_2 emissions from land are negative from 2040 as moderate dietary shifts take effect, and policies gradually drive investment in agricultural productivity and incentivising a/reforestation
- N_2O and CH_4 emissions in land use will be harder to reduce, and are expected to persist to 2050

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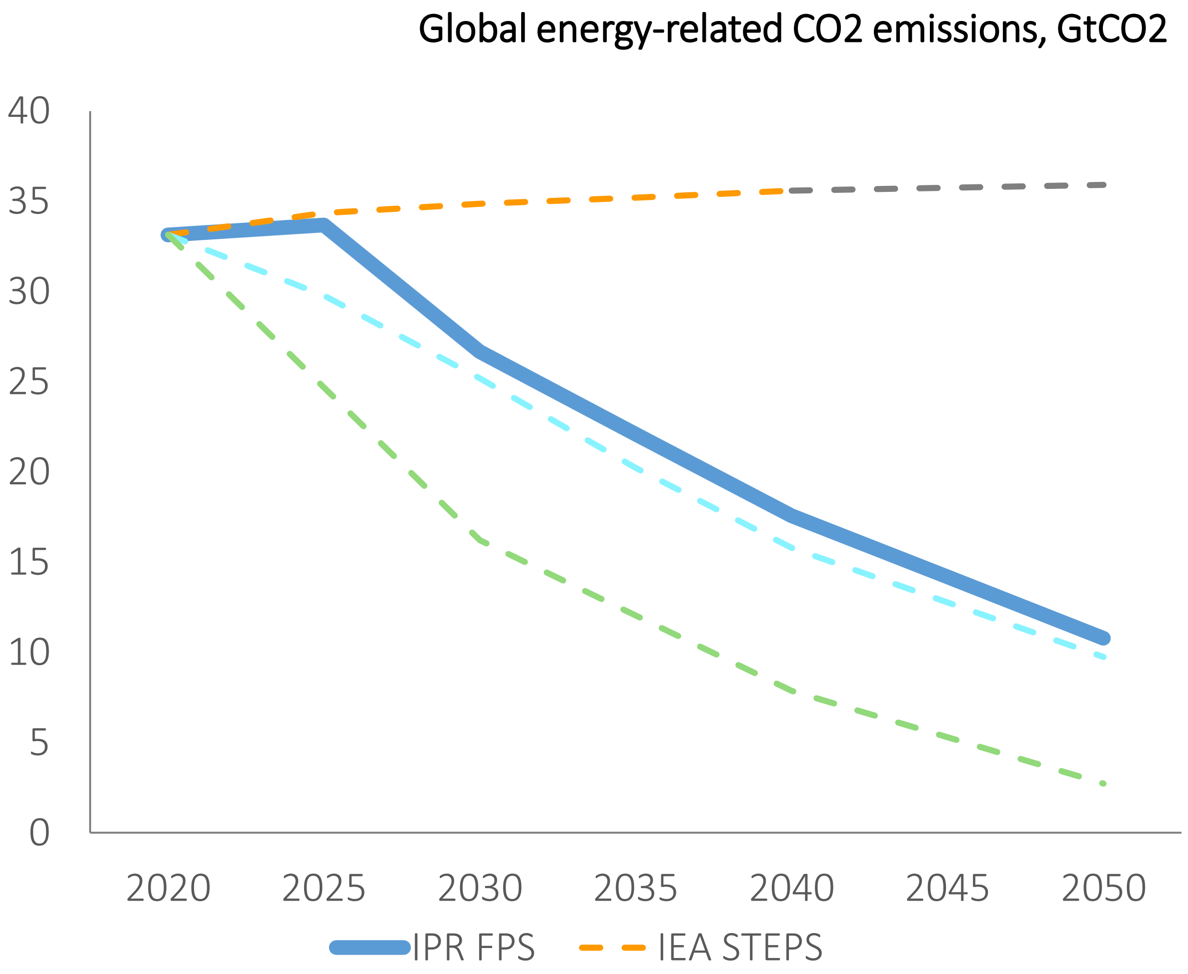
The IPR FPS reduces emissions compared with STEPS – but is still cumulatively above SDS



IPR FPS emissions peak in the 2020s due to the IPR in 2025. The emissions continue to decrease as the policy announcements come into effect and policy strengthens further

- The IPR FPS is significantly closer to the IEA SDS than the than IEA STEPS by 2050, with energy emissions 25.1 $GtCO_2$ below STEPS, but only 1.0 $GtCO_2$ above IEA SDS
- Energy-related CO_2 emissions decrease by around 60% 2025-2050 in the IPR FPS scenario. From 2025 to 2050 the SDS and IPR FPS scenarios decarbonise at the around same annual rate with SDS at 4.4% a year and IPR FPS at 4.5%
- The IPR FPS and IEA SDS decarbonise on similar pathways but meet these decarbonisation goals in different ways

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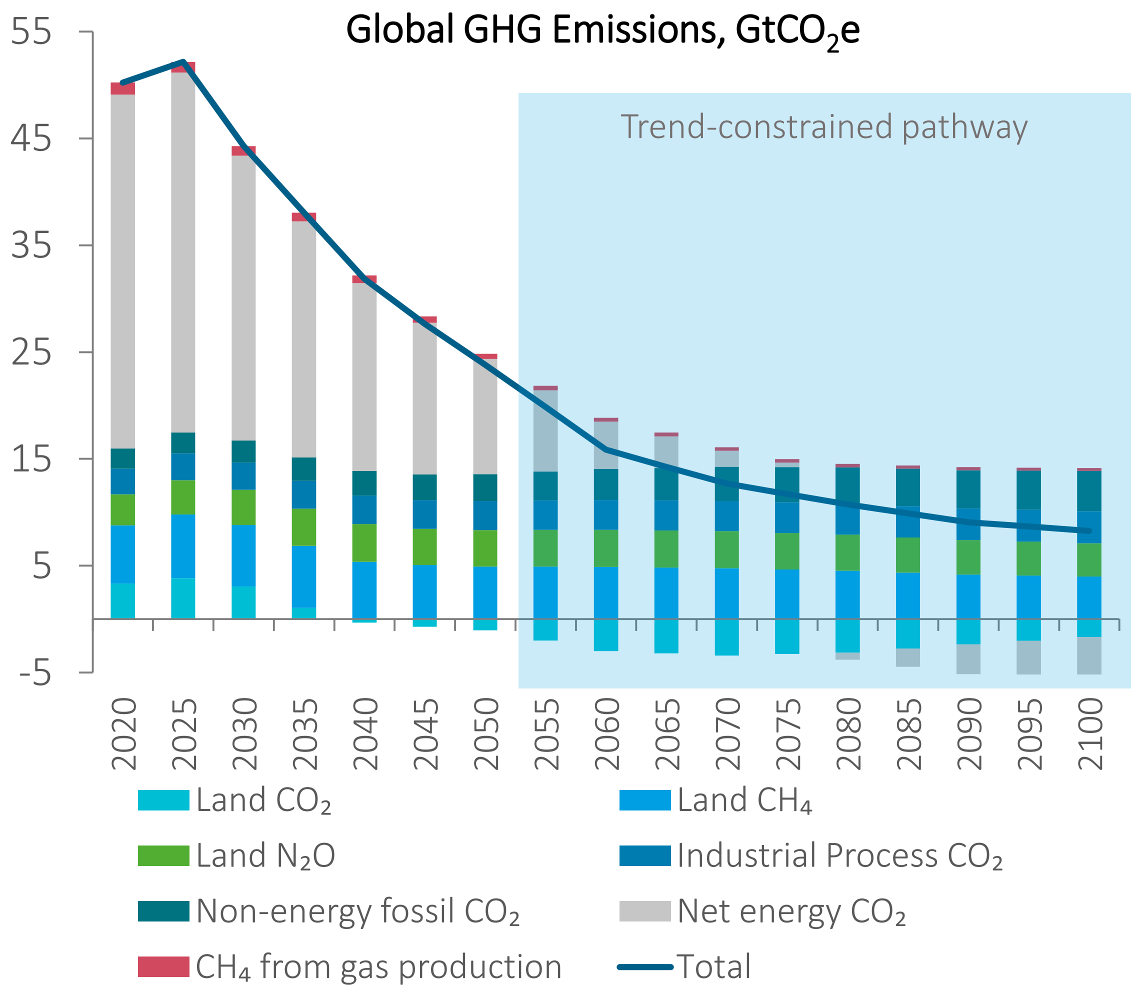
Note: as IEA does not project 2020 CO_2 emissions, IEA scenarios pathways aligned to IPR FPS scenario in 2020

The IPR FPS is forceful and, combined with the ‘trend-constrained pathway’ after 2050, leads towards 2°C, but does not lead to 1.5°C*



Trend-constrained pathway

- The trend constrained pathway assumes that from 2050 onwards there are no new breakthroughs in technology and that land use constraints are important in limiting Negative Emission technologies such as BECCS
- Energy-related CO_2 emissions are negative from 2090 onward driven by reductions in emissions and CCS in industry and some BECCS in power
- Hard to abate land emissions for N_2O and CH_4 persist through the end of the century
- This contrasts with IPCC P3 and P4 pathways that assume the deployment of large amounts of BECCS in order to reach their optimised temperature goal

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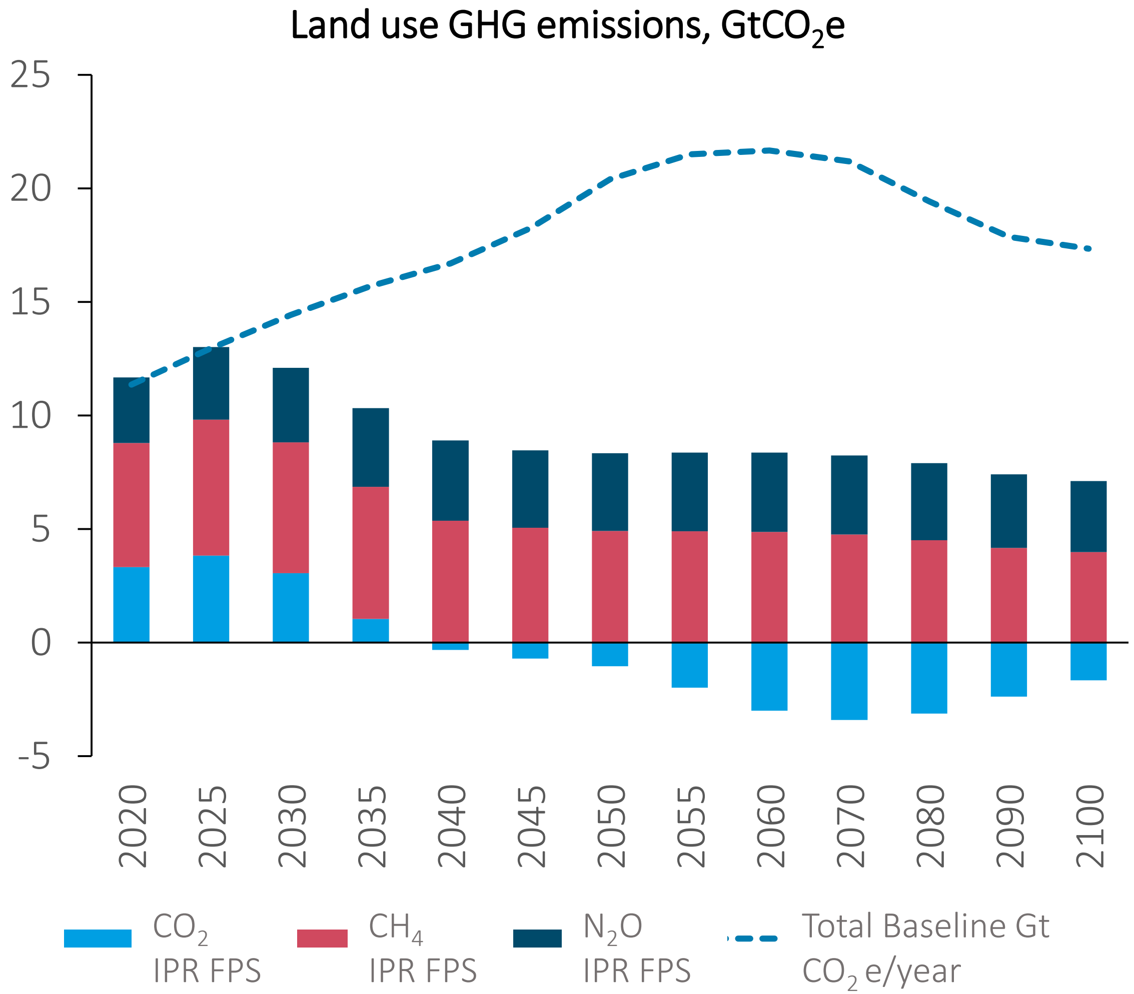
IPR FPS expects cumulative GHG emissions in land-use sectors to be 631 $GtCO_2e$ lower than the current baseline



CO_2 emissions become net negative starting in 2040, driven by net increases in forest cover

CH_4 and N_2O emissions, primarily from livestock and fertiliser use, persist as a dominant part of land sector GHGs through the end of the century

- Increases in baseline are due primarily to increasing population and shifts toward meat in diets associated with development
- IPR FPS expects lower emission growth with technical mitigation in agriculture and some diet shift away from ruminant meat (especially beef) starting in 2020
- Non-CO_2 GHGs persist since difficult and expensive to reduce without a radical shift in diets and steep increases in food prices

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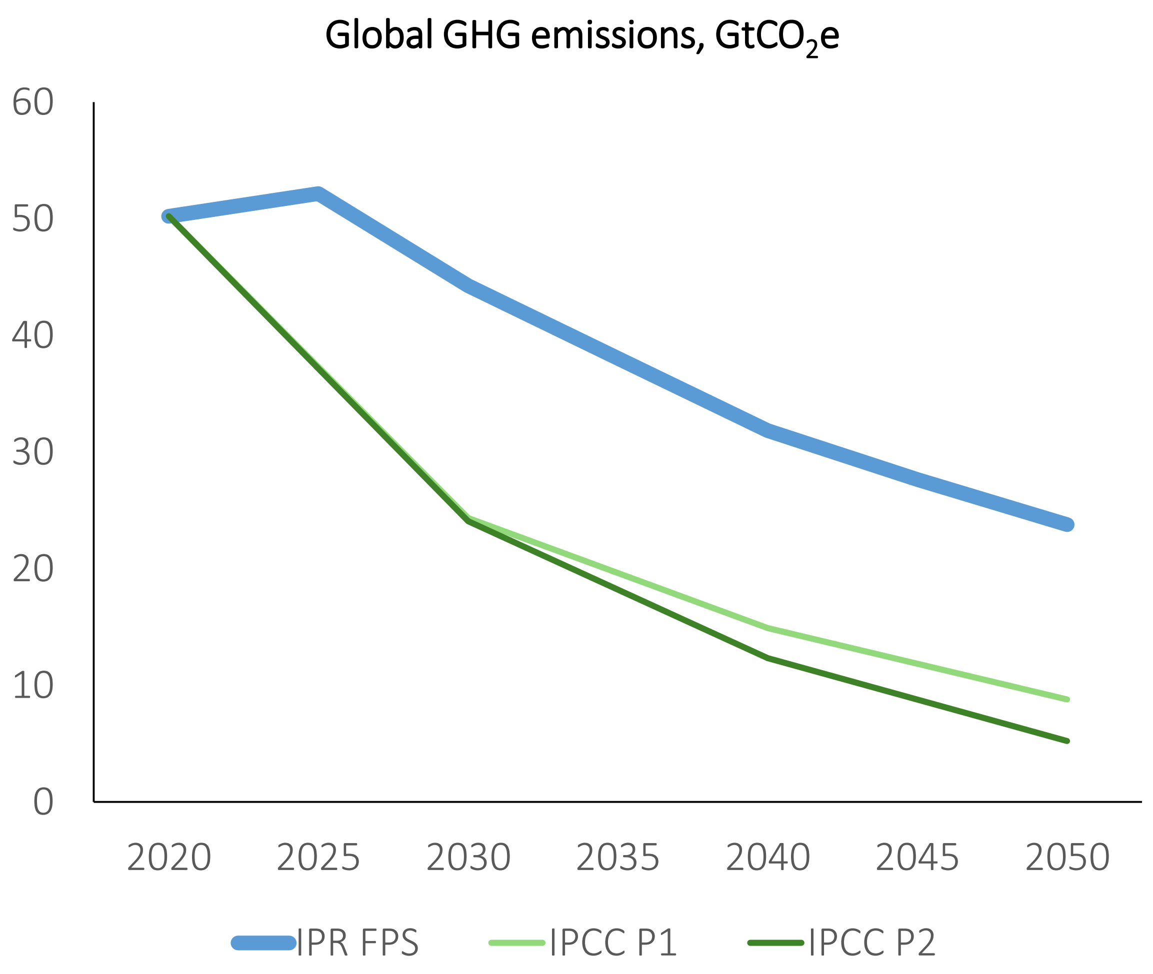
The IPCC 1.5°C P1 scenario decarbonises faster than IPR FPS as it does not utilise CCS technologies and has dramatic demand reductions



The IPCC 1.5°C scenarios decarbonise faster than IPR FPS

- The IPCC 1.5°C scenarios show a variety of pathways, with particularly important differences in assumptions around the levels of CCS and negative emissions, especially after 2050
- The IPCC P1 1.5°C scenario decarbonises rapidly as it is highly ambitious in its assumptions around demand reductions and does not use CCS
- The IPCC P2 1.5°C scenario also decarbonises rapidly, driven by higher levels of afforestation and CCS
- The rate of decarbonisation needed to meet a 1.5°C target is much higher than IPR in the short term even under a moderate CCS scenario.
- IPPC P3 and P4 are shown on page 94 and include large amounts of Negative Emission Technologies that have yet to be deployed at scale

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Achieving the 1.5°C target will require accelerated and substantial effort across multiple emerging solutions

Today	2030 –2050	Post 2050

Faster investor and policy action today

ACT NOW
to move more smoothly and cost-effectively to 1.5°C

- Second Ratchet by 2035
- Circular economy
- The agricultural revolution
- Bioeconomy
- Hydrogen economy
- Consumer preferences, such as dietary shifts
- Negative emissions technologies
- AI revolution / future tech
- Last resort measures

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Executive Summary - Sector results

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Energy – key findings: the phase out of fossil fuels

Thermal coal phases out rapidly in electricity and with a decline in industry. Coal demand peaks by 2020-2022 at the latest.

- In 2040, thermal coal is virtually out of the energy system, with small amounts remaining but declining in selected regions and industry

Oil demand peaks between 2026-28

- Road transport oil demand peaks in 2025; industry and other uses such as petrochemicals continue to grow but at a rate that is slower than the decline caused by ICE phase-outs

Natural gas continues as a transition fuel and to replace a share of coal in industry – gas demand plateaus over the 2030s and begins to decline in the 2040s.

- Natural gas in electricity begins to decline from 2030; renewables replace thermal coal and satisfy new demand
- Natural gas replaces thermal coal in industry and helps reduce emissions from heating, but then is gradually replaced by zero-carbon electricity and hydrogen from 2040 onwards

Renewables grow quickly and supersede fossil fuels in electricity by 2030, and virtually replace all fossil fuels by 2050

- Renewables generate approximately half of all electricity in 2030; Solar and wind alone generate approximately 2/3 of all electricity in 2050
- Nuclear does not grow to replace fossil fuels and stays broadly constant, with regional variation

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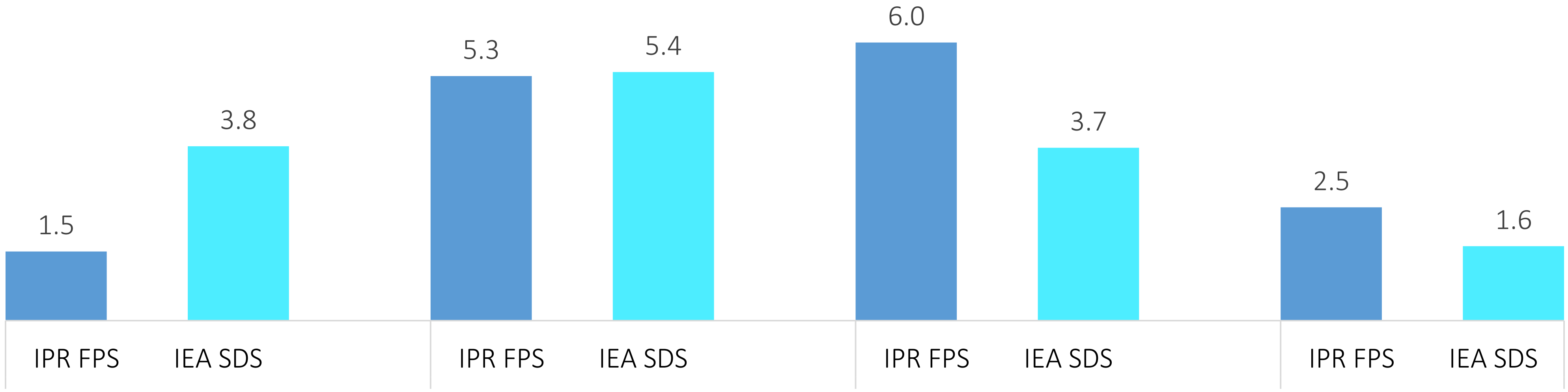
Where IPR FPS is different from IEA SDS in 2040

Power		Transport		Industry		Buildings	
IPR FPS	IEA SDS	IPR FPS	IEA SDS	IPR FPS	IEA SDS	IPR FPS	IEA SDS
Low carbon generation		Low carbon fuel share		Low carbon fuel share		Low carbon fuel share	
81%	79%	26%	27%	46%	43%	74%	70%
total electricity demand		total fuel demand		total fuel demand		total fuel demand	
40,000 TWh	39,000 TWh	88 EJ	111 EJ	156 EJ	134 EJ	149 EJ	120 EJ

IPR FPS has higher share for EVs vs. biofuels than SDS

CO2 emissions by sector in 2040, GtCO2



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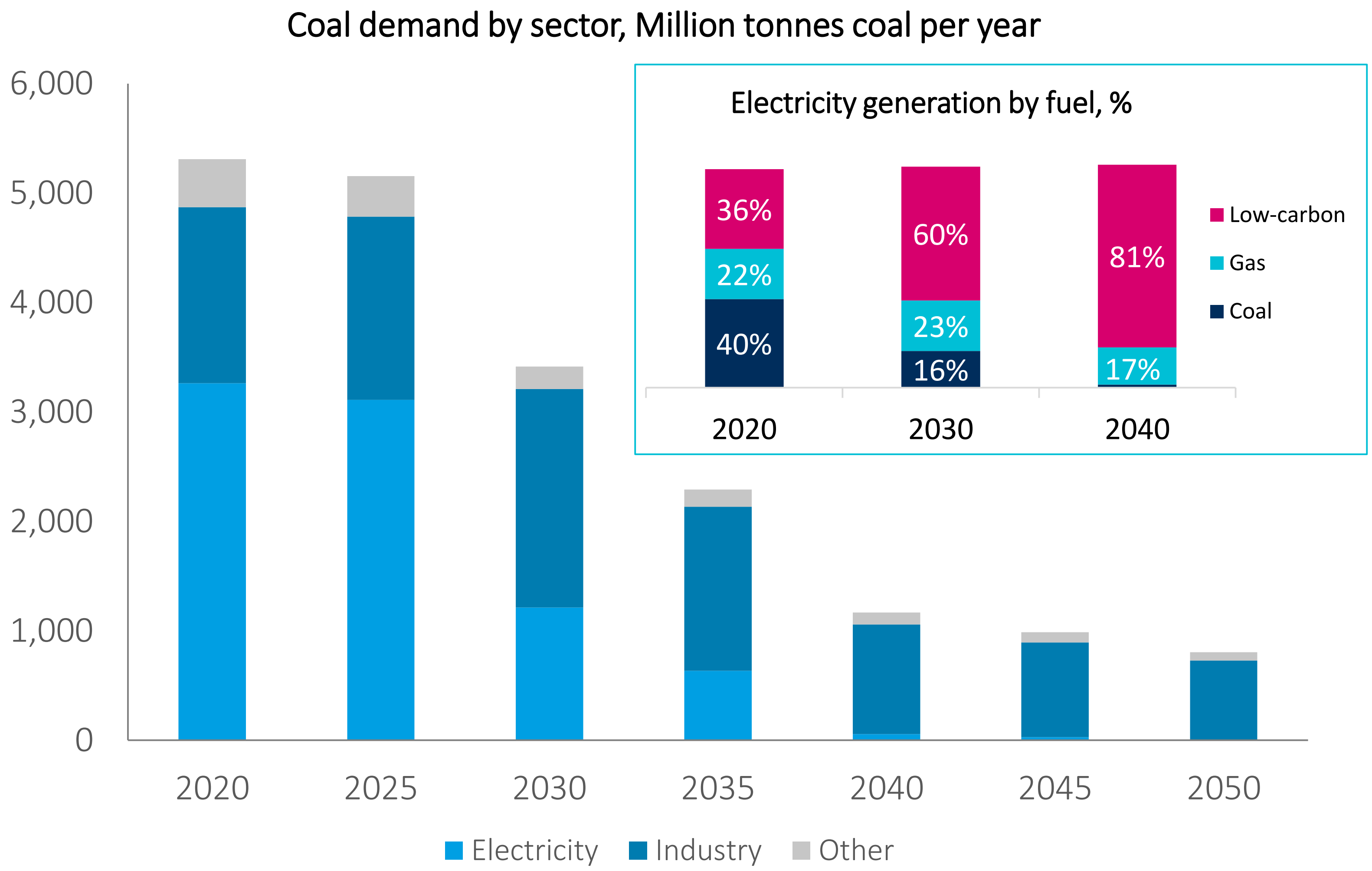
Coal demand is at its peak and will decline rapidly by 2025

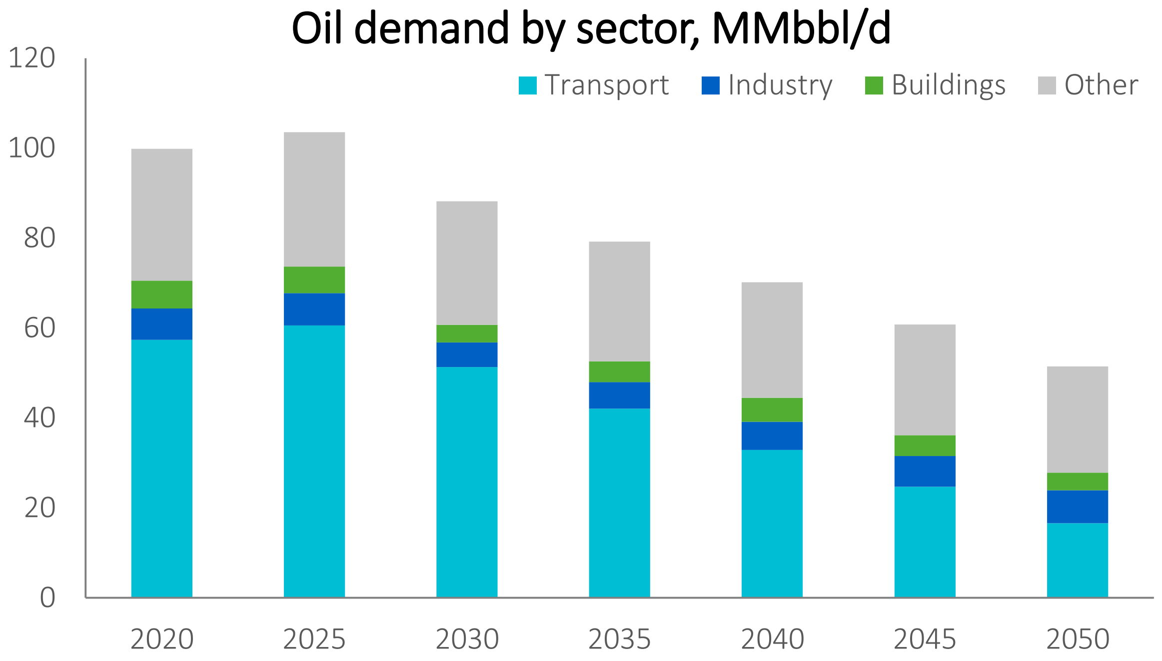


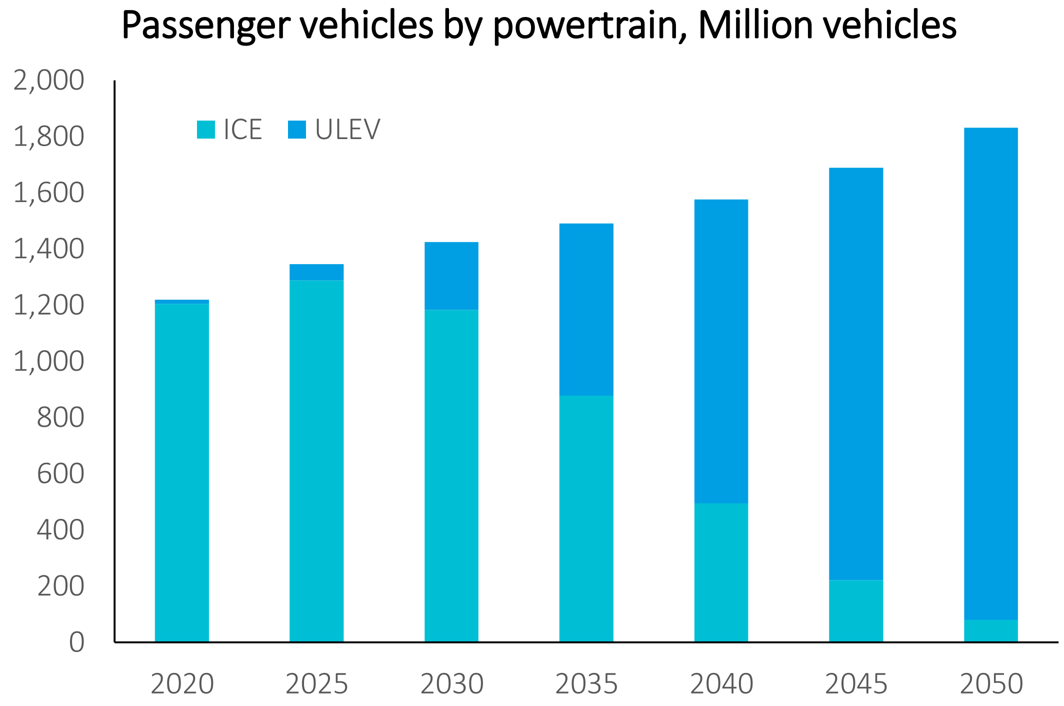
Driven by relative costs and policy, demand for coal for electricity generation declines by 23% per year from 2025 to 2040

- Coal is almost completely phased out of the electricity sector by 2040
- In the 2030s demand for coal in industry decreases significantly
- Electricity, gas and hydrogen replace coal across industry sectors

Note: 'Other' coal use includes energy used in the energy industry, use in agriculture and losses

Oil demand peaks 2026-28 and falls rapidly as transport uses alternative fuels





Oil demand peaks between 2026-28 driven by improving ICE efficiency and early uptake of electric vehicles

- Oil demand from transport decreases by around 70%, while total oil demand decreases around 50% 2025-2050
- Road transport oil demand peaks in 2025
- However, oil demand in aviation and shipping and as a feedstock for petrochemicals remains significant through to 2050

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Note: 'Other' oil use includes energy used during oil extraction and refining, feedstock for petrochemicals, and use in agriculture

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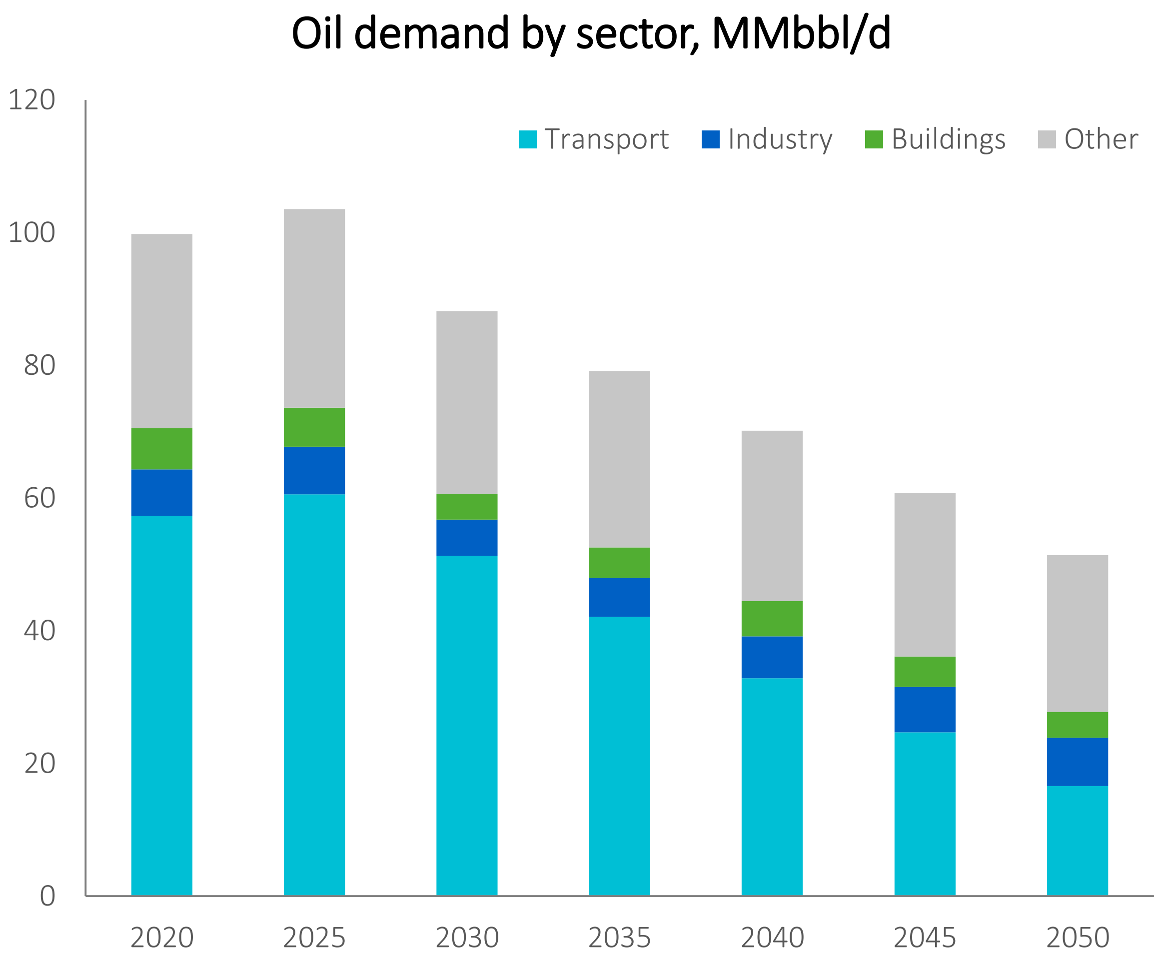

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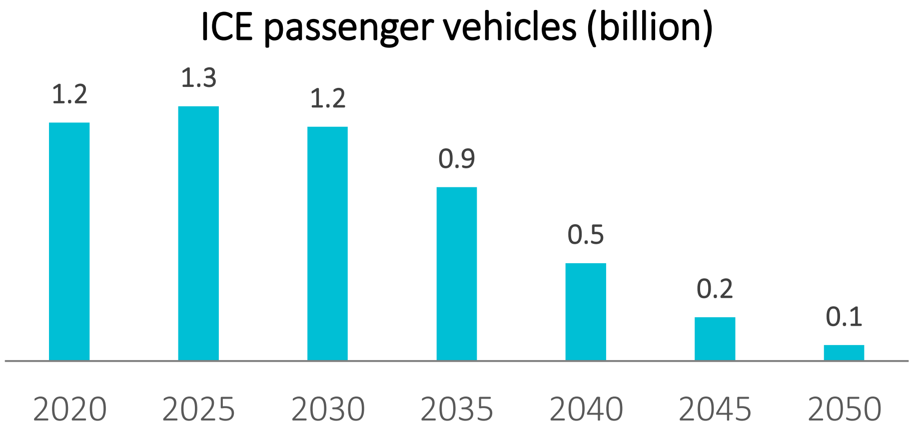
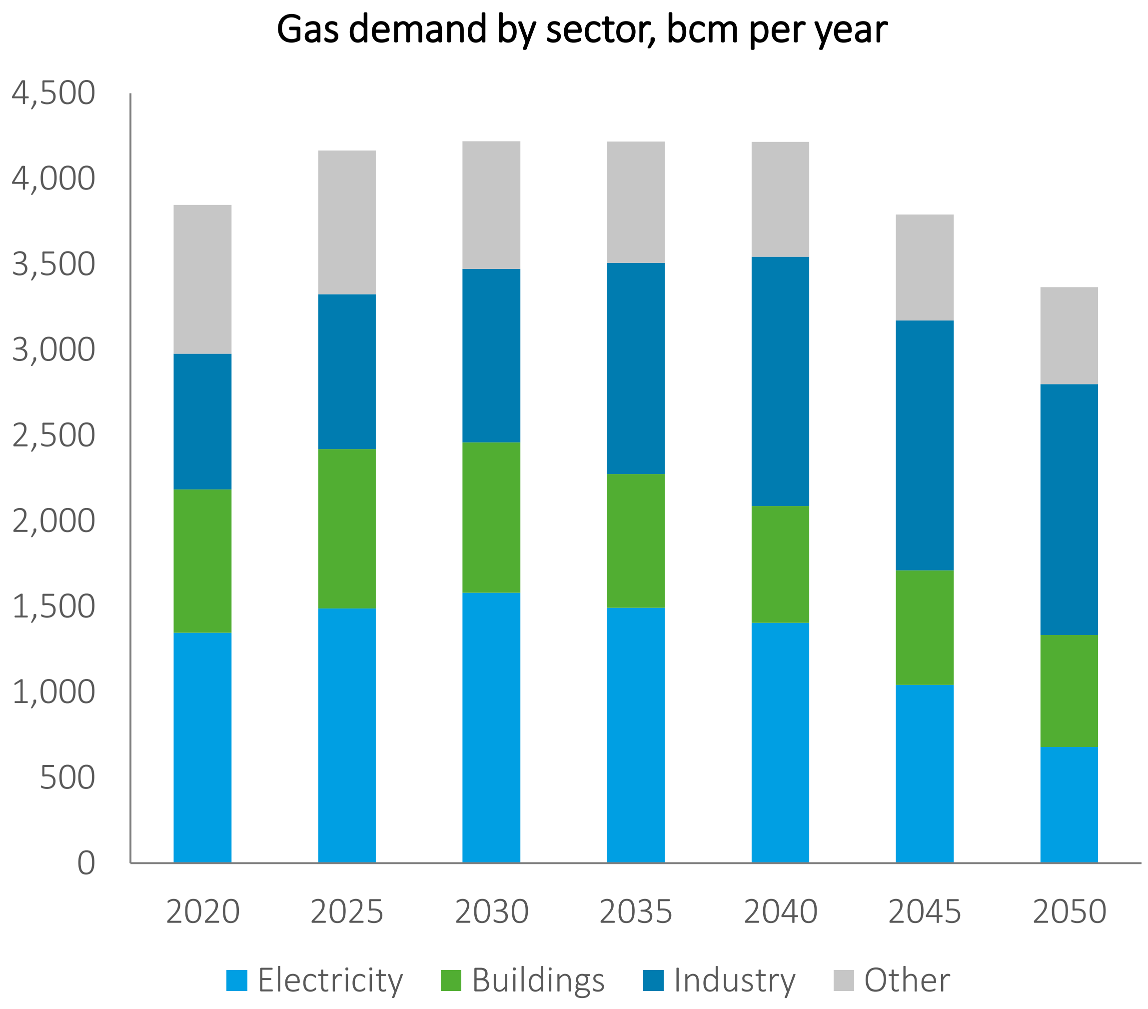


Gas replaces a part of coal in industry and plateaus during the 2030s



Gas demand in electricity increases to 2030, but begins to decline steadily thereafter

- Natural gas in electricity declines from 2030 onwards; renewables replace thermal coal and satisfy new demand
- Electricity is the largest source of gas demand to 2040, when industry emerges as the largest source, including demand for both fuel and feedstock
- Natural gas replaces thermal coal in industry and helps reduce emissions from heating, but then is replaced by zero-carbon energy from 2040 onwards
- The hydrogen economy emerges gradually as an alternative to gas in industry

Note: 'Other' gas use includes energy used during natural gas extraction and processing, and as feedstock for petrochemicals

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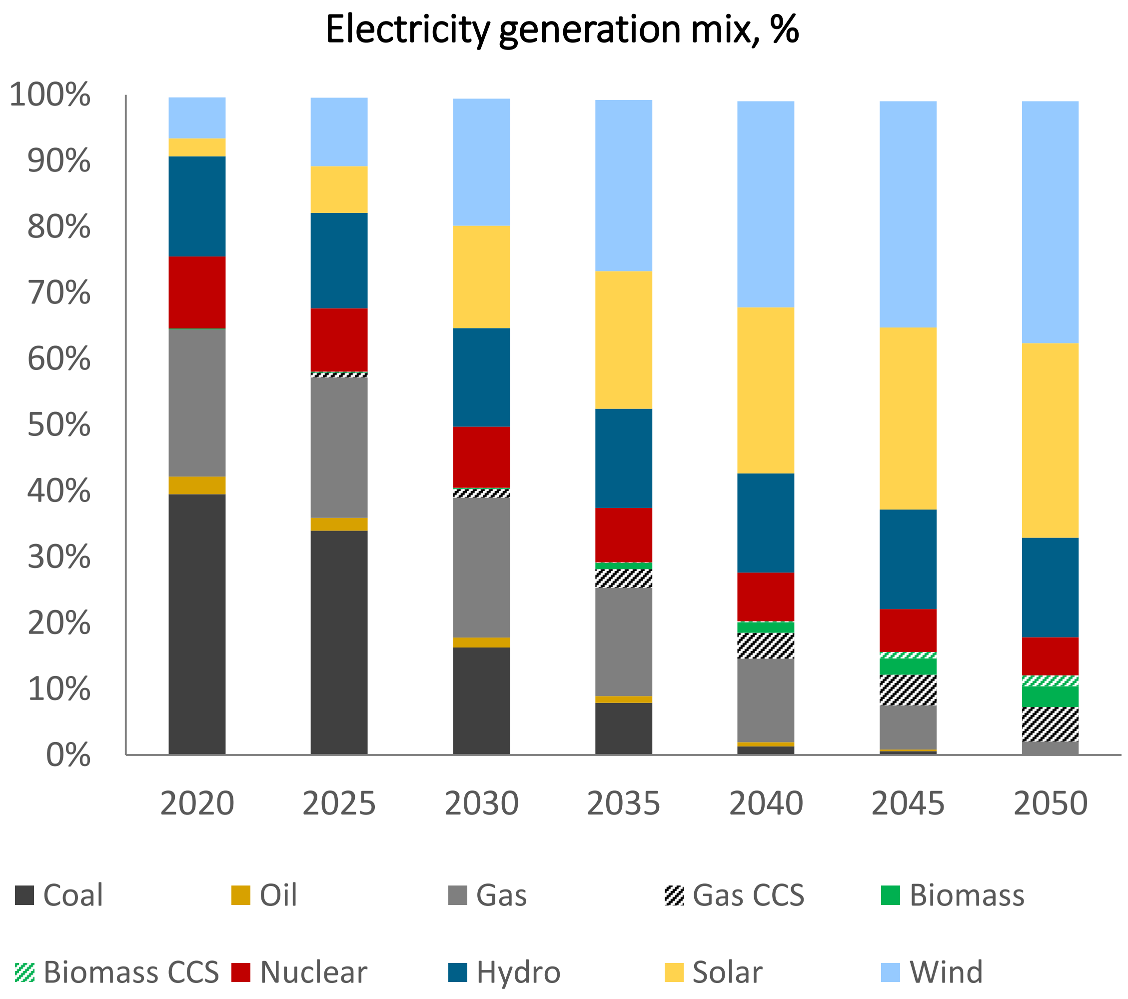
Renewable generation grows quickly and supersedes fossil fuels by 2030



Renewables generate approximately half of all electricity in 2030, and virtually replace all fossil fuels by 2050

- Solar and wind alone will generate approximately 2/3 of all electricity in 2050
- IPR FPS has 72% renewable generation in 2040, more than in the IEA SDS, IEA STEPS, and BNEF NEO
- Coal is phased out by 2050 while gas retains a minor role. By 2050, CCS is applied to around 72% of gas generation but this is only 5% of the total generation mix
- Biomass with CCS grows to 2% of the generation mix by 2050, slow development of CCS is a barrier to use of biomass as a negative emissions technology as are land use constraints
- Overall, nuclear does not grow to replace fossil fuels or renewables given cost and societal issues

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Transport, Industry and Carbon Capture and Storage – key findings

ICE sales bans, supported by technology cost reductions, drive rapid deployment of ultra-low emissions vehicles

- As a result of its policy assumptions, IPR FPS expects twice as many electric passenger and light-duty vehicles as Bloomberg New Energy Finance (BNEF) by 2040 with near total decarbonisation by 2050
- Heavy-duty vehicles are expected to follow a similarly rapid shift to zero-emissions vehicles, with a greater role for hydrogen, and near total decarbonisation by 2060

Industry decarbonises quickly, but at pace commensurate with technology readiness and long plant lifecycles

- Coal-to-gas switching plays a major role in next two decades, as technically ready, cost effective and non-disruptive to production
- Electricity and hydrogen begin pushing out coal and gas as market price of carbon rises, technology costs fall, and the cycle of plant replacement enables greater and greater industrial transformation

Carbon Capture and Storage (CCS) plays a small role in power and industry (to cover hard-to-abate sources)

- Fossil fuel electricity declines rapidly
- Industrial CCS plays a role in the pace of industrial transformation
- Some bioenergy with CCS can play a role as a long-term solution for generating negative emissions

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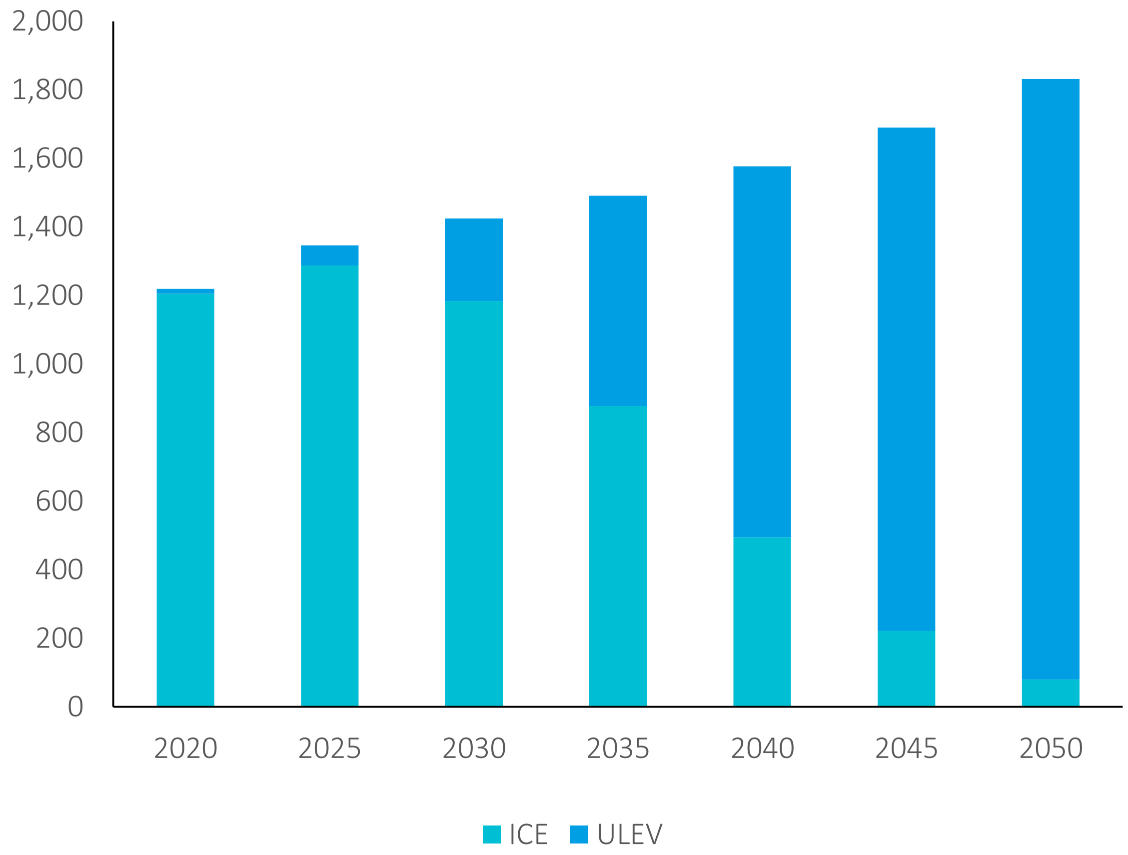
ICE vehicles peak in 2025 – by 2040, ultra-low emissions vehicles are the majority

Passenger vehicles by powertrain, Million vehicles



Number of ICE vehicles peaks in 2025 driven by EV cost reductions and ICE sales bans, with significant implications for demand along the automotive supply chain

- Acceleration of ULEVs driven by 2035 ICE bans in Western Europe and China; 2040 bans USA, Japan and other regions
- By 2050 relatively few ICE vehicles remain, primarily in less developed countries that transition more gradually
- In the BNEF New Energy Outlook, sales of ICE passenger vehicles have already peaked and number of ICE passenger vehicles peaks around 2030. In 2040 around a third of the fleet are EVs

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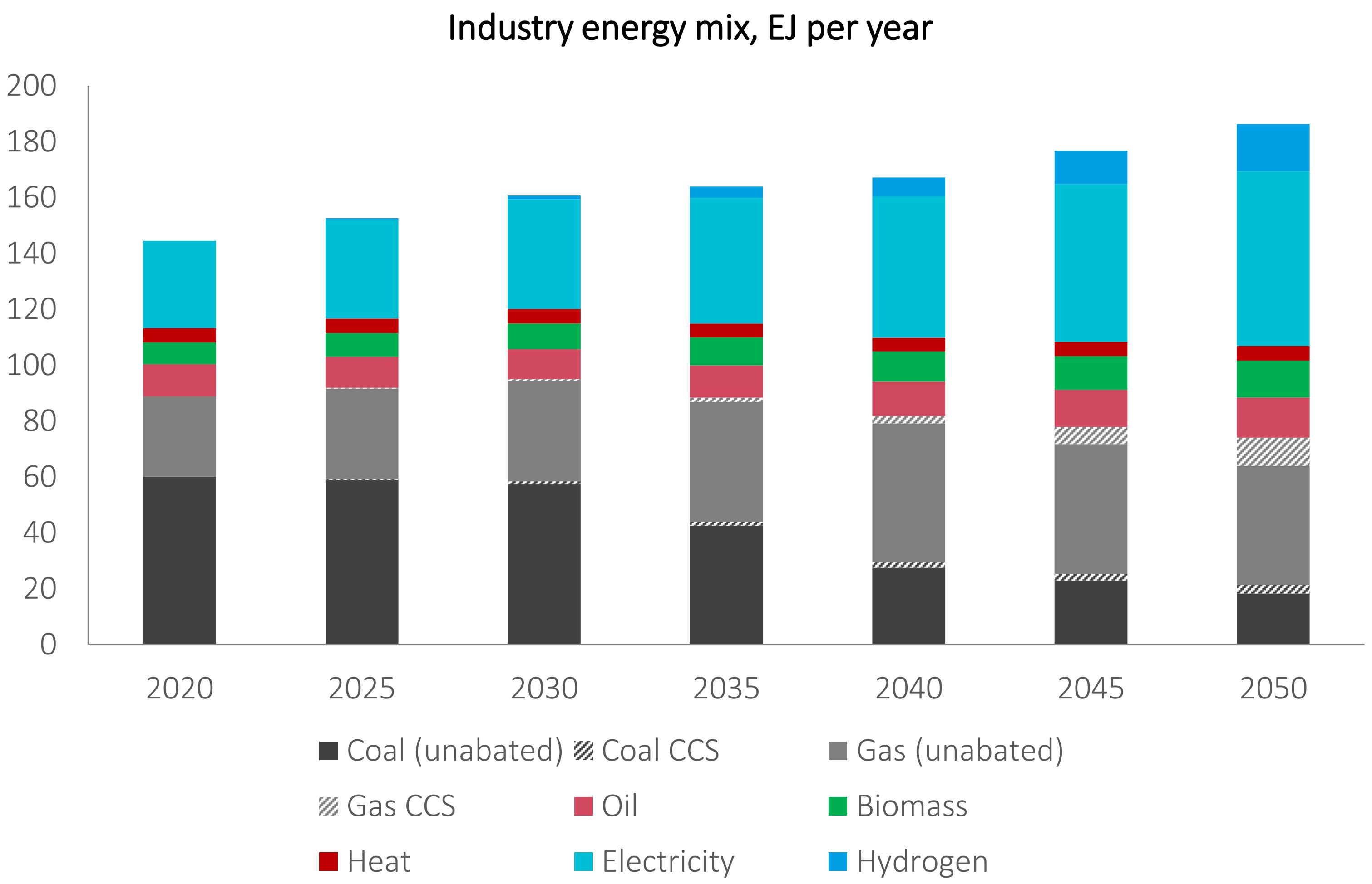
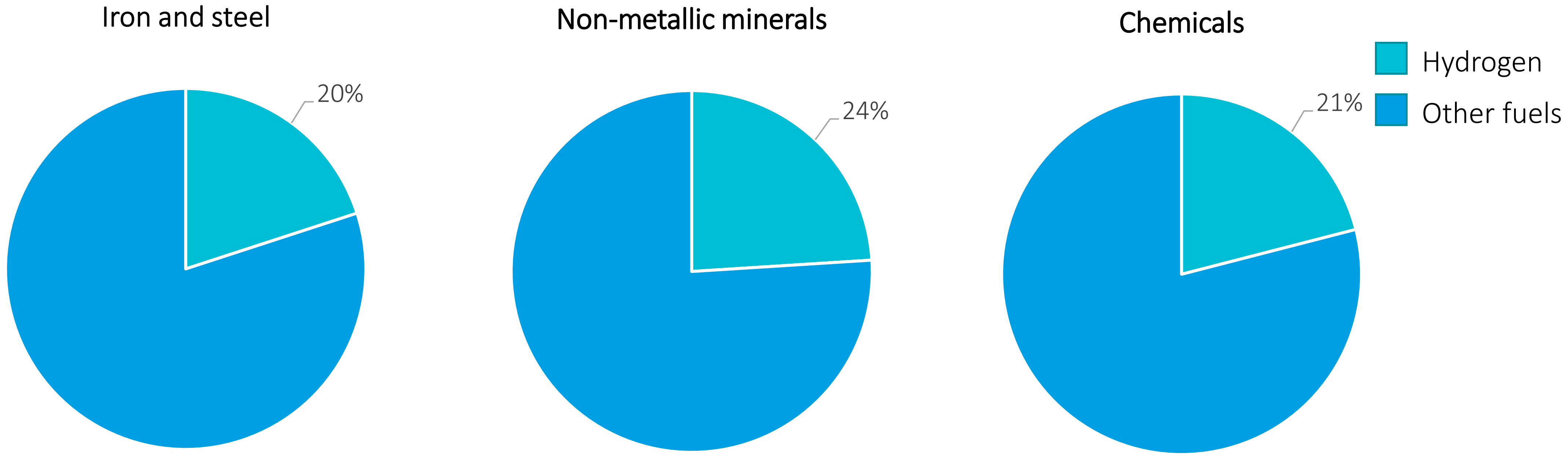
Electrification, hydrogen and CCS contribute to the progressive decarbonisation of industry



Coal-to-gas switching – proven, economical and non-disruptive – accelerates as a near-term solution to reducing industrial emissions

- Electrification, hydrogen, and CCS contribute to decarbonising energy intensive industry sectors in medium to long term with the carbon price forecasts playing an important role
- Fuel mix changes proceed at a pace consistent with economics of emerging technologies, and long plant lifecycles

By 2050, hydrogen contributes at least 20% of energy demand in hard-to abate sectors

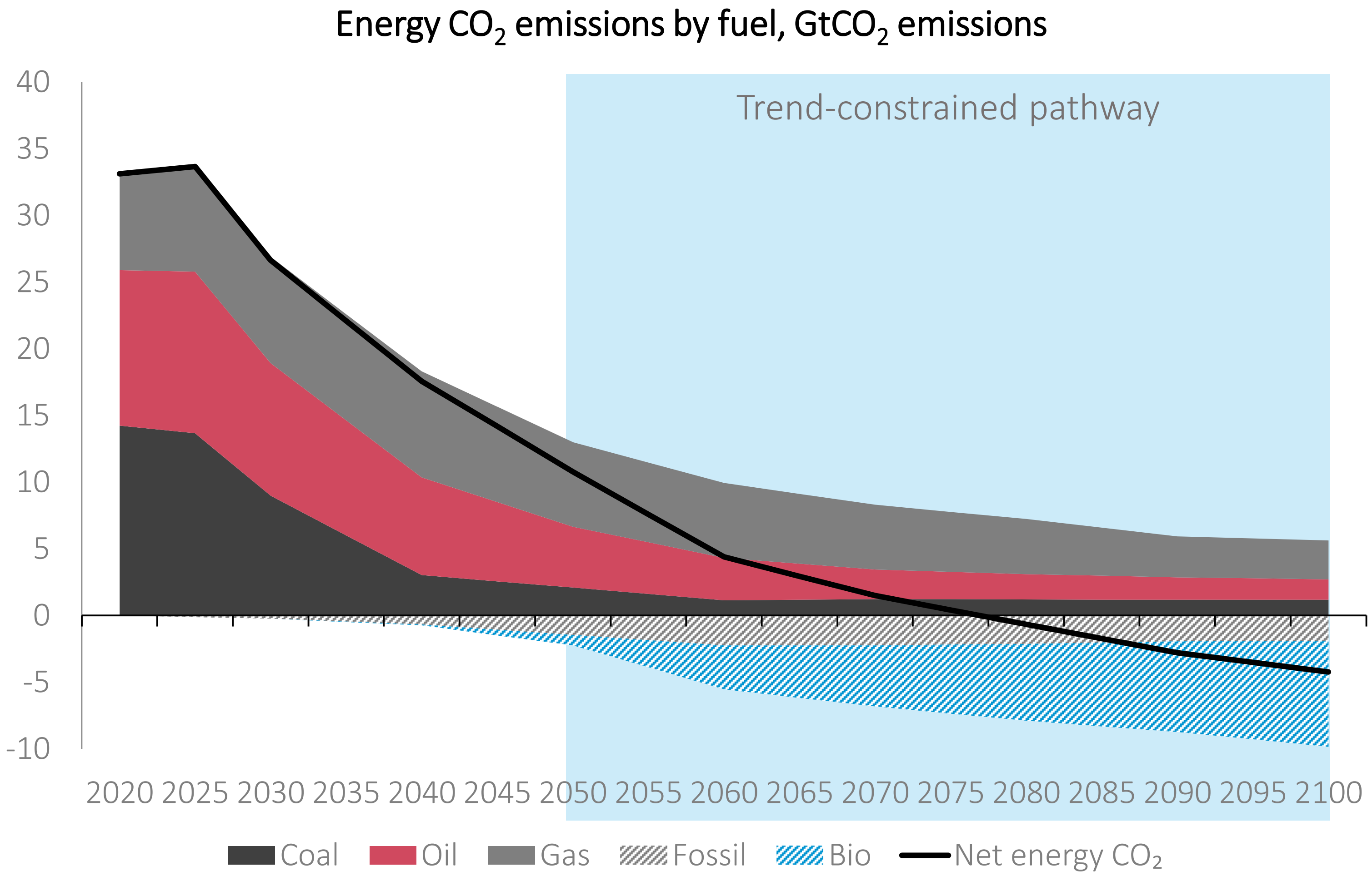


Hydrogen can become a significant energy source in industry. Advantages of hydrogen include:

- Hydrogen is an alternative to electrification technologies. Like natural gas, hydrogen can be burned as a fuel, and less innovation is needed to develop hydrogen burning technologies than many electrification technologies
- Hydrogen is an alternative to carbon capture and storage. Hydrogen allows decarbonisation of industry without fitting capture technologies to individual plant, and without developing new CO2 transport and storage infrastructure
- Hydrogen can also be used as a reduction agent in steelmaking, potentially eliminating the use of coke as a reduction agent and its resulting process emissions

INEVITABLE POLICY RESPONSE

Bioenergy with CCS is crucial to reduce energy CO_2 emissions below zero by 2100, with CCS in industry mitigating the impacts of remaining fossil fuel use



Coal emissions decline rapidly – remain for coking coal and other uses

- CCS on fossil fuels in industry and power and Bioenergy and CCS (BECCS) are needed to reduce emissions rapidly but face constraints
- Oil and natural gas have several uses beyond power and transport – aspirational policies are needed to tackle these remaining emissions
- For ambitious scenarios such as 1.5°C, many assume much more CCS will need deploying than shown here

INEVITABLE POLICY RESPONSE

Land-use – key findings

Deforestation virtually eliminated by 2030, but continues in short term

- Forecasted policies will take time to be fully implemented as land-use change involves significant legal, institutional and social change
- Economy-wide carbon price pressures will increase political incentive through Paris process
- International payments begin playing a bigger role by 2030 as rules gradually negotiated

Bioenergy meets around 10% of global energy demand by 2050, with the bulk coming from 2nd generation crops

- Food competition and political challenges of land-use change dampen economic incentives for bioenergy
- Wider land use shifts include growth in bioenergy crops which meet around 10% of global energy demand by 2050

Land competition induces substantial investment in yield-enhancing technologies – crop yields estimates imply a 1.5% compound average growth rate (CAGR) between 2015 and 2050

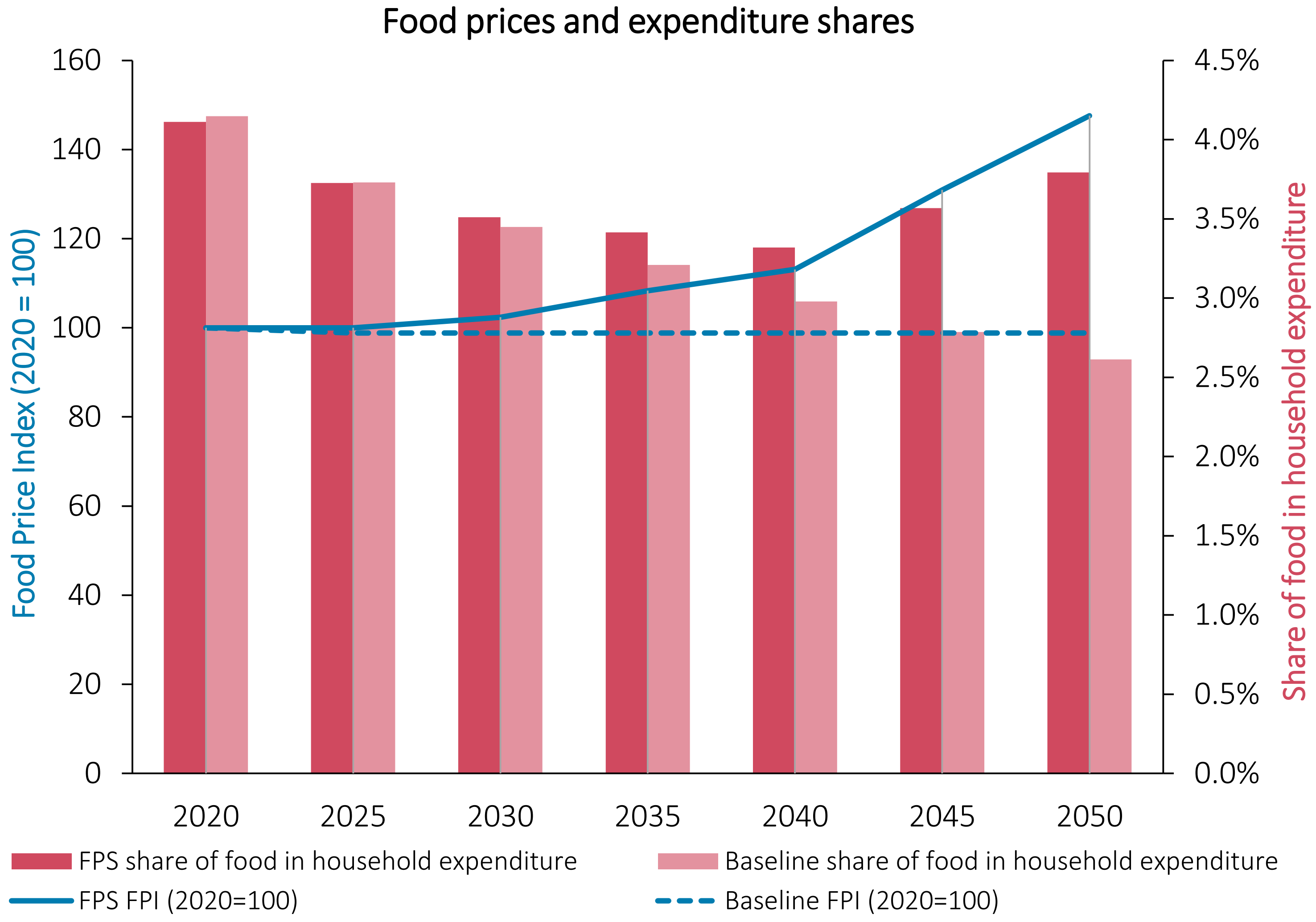
Dietary shift away from ruminant meat (especially beef) is significant against trend thanks to both price and social pressures, but behavioural barriers persist to a rapid and complete transformation of dietary habits

Globally, the IPR FPS keeps food expenditure's share in household income near stable

- The share decreases from roughly 4.1% in 2020 to 3.8% in 2050 as GDP per capita grows
- Regions with stronger land competition experience more significant food price increases; particularly bioenergy-rich regions such as Central and South America, Mexico, and Brazil

INEVITABLE POLICY RESPONSE

IPR FPS keeps food expenditure's share in household income near stable



Between 2020 and 2050, the share of food in household expenditures decreases from 4.1% to 3.8%

Wholesale prices from producers (farm gate) increase by 45% globally by 2050, with regions experiencing strong land competition observing the highest impact

- These include Central and South America, Mexico, and Brazil
- Food prices in some countries are sensitive to trade pattern changes resulting from shifts

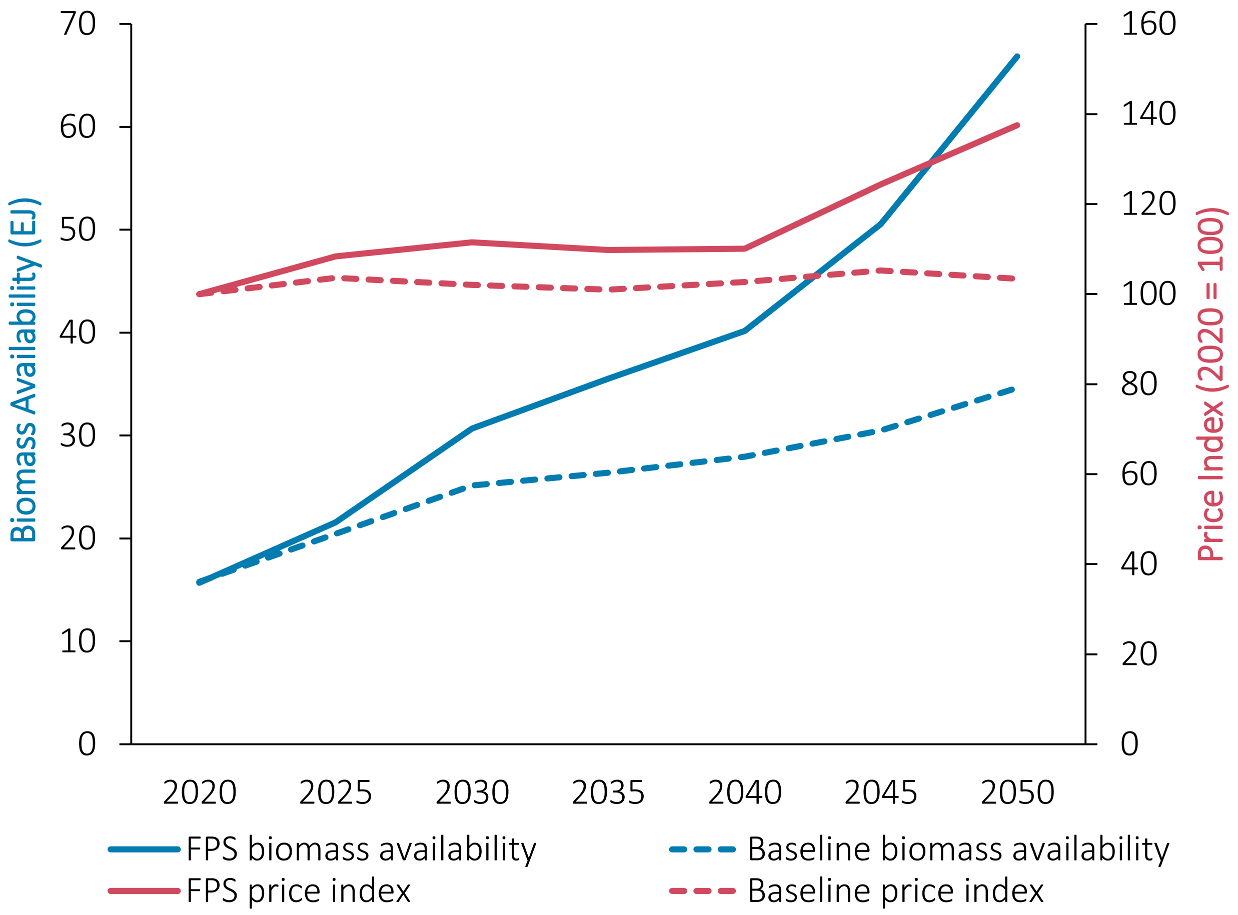
Food price increases are within historical bounds, for example:

- Global CAGR in food price index was 7% between 2005 and 2010
- Maximum IPR FPS CAGR is 3.0%

INEVITABLE POLICY RESPONSE

Bioenergy crops represent 65 EJ annually by 2050, with the bulk coming from 2^{nd} generation crops

Bioenergy production and prices



Bioenergy crops supply nearly 65 EJ annually by 2050

- First generation bioenergy crops continue to dominate in the coming decade
- Second generation crops, such as miscanthus, phase in beginning in 2025, and account for more than two thirds of bioenergy production in 2050

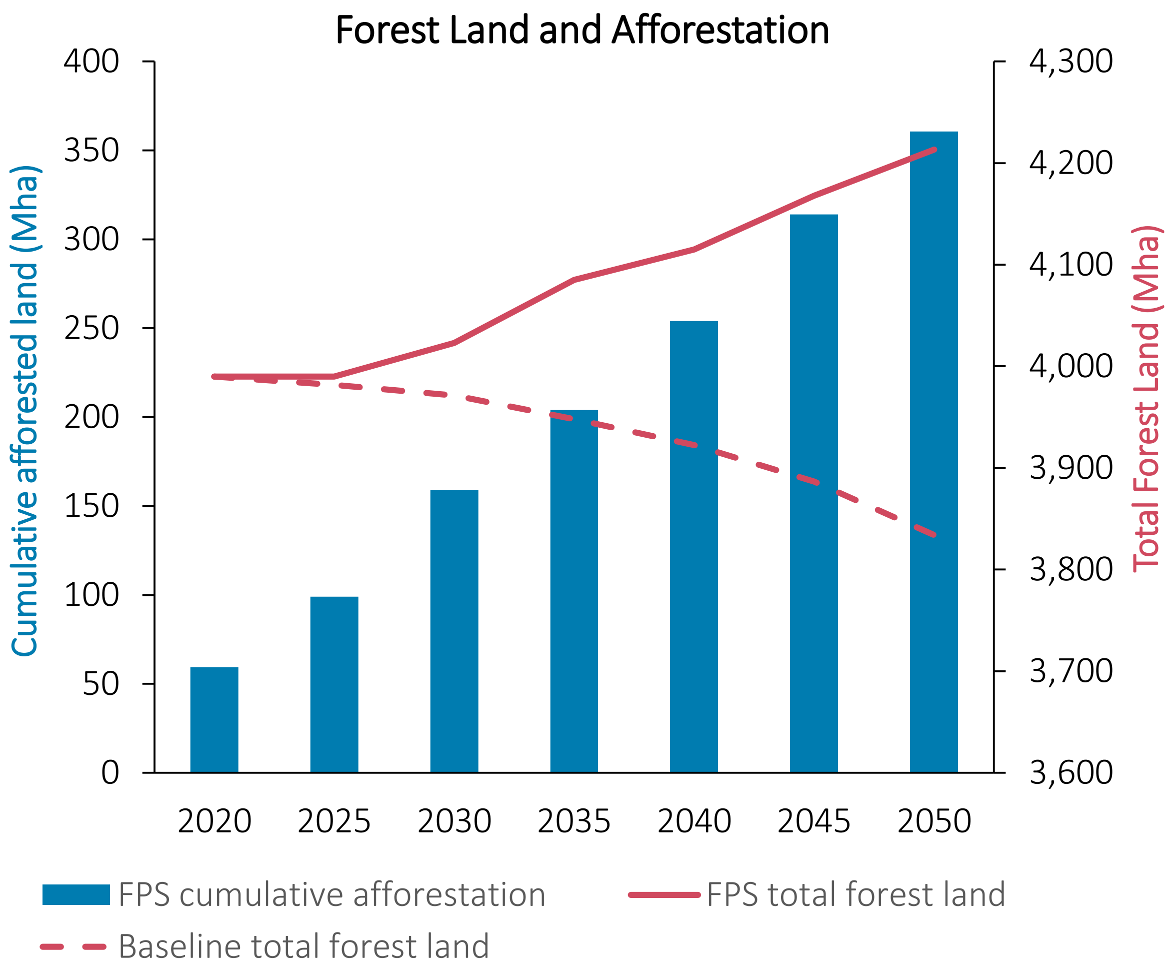
Environmental sustainability and land competition constrain bioenergy production

- Consistent with literature estimates of 100-125 EJ in 2100 of bioenergy as the sustainable limit

Bioenergy production increases across the globe, although relatively sooner in China, North America and Europe, which have better conditions for sustainable, industrial-scale production. The former Soviet Union emerges later as major producer.

INEVITABLE POLICY RESPONSE

Deforestation continues until mitigation policies phase into the land sector, and afforestation and reforestation efforts ramp up substantially



Note: 'Total Forest Land' is includes dense, high-carbon stock forest land only

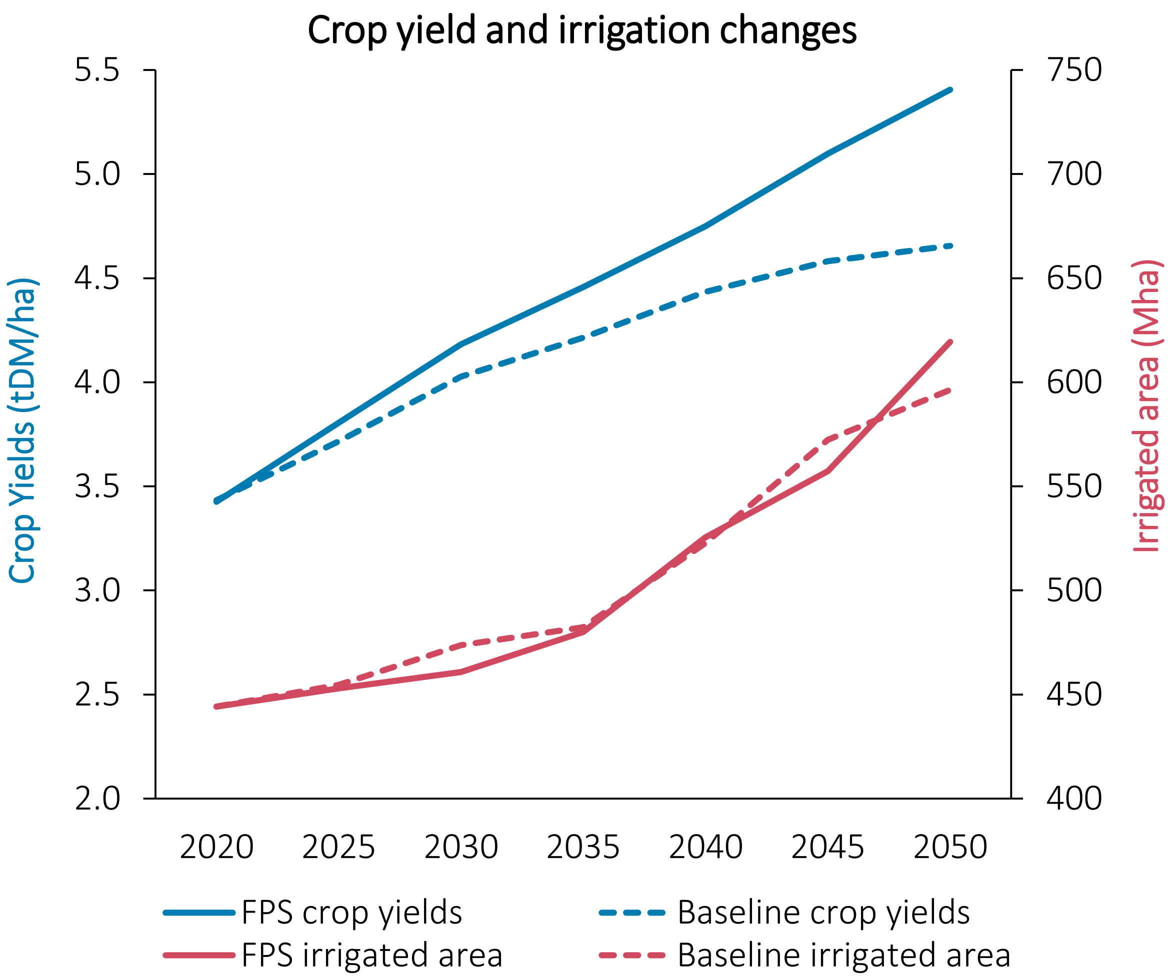
Deforestation practically eliminated by 2030, as domestic climate policies fully implemented, and international payments increasingly introduced

- IPR FPS expects rapid re/afforestation to meet feasible NDC land use targets in coming decade
- Total forest area recovers to 1995 levels between 2030 and 2035, although not all native forest
- Re/afforestation is driven by emerging payment systems – national and international – and impact of increasing prices in carbon markets
- World meets the Bonn Challenge of 350 Mha of land restoration, but well after 2030 target
- Re/afforestation occurs largely in tropical regions: Brazil, Latin America, China and Southeast Asia

Re/afforestation to 2050 draws estimated $780 billion in offsets financing

INEVITABLE POLICY RESPONSE

Land competition induces substantial investment in yield-enhancing technologies



Aggregate global productivity increases by 58% between 2020 and 2050

- This represents a roughly linear rate of increase in line with historical gains

Much of this is driven by baseline catch-up improvements in developing country agricultural systems

- Irrigated area expands globally, with the fastest coverage increases in Africa

Further productivity gains are achieved thanks to policy and price incentives

- Increasing public and private support for R&D and agricultural extension
- Global estimates for yield enhancing investments total $23,000 billion from 2015 to 2050

INEVITABLE POLICY RESPONSE

The Forecast Policy Scenario – FPS (2020-2050)

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RESPONSE

Energy – key findings: the phase out of fossil fuels

Thermal coal phases out rapidly in electricity and with a decline in industry. Coal demand peaks by 2020-2022 at the latest.

- In 2040, thermal coal is virtually out of the energy system, with small amounts remaining but declining in selected regions and industry

Oil demand peaks between 2026-28

- Road transport oil demand peaks in 2025; industry and other uses such as petrochemicals continue to grow but at a rate that is slower than the decline caused by ICE phase-outs

Natural gas continues as a transition fuel and to replace a share of coal in industry – gas demand plateaus over the 2030s and begins to decline in the 2040s.

- Natural gas in electricity begins to decline from 2030; renewables replace thermal coal and satisfy new demand
- Natural gas replaces thermal coal in industry and helps reduce emissions from heating, but then is gradually replaced by zero-carbon electricity and hydrogen from 2040 onwards

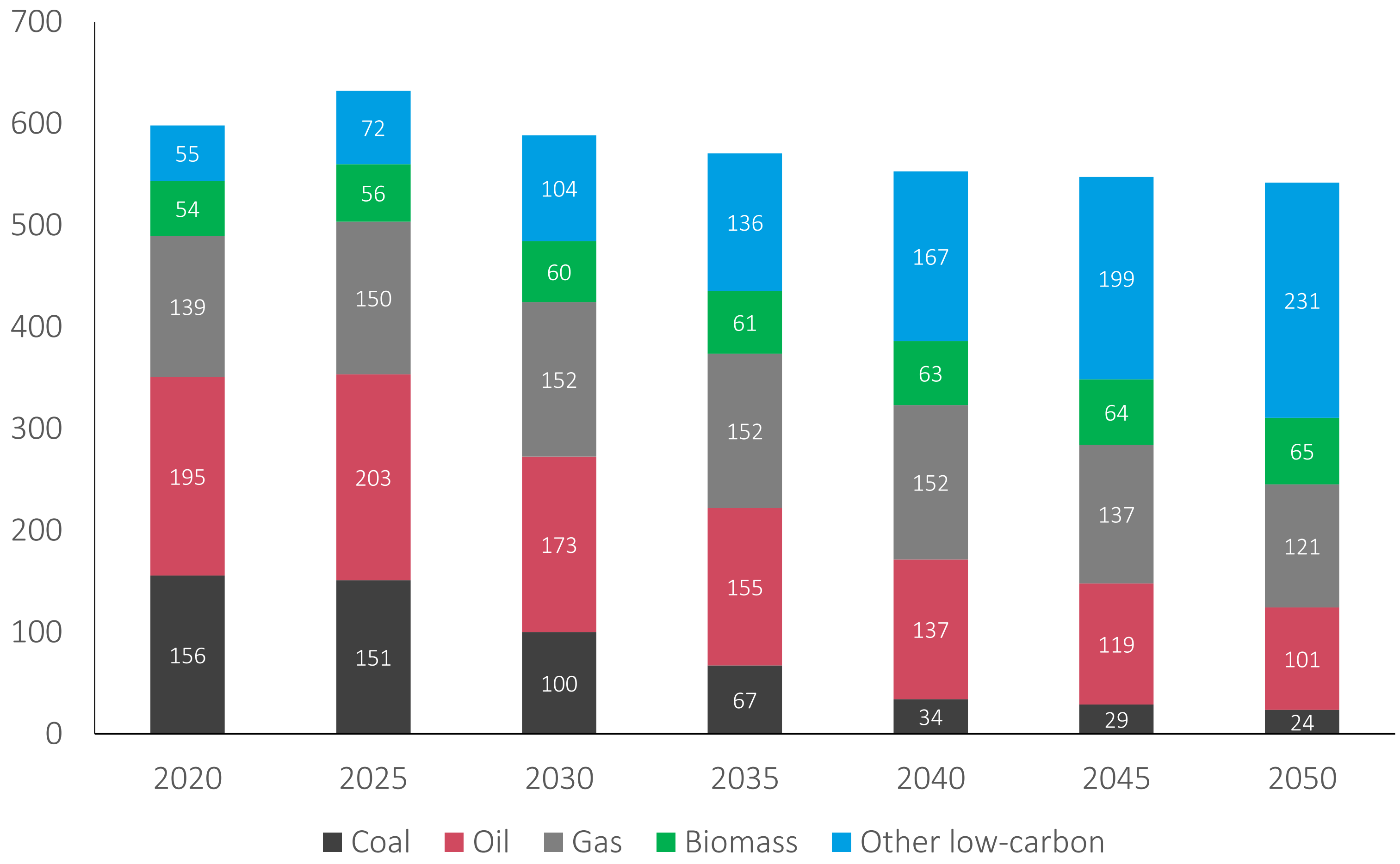
Renewables grow quickly and supersede fossil fuels in electricity by 2030, and virtually replace all fossil fuels by 2050

- Renewables generate approximately half of all electricity in 2030; Solar and wind alone generate approximately 2/3 of all electricity in 2050
- Nuclear does not grow to replace fossil fuels and stays broadly constant, with regional variation

INEVITABLE POLICY RESPONSE

Primary energy demand for fossil fuels decreases rapidly

Primary energy demand, EJ per year

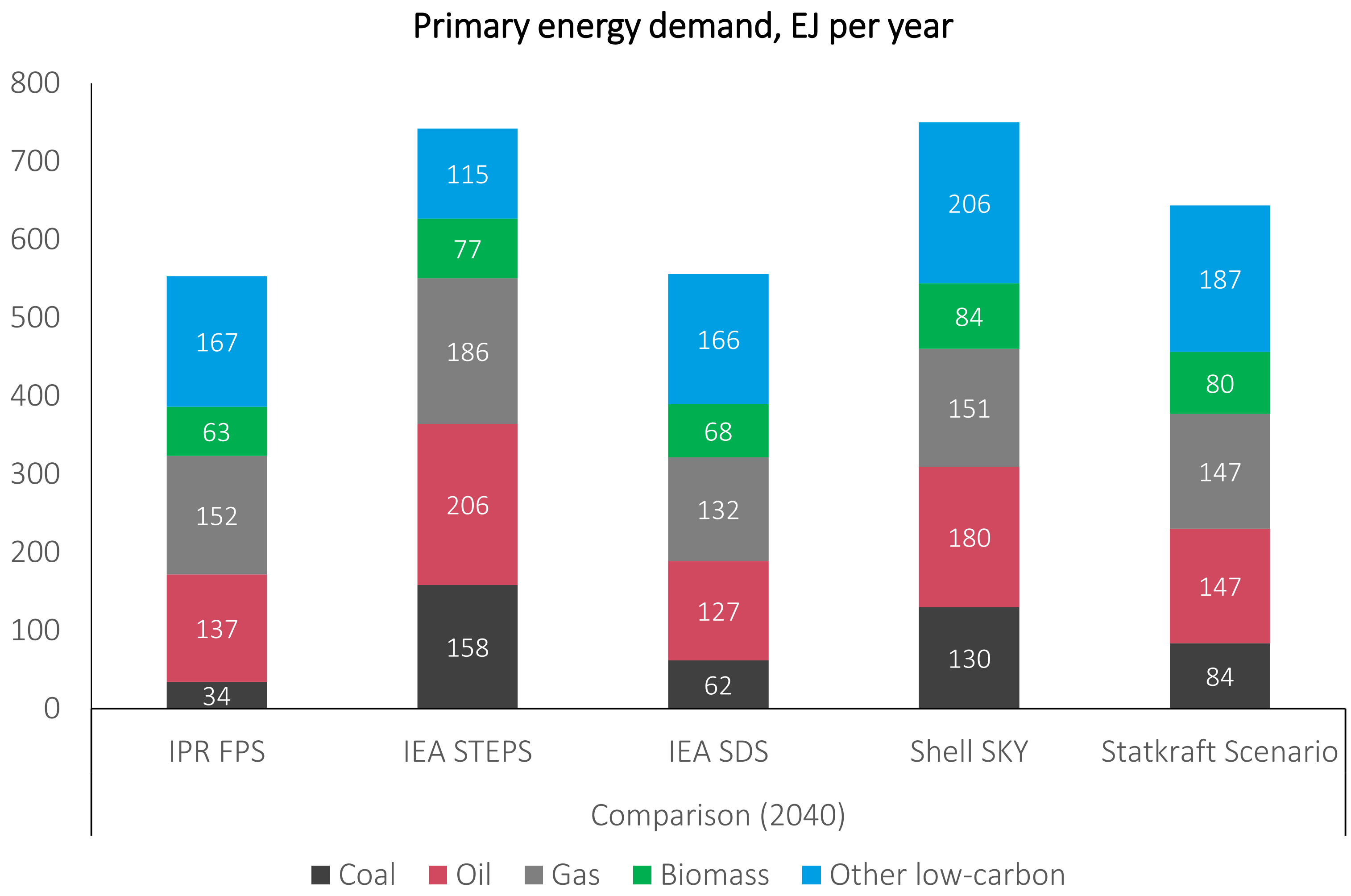


Primary Energy Demand for fossil fuels decreases rapidly

- After plateau since around 2011, coal declines quickly from 2025 owing to rapid decarbonisation of power sector
- Oil peaks between 2025 and 2030 with steady decline to 2050 due to transport sector polices
- Gas's share increase as a transition fuel; a coal to gas shift in industry increases overall demand, which peaks around 2040

INEVITABLE POLICY RESPONSE

Primary energy demand for fossil falls in line with comparable scenarios



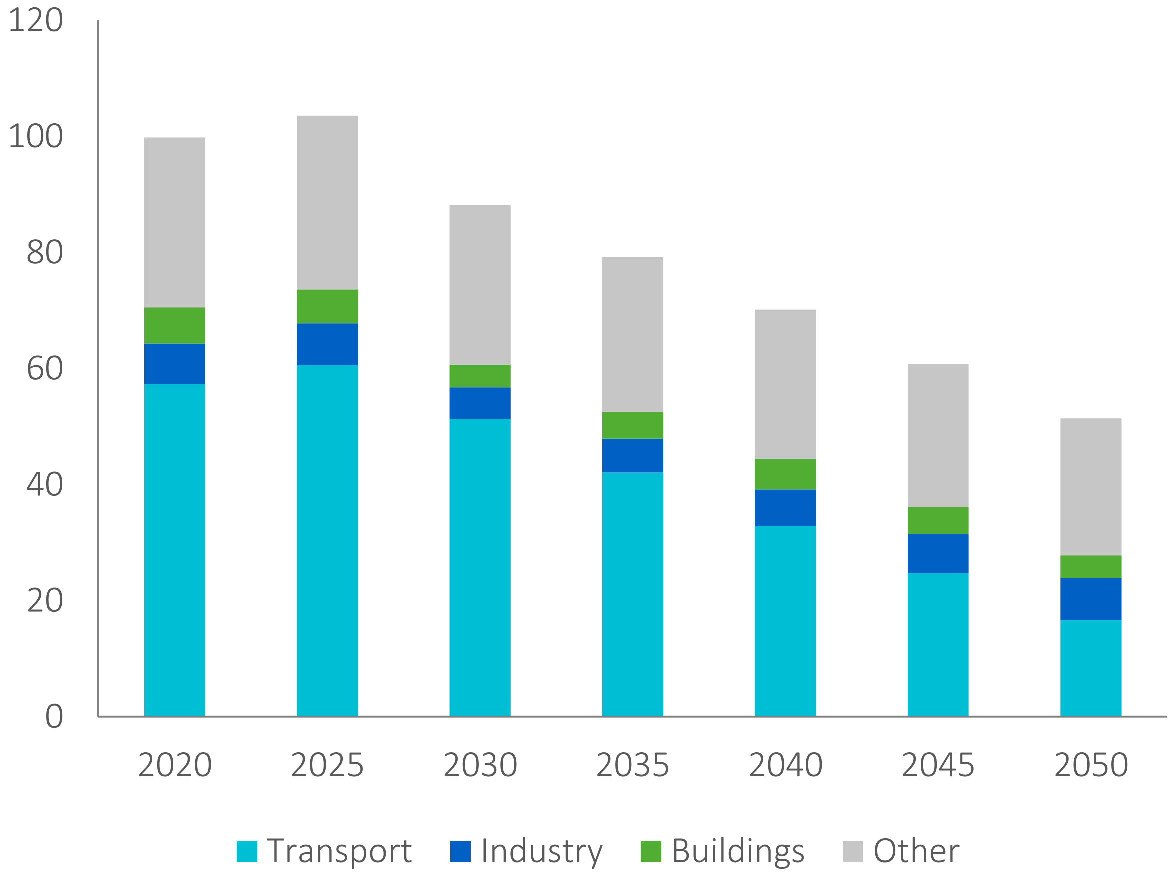
Primary Energy Demand for fossil fuels decreases rapidly

- There is more coal-to-gas switching in IPR FPS relative to the SDS, with natural gas being 27% of primary energy demand in 2040 in IPR FPS, compared to 24% in SDS
- Gas primary energy demand starts declining around 2040

INEVITABLE POLICY RESPONSE

Oil demand peaks 2026-28 and falls rapidly as transport uses alternative fuels

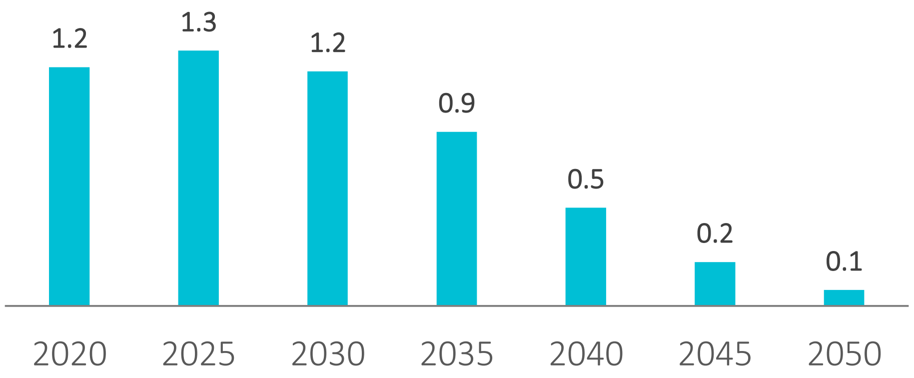
Oil demand by sector, MMbbl/d



Oil demand peaks between 2026-28 driven by early uptake of electric vehicles

- Oil demand from transport decreases by around 70%, while total oil demand decreases around 50% from 2025 to 2050
- Road transport oil demand peaks in 2025
- However, oil demand in aviation and shipping and as a feedstock for petrochemicals remains significant through to 2050

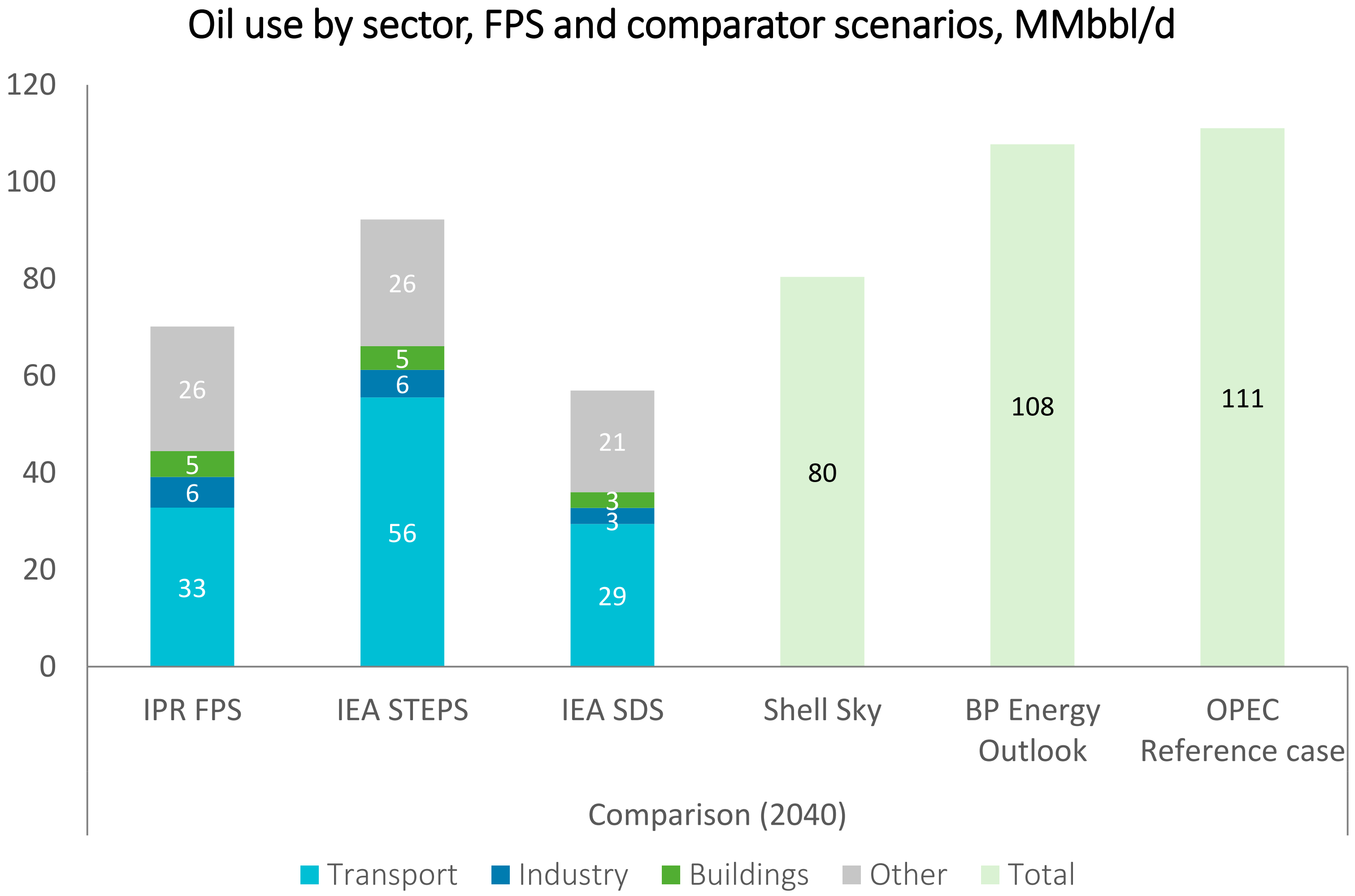
ICE passenger vehicles (billion)



Note: 'Other' oil use includes energy used during oil extraction and refining, feedstock for petrochemicals, and use in agriculture

INEVITABLE POLICY RESPONSE

Decline in oil use in transport is comparable to IEA's SDS

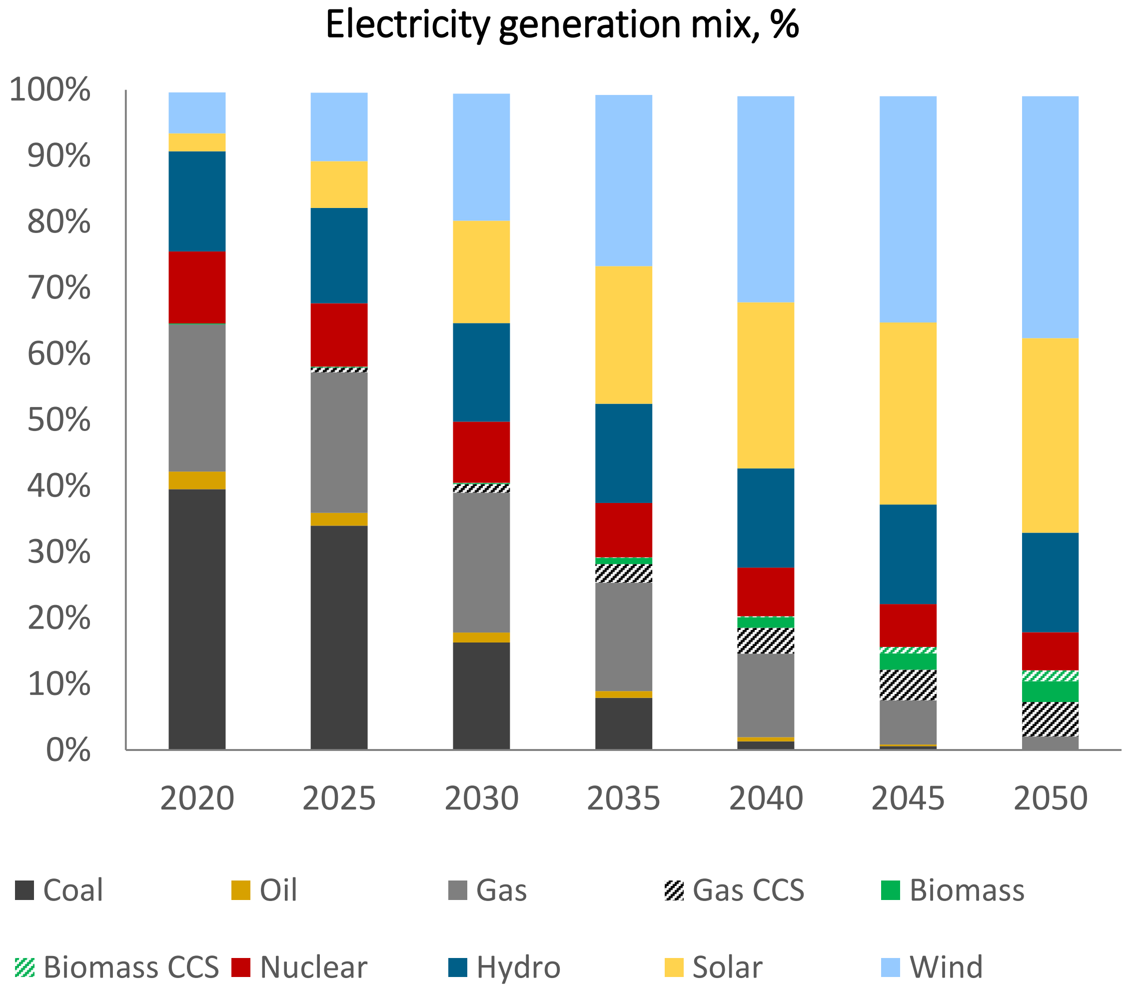


The SDS scenario has comparable oil use by 2040

- Passenger car EV uptake in the SDS scenario is 14.5% by 2030, as compared to 17% in IPR FPS
- Decreasing ICE vehicles in stock drives the decreasing demand for oil from the transport sector in both scenarios

Note: 'Other' oil use includes energy used during oil extraction and refining, feedstock for petrochemicals, and use in agriculture

Renewable generation grows quickly and supersedes fossil fuels by 2030

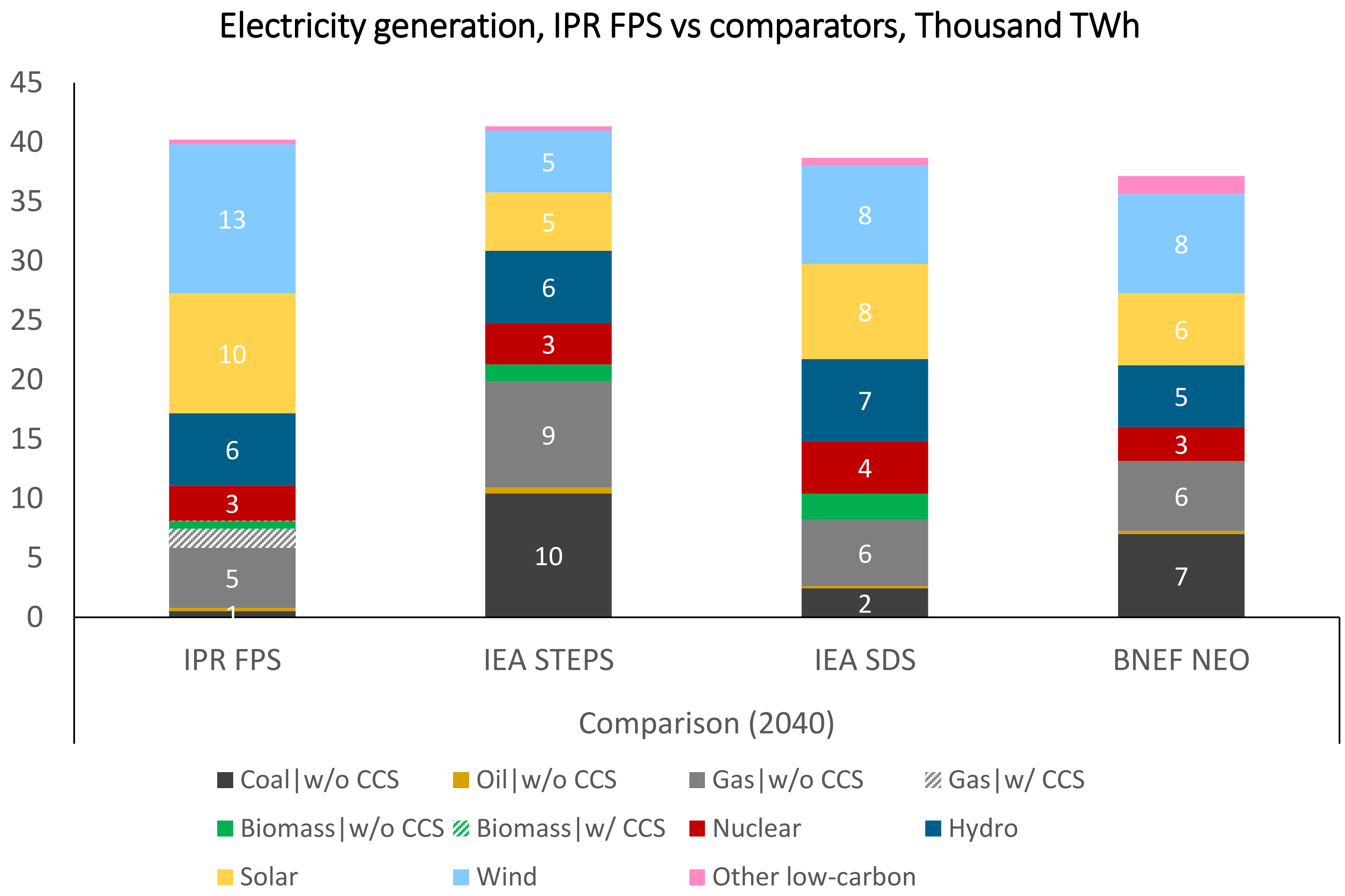


Renewables generate approximately half of all electricity in 2030, and virtually replace all fossil fuels by 2050

- Solar and wind alone will generate approximately 2/3 of all electricity in 2050
- IPR FPS has 72% renewable generation in 2040, more than in the IEA SDS, IEA STEPS, and BNEF NEO
- Coal is phased out by 2050 while gas retains a minor role. By 2050, CCS is applied to around 72% of gas generation but this is only 5% of the total generation mix
- Biomass with CCS grows to 2% of the generation mix by 2050, slow development of CCS is a barrier to use of biomass as a negative emissions technology as are land use constraints
- Overall, nuclear does not grow to replace fossil fuels or renewables given cost and societal issues

INEVITABLE POLICY RESPONSE

Fossils fuels phase out of electricity generation more quickly in FPS than SDS

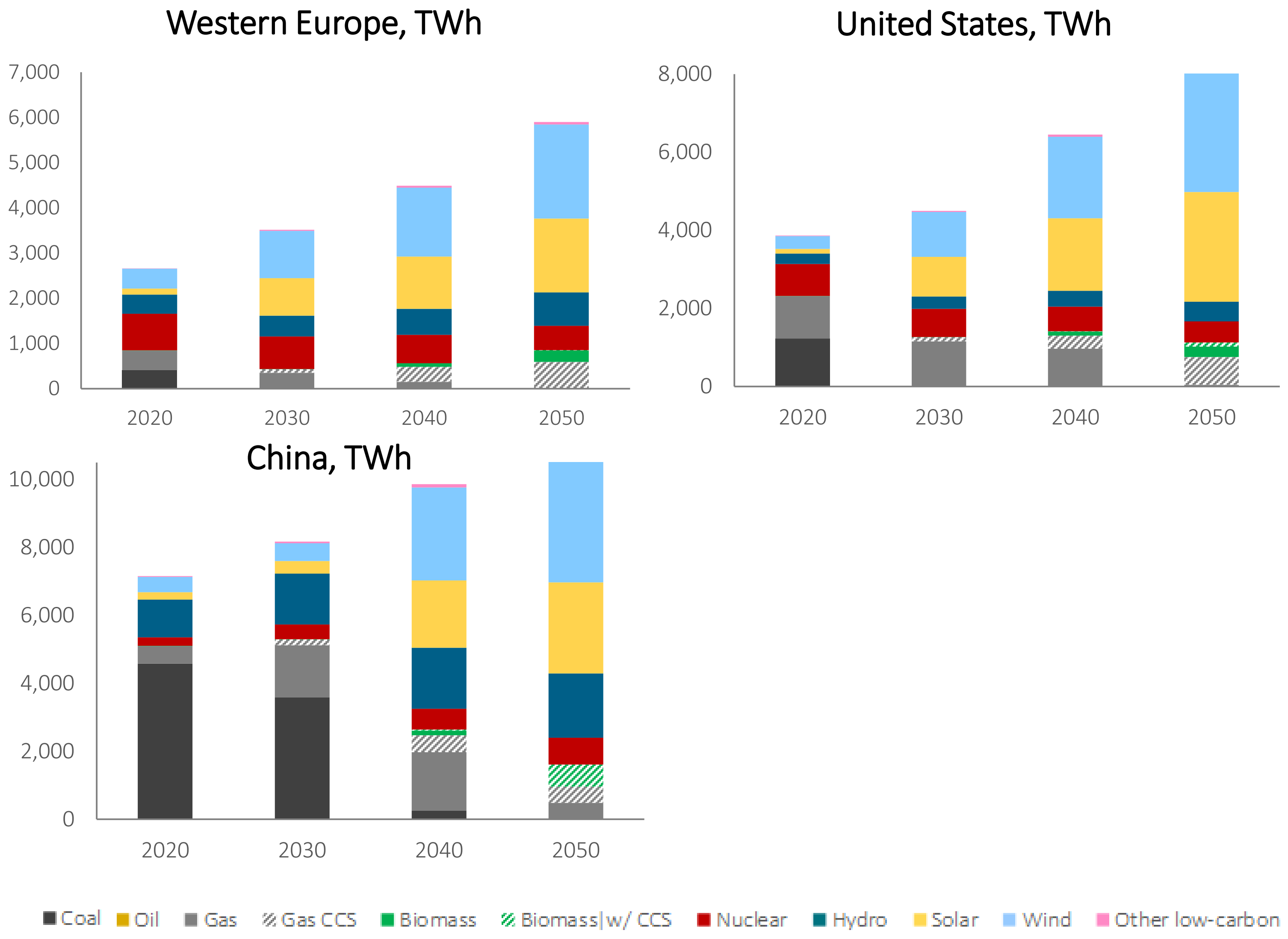


FPS expects faster phase out of fossil fuels in electricity generation than other low-carbon scenarios

- Solar and wind grow rapidly to satisfy increasing demand
- Growth of nuclear limited
- Coal almost entirely phased out by 2040
- Remaining gas begins to shift to CCS
- Biomass in power plays a minor role as sustainable energy crop production remains limited

INEVITABLE POLICY RESPONSE

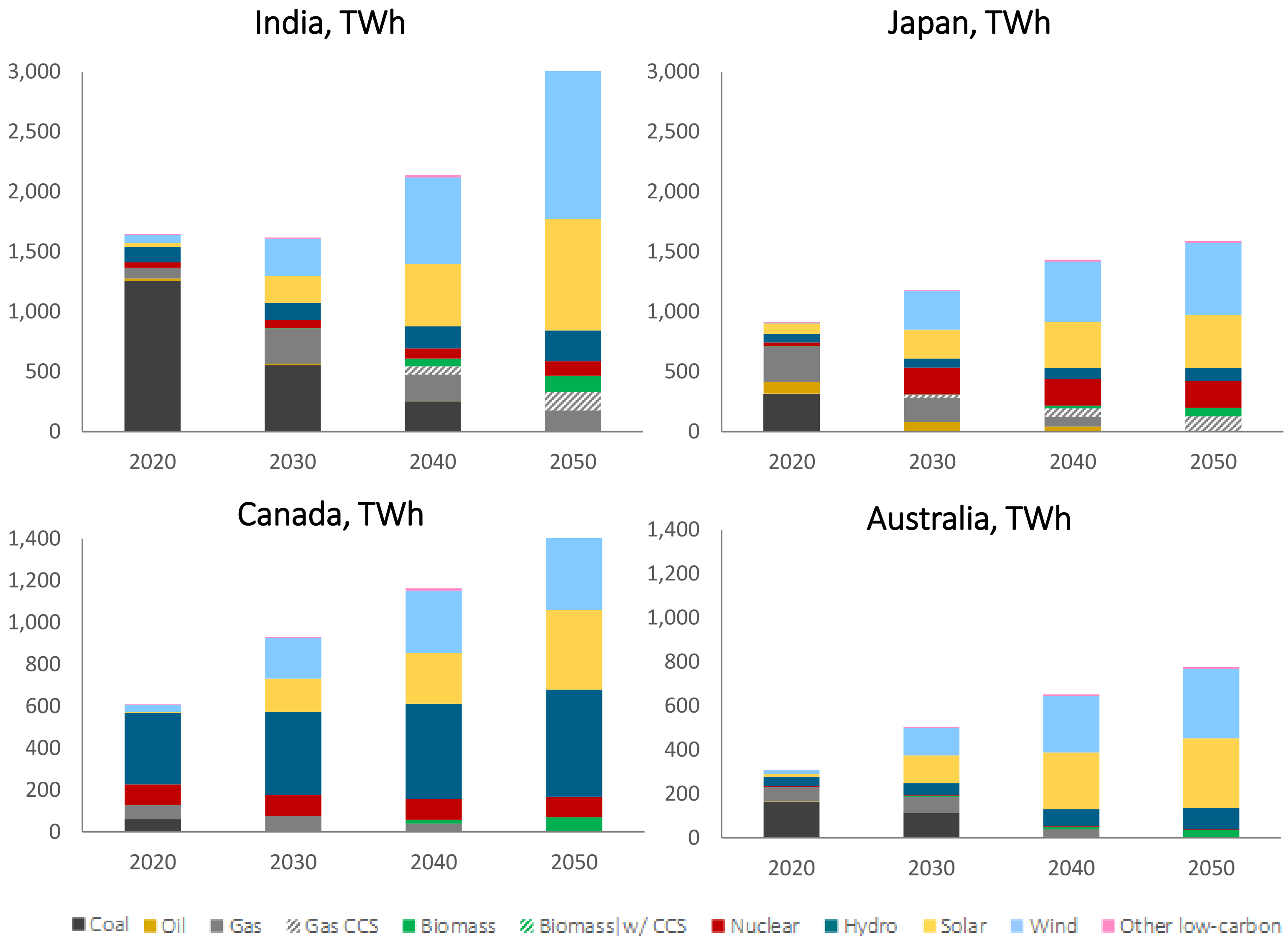
Generation mix: Western Europe, United States, China



- Coal phases out by 2030 in Western Europe, United States
- Coal phases out by 2050 in China
- Some CCS in United States, Western Europe and China by 2050
- Decarbonisation largely driven by significant deployment of wind and solar in all countries

INEVITABLE POLICY RESPONSE

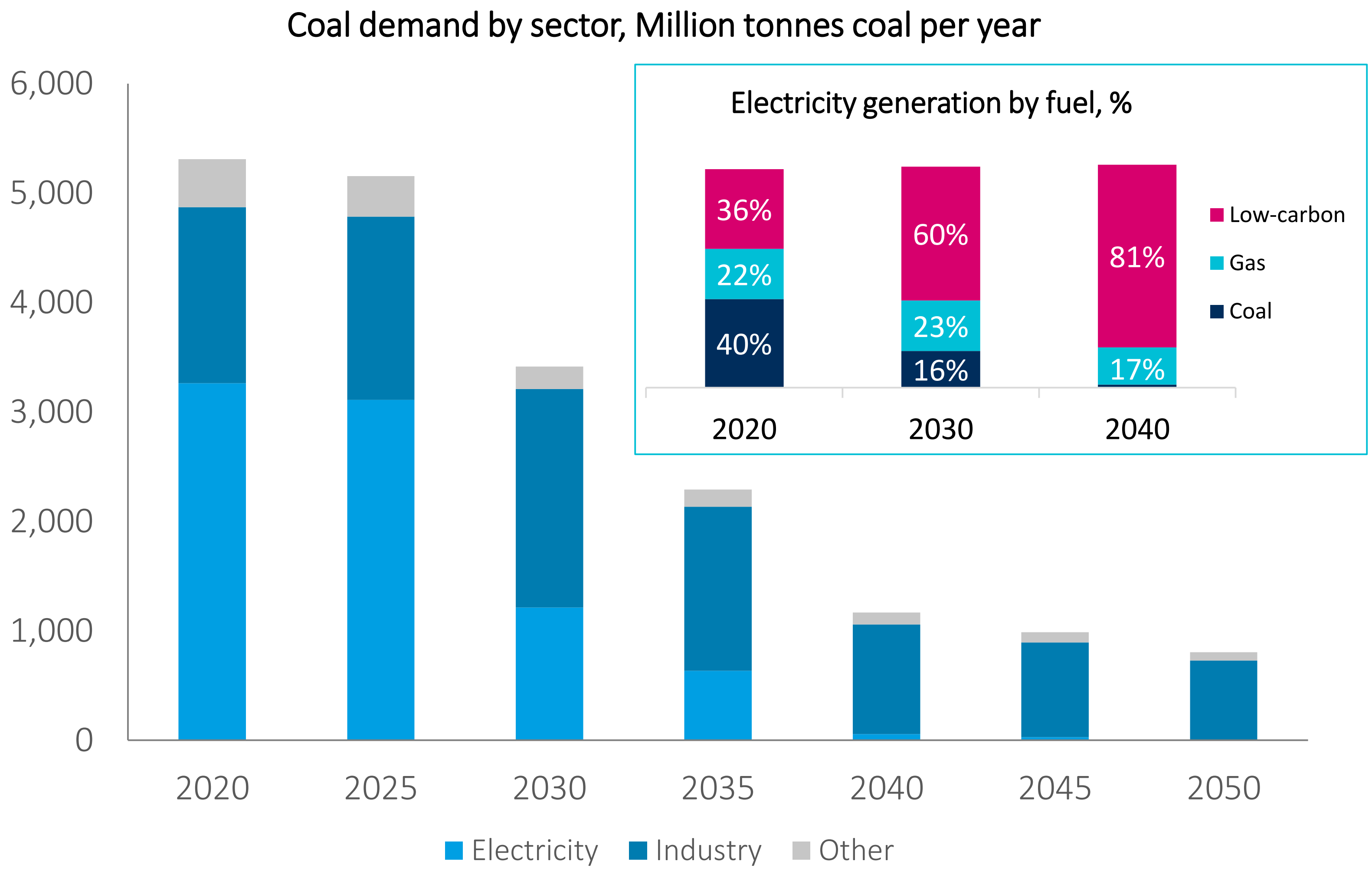
Generation mix: India, Canada, Australia, Japan



- Coal phases out by 2050 in India.
- Canada retains significant role for hydro
- Some CCS in Japan by 2050
- By 2050 minimal CCS deployment in India and Australia; none in Canada
- Decarbonisation largely driven by significant deployment of wind and solar in all countries

INEVITABLE POLICY RESPONSE

Coal demand is at its peak and will decline rapidly by 2025



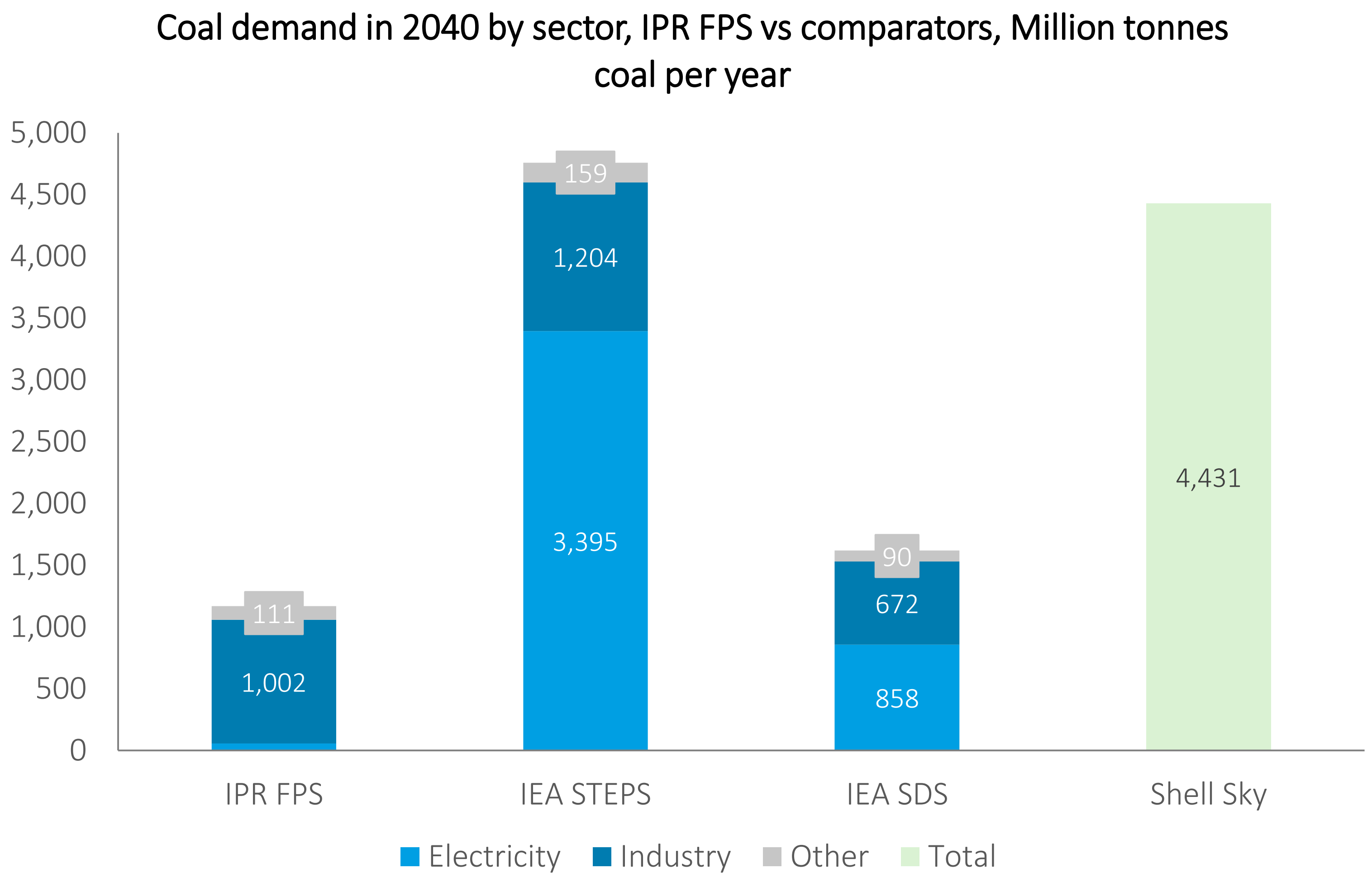
Driven by relative costs and policy, demand for coal for electricity generation declines by 23% per year from 2025 to 2040

- Coal is almost completely phased out of the electricity sector by 2040
- In the 2030s demand for coal in industry decreases significantly
- Electricity, gas and hydrogen replace coal across industry sectors

INEVITABLE POLICY RESPONSE

Note: 'Other' coal use includes energy used in the energy industry, use in agriculture and losses

IPR FPS coal demand declines rapidly in the electricity sector relative to other scenarios

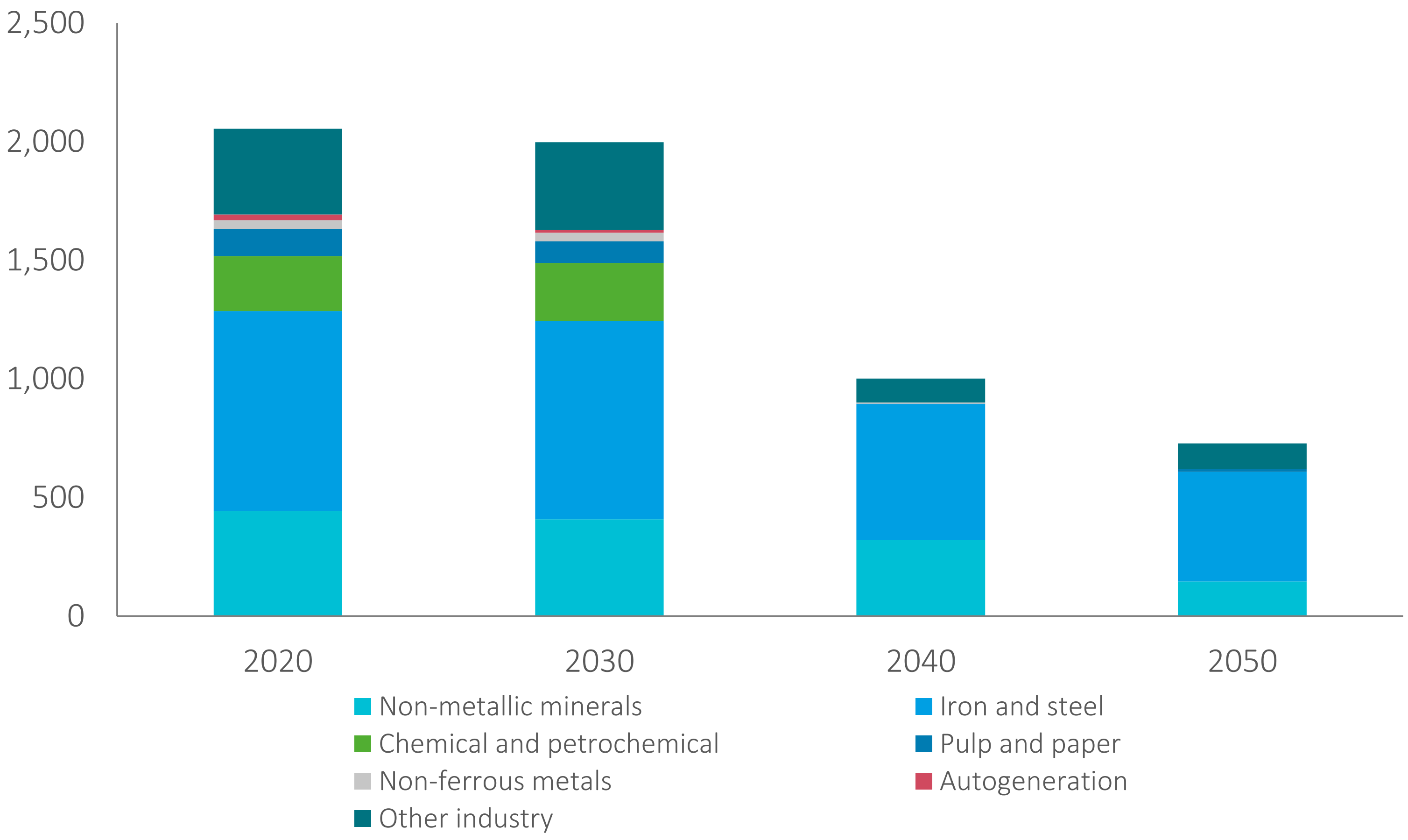


- In the SDS scenario coal demand in the electricity sector decreases overall, but coal demand declines more rapidly in IPR FPS in the electricity sector than in the SDS scenario.
- Similarly to the SDS scenario there is a switching away from coal demand from the industrial sector, but FPS coal demand levels in industry remain higher than SDS in 2040

Note: 'Other' coal use includes energy used in the energy industry, use in agriculture and losses

Coal in industry declines rapidly, remaining largely in the steel and cement sectors

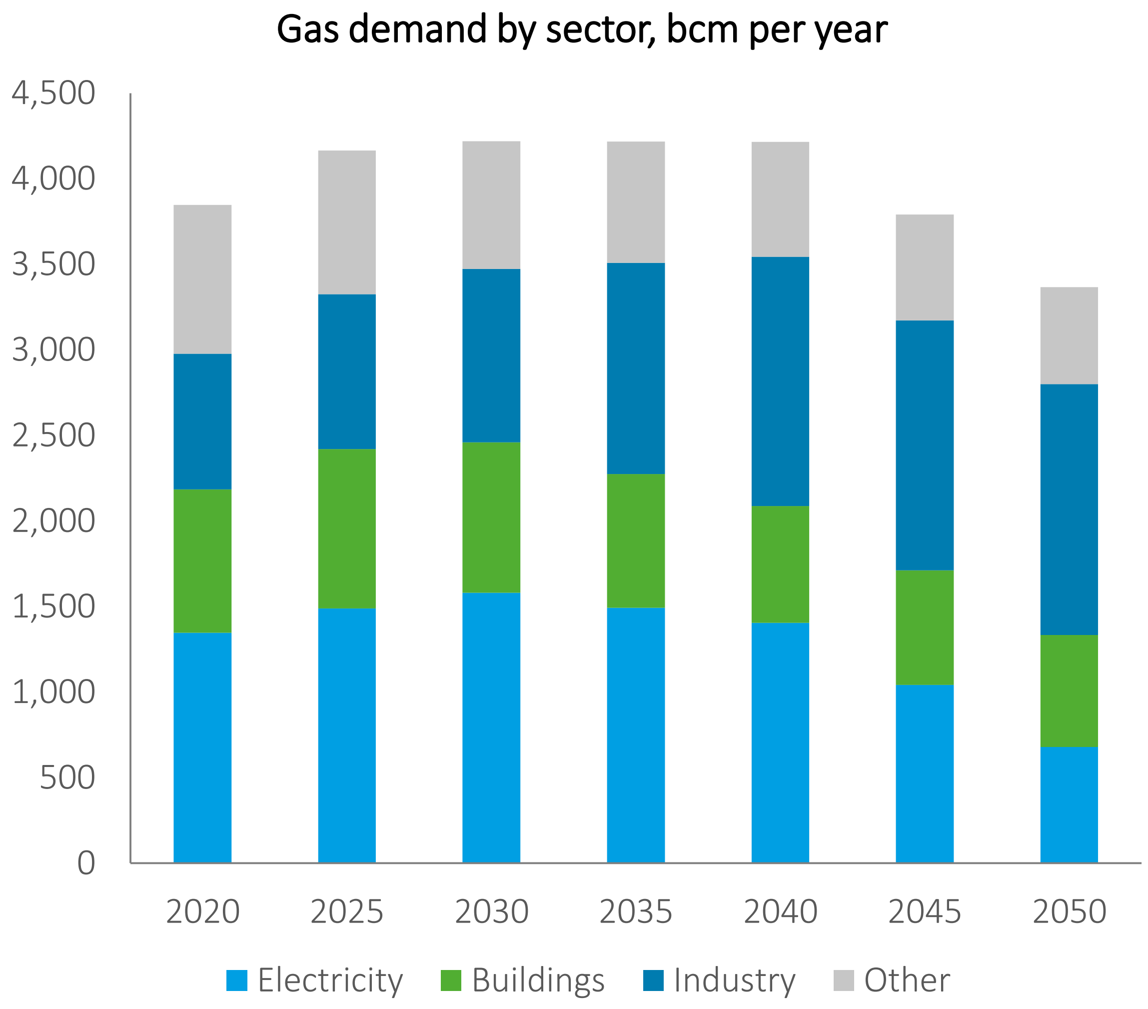
Coal demand by industry sector, Million tonnes coal per year



- Coal in industry declines rapidly in many industrials sectors but remains in hard to abate sectors such as steel and cement sectors
- Gas and electricity replace coal in light industry and chemicals sectors
- While coal use continues in steel (due to the need for coking coal) and non-metallic minerals

INEVITABLE POLICY RESPONSE

Gas replaces a part of coal in industry and plateaus over the 2030s



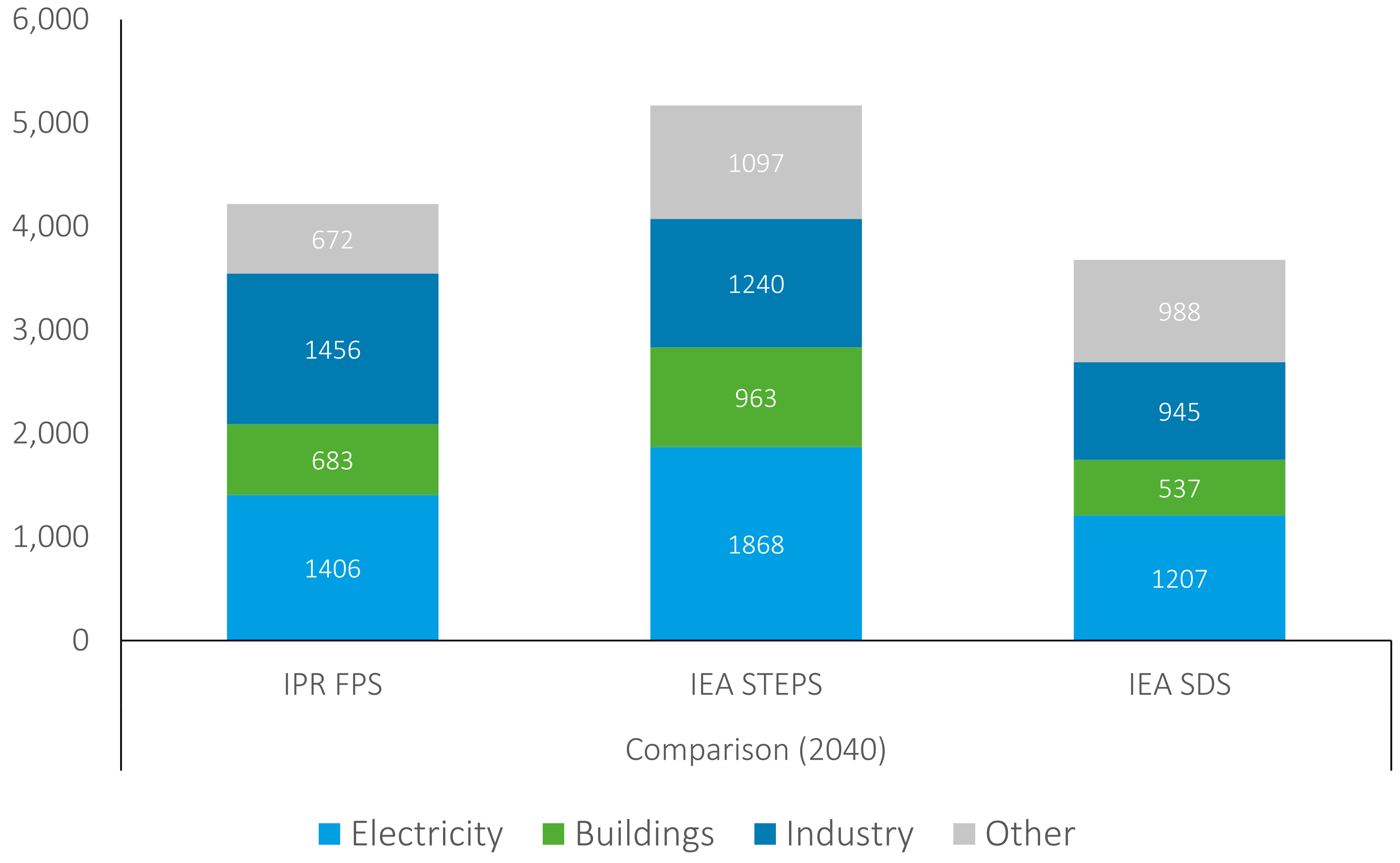
Gas demand in electricity increases to 2030, but begins to decline steadily thereafter

- Natural gas in electricity declines from 2030 onwards; renewables replace thermal coal and satisfy new demand
- Electricity is the largest source of gas demand to 2040, when industry emerges as the largest source, including demand for both fuel and feedstock
- Natural gas replaces thermal coal in industry and helps reduce emissions from heating, but then is replaced by zero-carbon energy from 2040 onwards
- The hydrogen economy emerges gradually as an alternative to gas in industry

Note: 'Other' gas use includes energy used during natural gas extraction and processing, and as feedstock for petrochemicals

Gas comparison IEA vs IPR FPS

Gas use by sector, FPS and comparator scenarios, bcm per year



- Due to rapid phase out of coal in electricity generation, gas use remains above IEA SDS levels though below the level in IEA STEPS
- Gas demand in buildings is in line with IEA scenarios
- Gas use in industry is higher than in comparator scenarios

Note: 'Other' gas use includes energy used during natural gas extraction and processing, and as feedstock for petrochemicals

Methane from gas production

There is a significant amount of methane emitted during gas production which contributes to the GHG emissions due to venting and leaks

- In 2015 1.08 $GtCO_2e$ of methane was lost from the gas production process due to venting emissions (intentional) and fugitive emissions (unintentional leaks).
- This equates to a 17% uplift in GHG emissions from gas production. As 2015 carbon emissions from gas combustion were 6.4 $GtCO_2$, a 1.08 $GtCO_2e$ of methane emissions implies a 17% uplift.

The IEA estimate that around half of these fugitive emissions could be abated at zero or negative cost

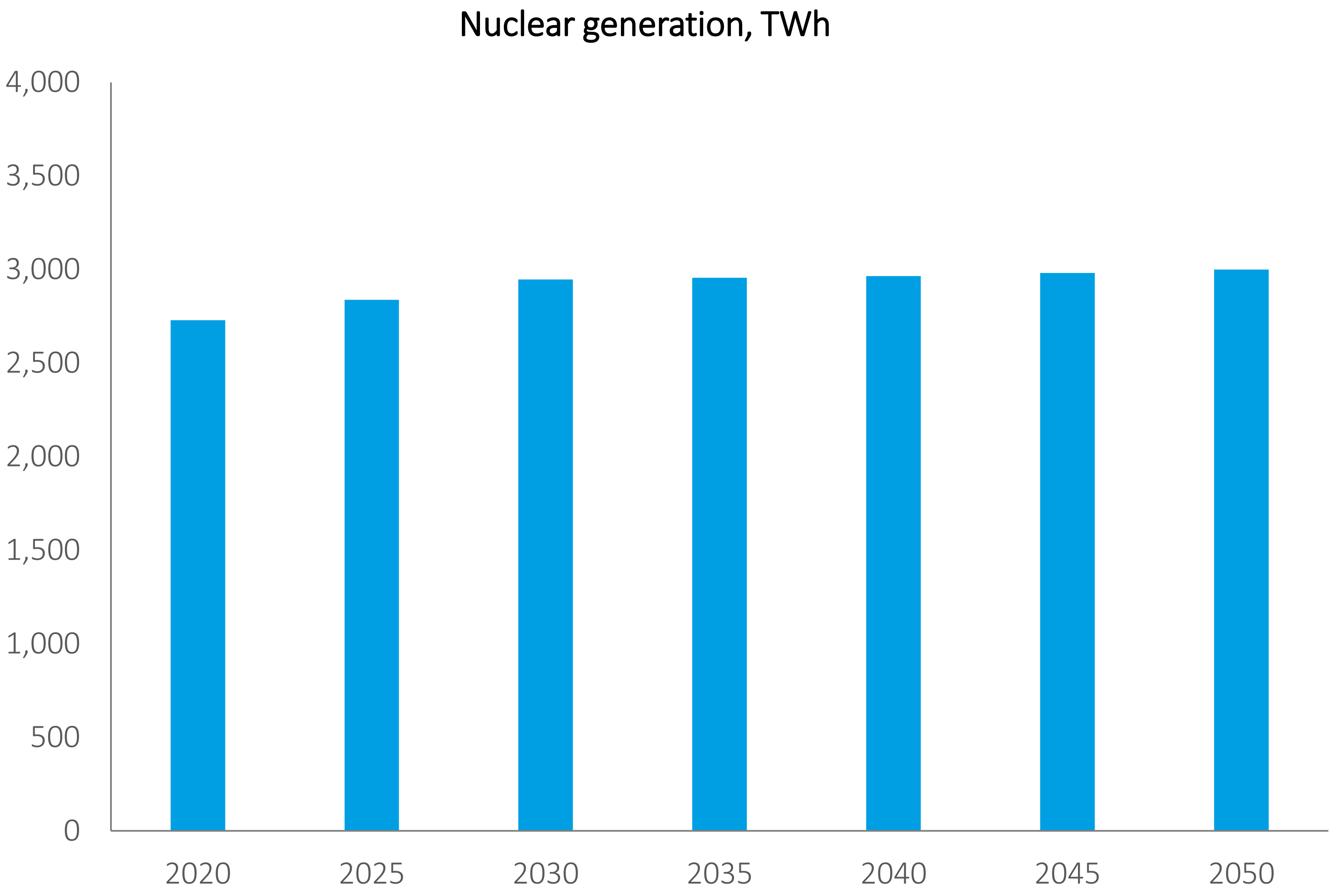
- There are several voluntary schemes which are being put in place to allow firms to take advantage of this drawing on best practice: The Oil & Gas Methane Partnership, The Oil and Gas Climate Initiative, The Methane Guiding Principles.

The IPR FPS scenario forecast is that all zero or negative cost measures are put in-place by 2030

- As additional regulations are introduced the uplift from methane emissions decreases to 75% below 2015 levels by 2060.

INEVITABLE POLICY RESPONSE

In IPR FPS, nuclear does not grow to replace fossil fuels

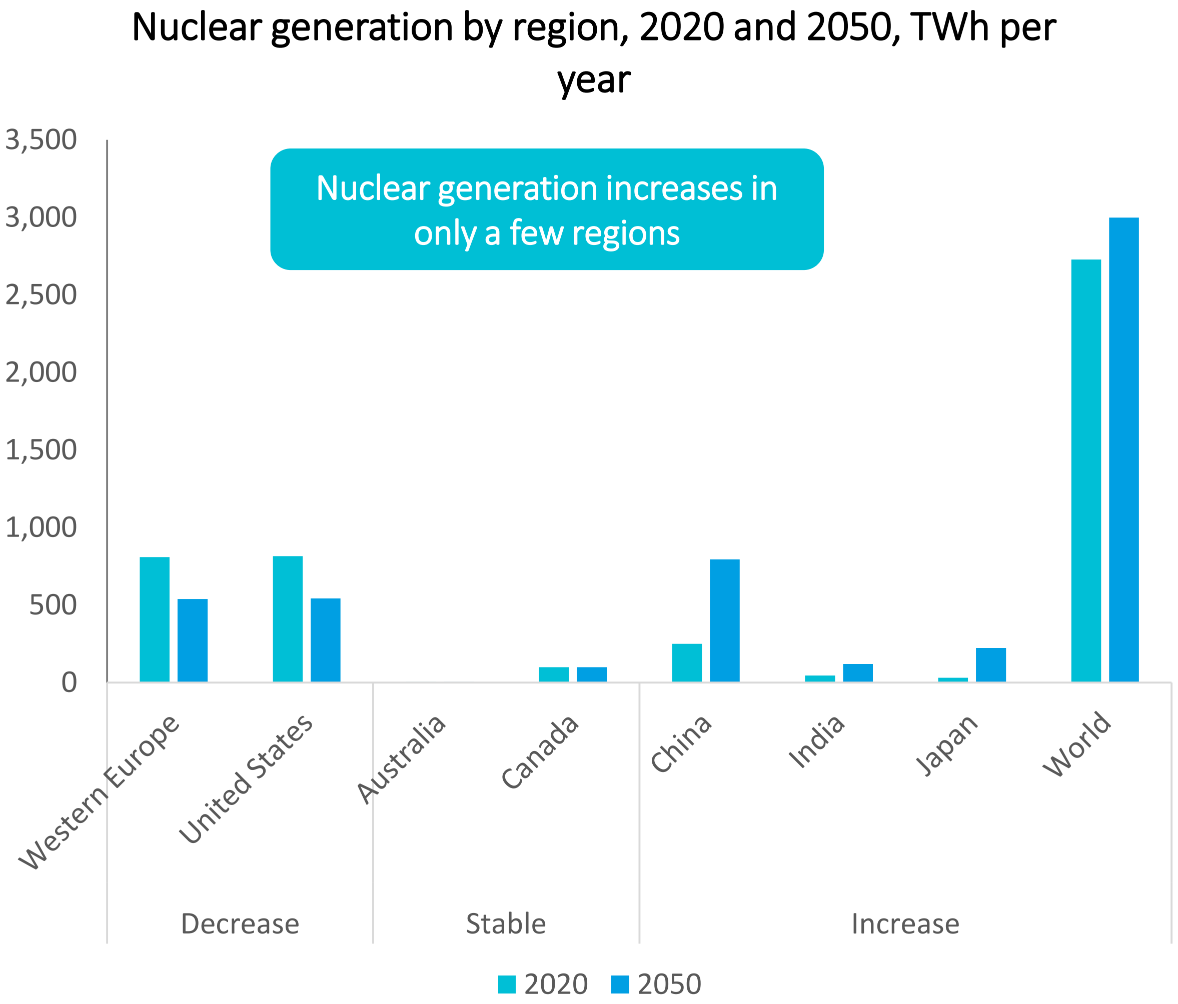


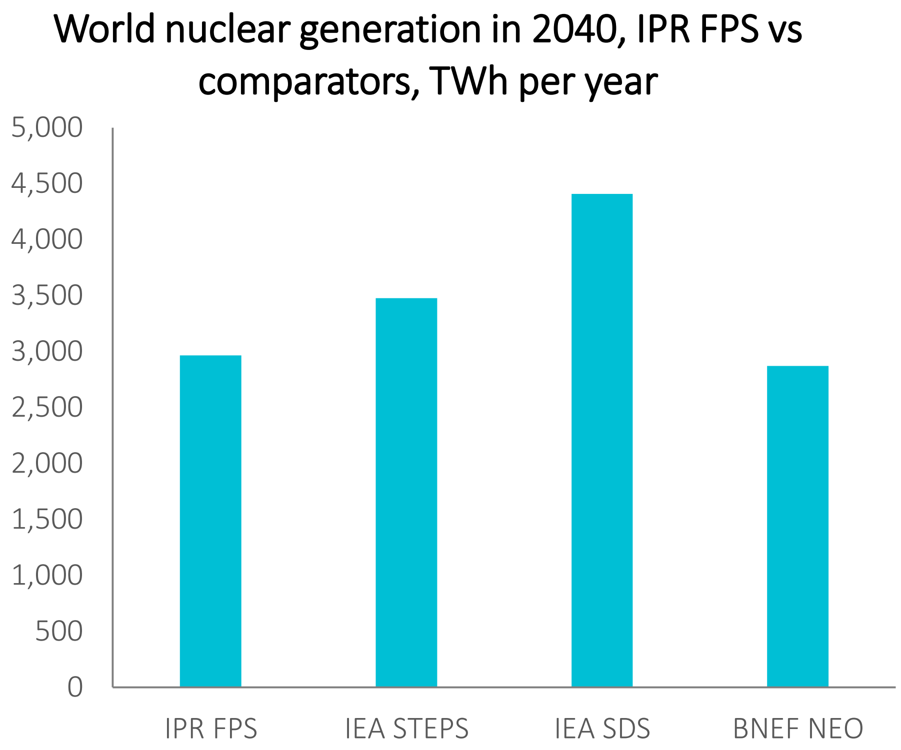
Nuclear does not grow to replace fossil fuels

- A main challenge to nuclear expansion is the high investment needed to continue operating these plants safely, and the continued high cost of new capacity
- In addition, there remains significant political opposition related to nuclear power
- Nuclear generation is highly dependent on Government policy so significant political will would be required for growth to exceed these expectations

INEVITABLE POLICY RESPONSE

IPR FPS is conservative on nuclear generation relative to comparators

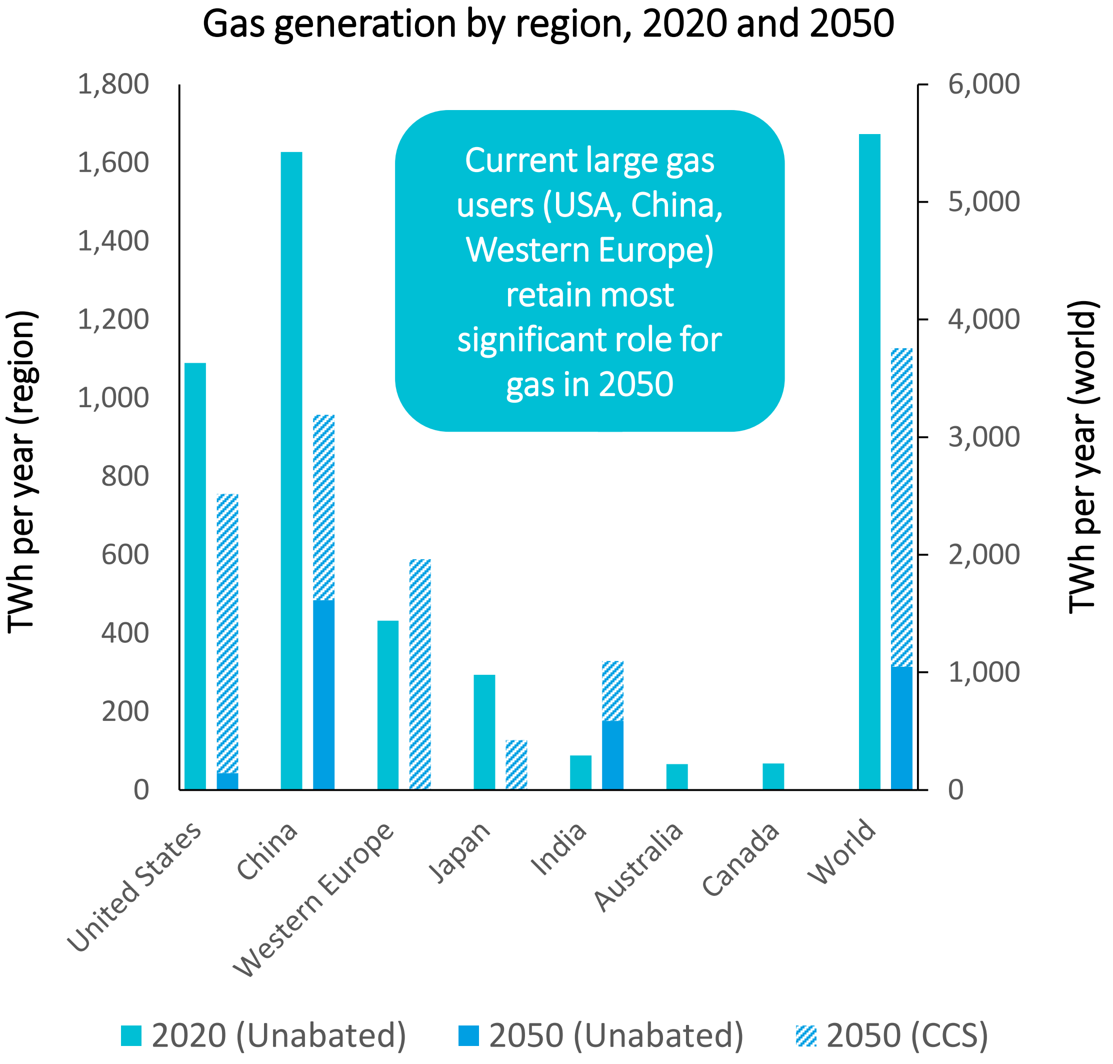


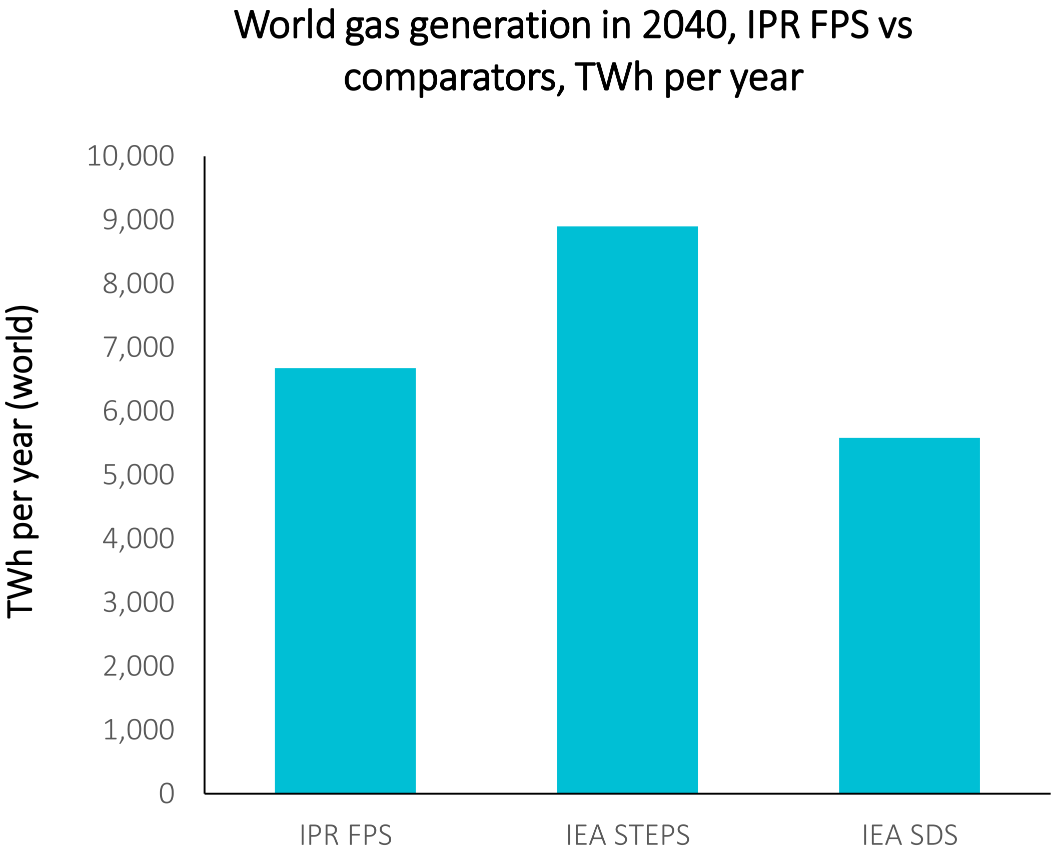


While BNEF NEO is comparably conservative on nuclear, IEA SDS scenario includes considerable nuclear increase

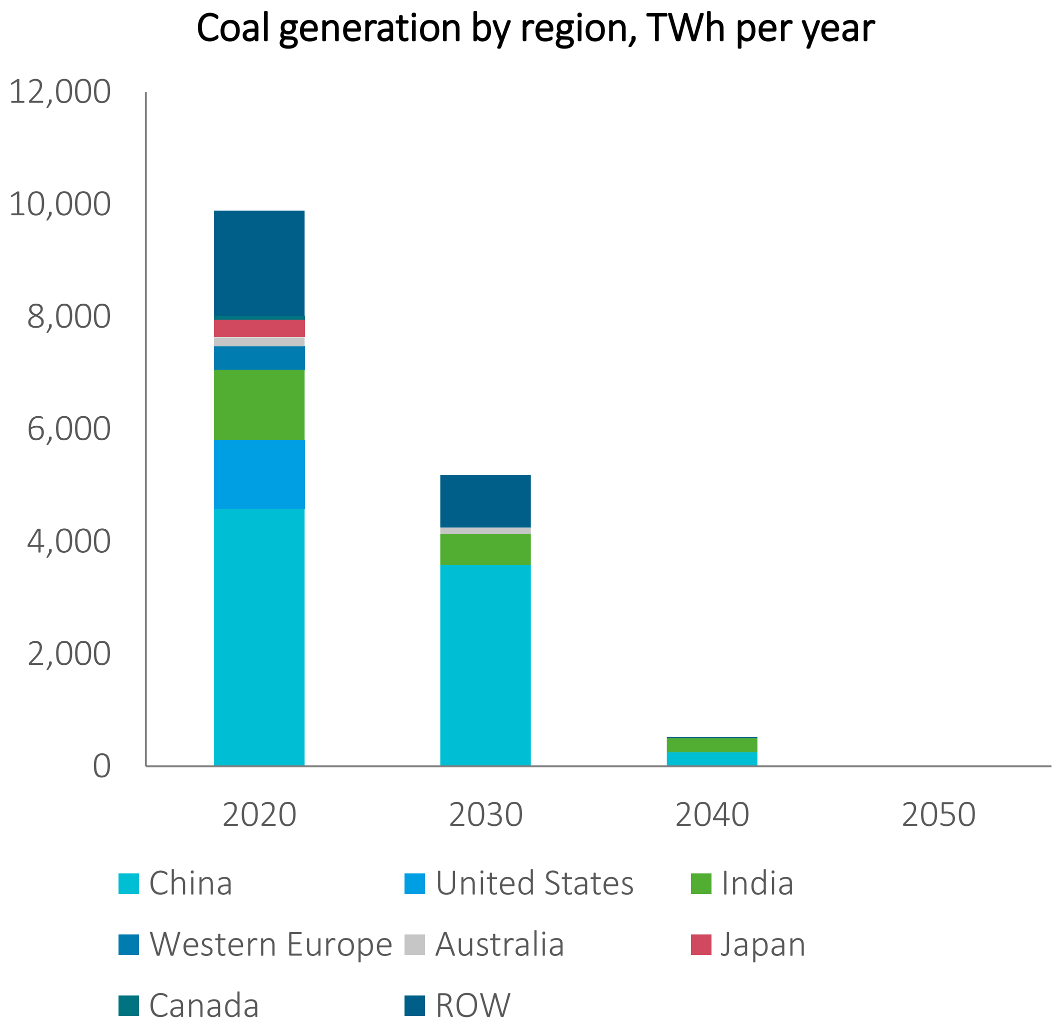
INEVITABLE POLICY RESPONSE

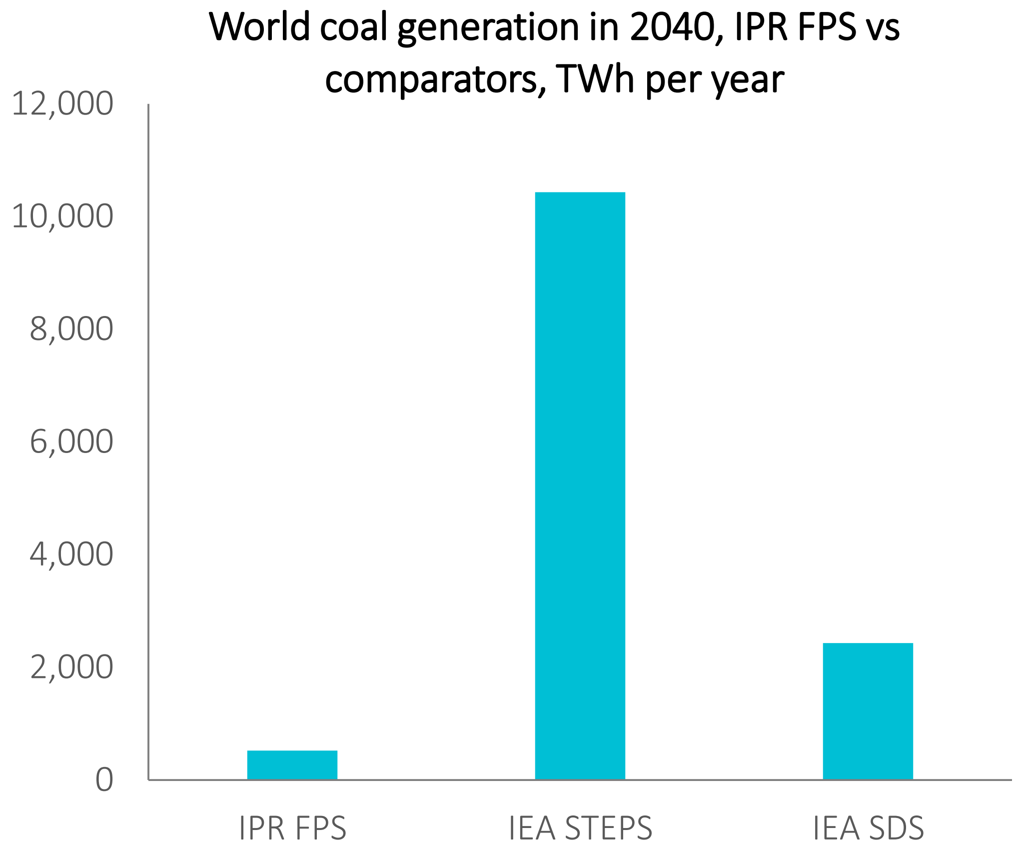
Gas generation decreases significantly, and remaining gas is largely fitted with CCS





Coal comparison IEA vs. IPR FPS





Transport, Industry and Carbon Capture and Storage – key findings

ICE sales bans, supported by technology cost reductions, drive rapid deployment of ultra-low emissions vehicles

- As a result of its policy assumptions, IPR FPS expects twice as many electric passenger and light-duty vehicles as Bloomberg New Energy Finance (BNEF) by 2040 with near total decarbonisation by 2050
- Heavy-duty vehicles are expected to follow a similarly rapid shift to zero-emissions vehicles, with a greater role for hydrogen, and near total decarbonisation by 2060

Industry decarbonises quickly, but at pace commensurate with technology readiness and long plant lifecycles

- Coal-to-gas switching plays a major role in next two decades, as technically ready, cost effective and non-disruptive to production
- Electricity and hydrogen begin pushing out coal and gas as market price of carbon rises, technology costs fall, and the cycle of plant replacement enables greater and greater industrial transformation

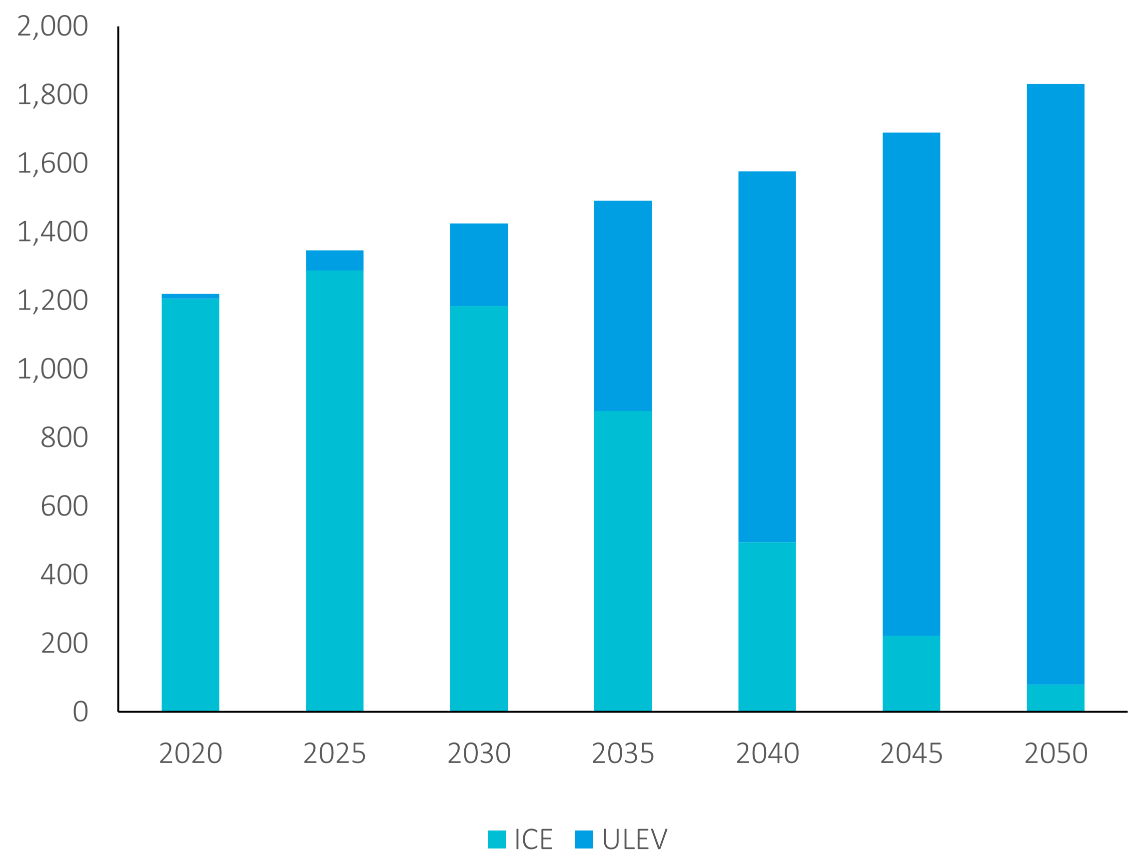
Carbon Capture and Storage (CCS) plays a small role in power and industry (to cover hard-to-abate sources)

- Fossil fuel electricity declines rapidly
- Industrial CCS plays a role in the pace of industrial transformation
- Some bioenergy with CCS can play a role as a long-term solution for generating negative emissions

INEVITABLE POLICY RESPONSE

ICE vehicles peak in 2025 – by 2040, ultra-low emissions vehicles are the majority

Passenger vehicles by powertrain, Million vehicles

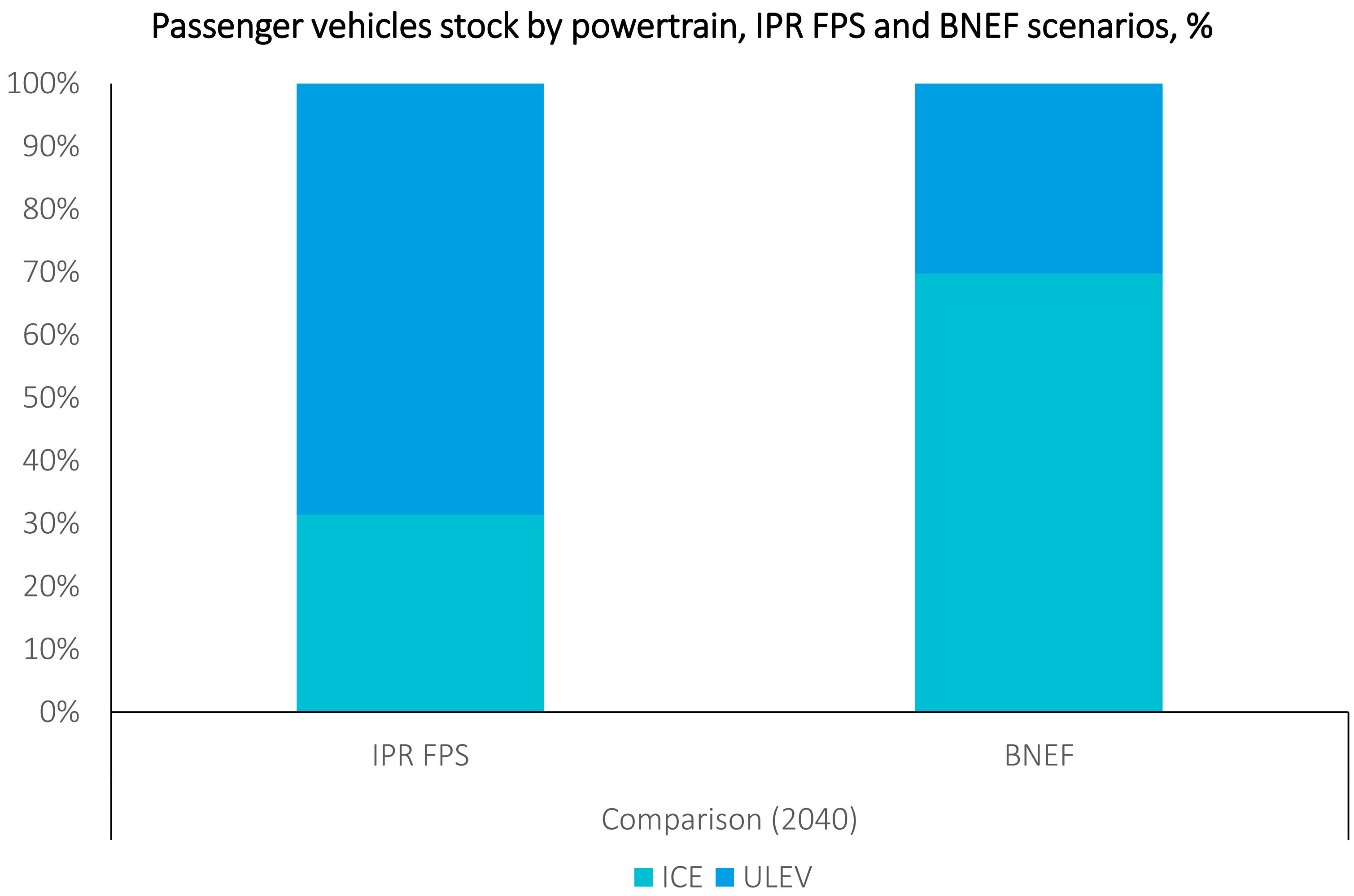


Number of ICE vehicles peaks in 2025 driven by EV cost reductions and ICE sales bans, with significant implications for demand along the automotive supply chain

- Acceleration of ULEVs driven by 2035 ICE bans in Western Europe and China; 2040 bans USA, Japan and other regions
- By 2050 relatively few ICE vehicles remain, primarily in less developed countries that transition more gradually
- In the BNEF New Energy Outlook, sales of ICE passenger vehicles have already peaked and number of ICE passenger vehicles peaks around 2030. In 2040 around a third of the fleet are EVs

INEVITABLE POLICY RESPONSE

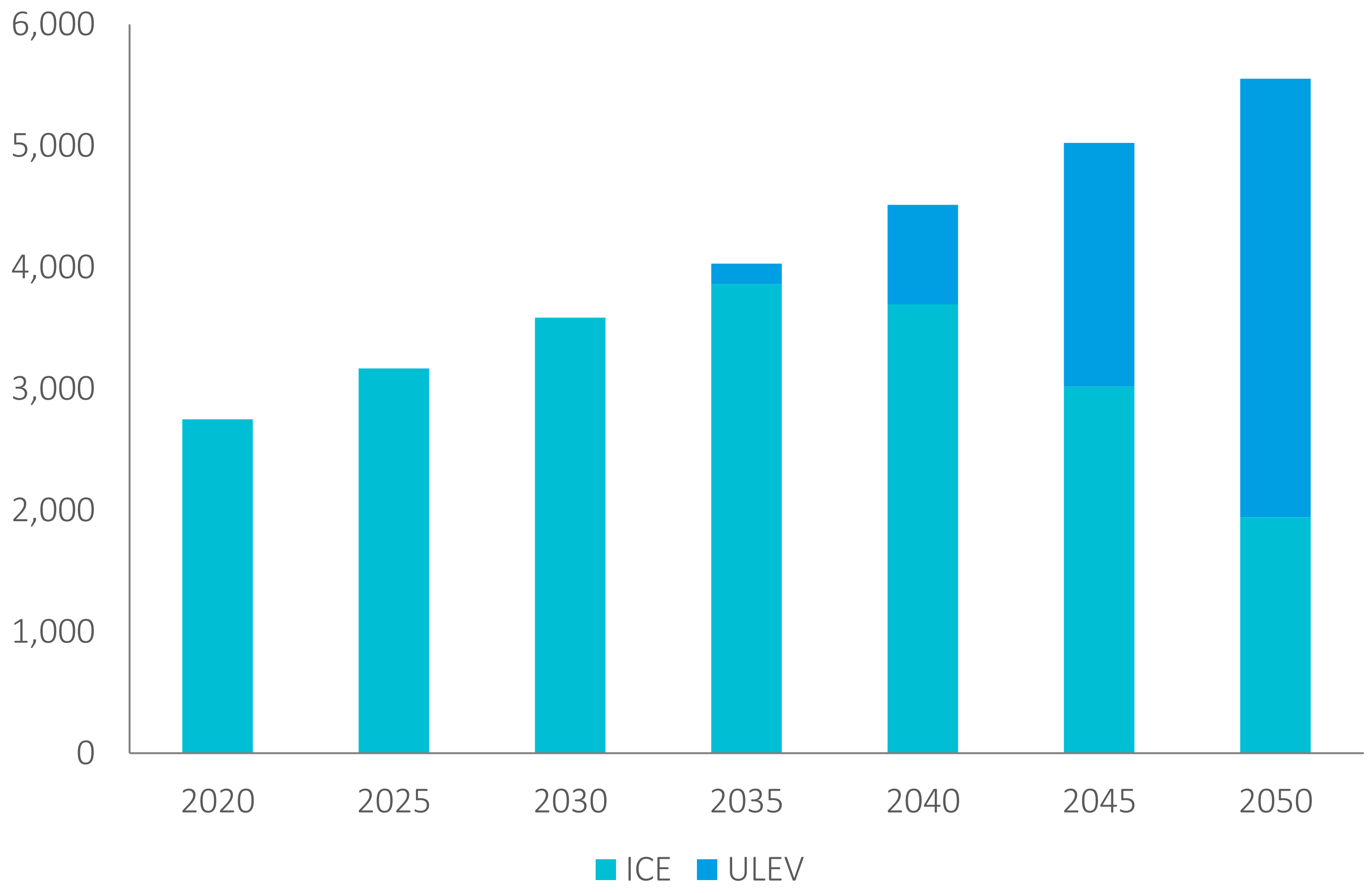
Passenger vehicles by powertrain in 2040, IPR FPS and BNEF scenarios



- ICE bans result in more aggressive deployment of ULEV than in BNEF New Energy Outlook (NEO)
- In the BNEF NEO
  - sales of ICE passenger vehicles have already peaked
  - number of ICE passenger vehicles peaks around 2030
  - around a third of the fleet are EVs in 2040

Deployment of ultra low emission trucks is expected to be slower than for passenger vehicles

Truck travel by powertrain, Billion vehicle km



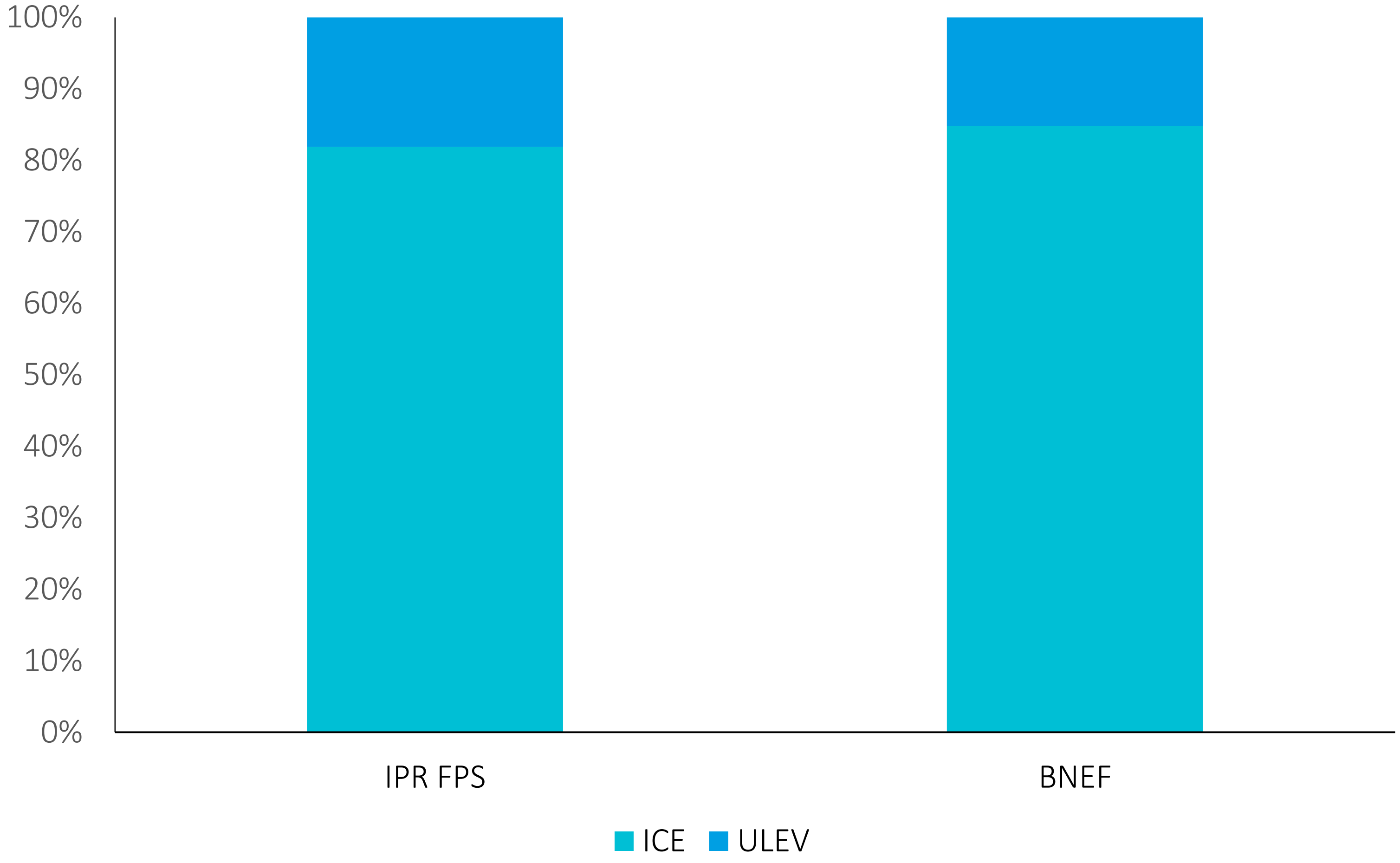
- Some early uptake of ultra low emission vehicle trucks by 2030, driven by 2040 ICE bans in China and Western Europe
- Further uptake by 2040, as ICEs are phased out in China and Western Europe, and other regions impose ICE bans
- Ultra low emission vehicle trucks make up the majority of the fleet in most regions; significant ICE fleets continue to exist in Africa, India and elsewhere
- We expect the majority of ULEV trucks to be battery electric; however up to one third could be hydrogen fuel cell trucks, which may be better suited to long distance usage

INEVITABLE POLICY RESPONSE

Note: Ultra-low emission vehicles (ULEVs) include battery electric, plug-in hybrid and hydrogen fuel cell vehicles

Trucks by powertrain in 2040, FPS and BNEF scenarios

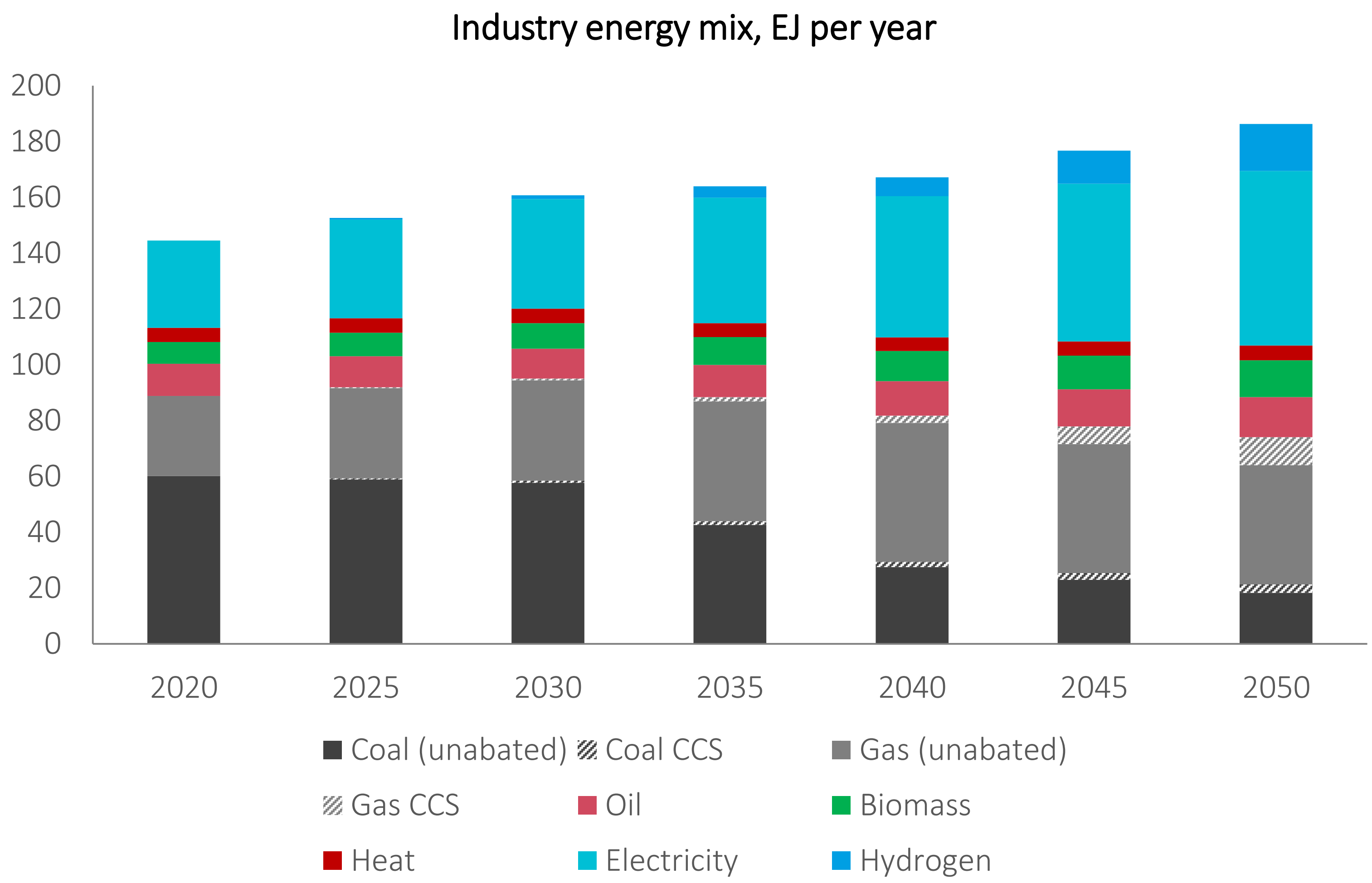
Trucks stock share by powertrain, IPR FPS and BNEF scenarios, %



- By 2040, around 18% of the truck fleet is an ultra low emission truck in the IPR FPS scenario
- This uptake is slightly more rapid than in the BNEF scenario, which projects only a 15% share of new vehicle sales in 2040

Note: Ultra-low emission vehicles (ULEVs) include battery electric, plug-in hybrid and hydrogen fuel cell vehicles

Electrification, hydrogen and CCS contribute to the progressive decarbonisation of industry



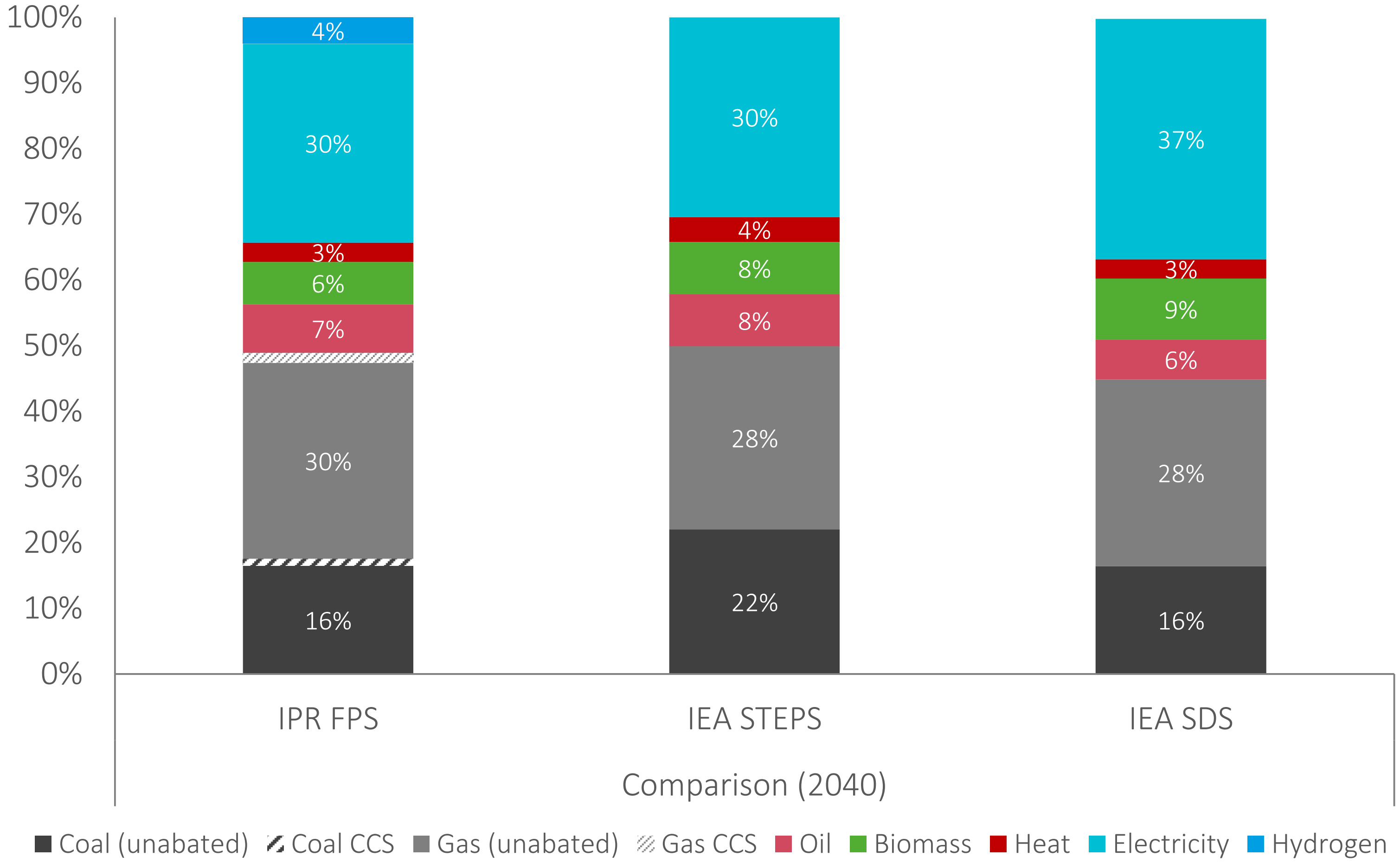
Coal-to-gas switching – proven, economical and non-disruptive – accelerates as a near-term solution to reducing industrial emissions

- Electrification, hydrogen, and CCS contribute to decarbonising energy intensive industry sectors in medium to long term with the carbon price forecasts playing an important role
- Fuel mix changes proceed at a pace consistent with economics of emerging technologies, and long plant lifecycles

INEVITABLE POLICY RESPONSE

The IPR FPS scenario reduces industrial coal use faster than the SDS scenario

Industry energy mix, IPR FPS and comparator scenarios, %

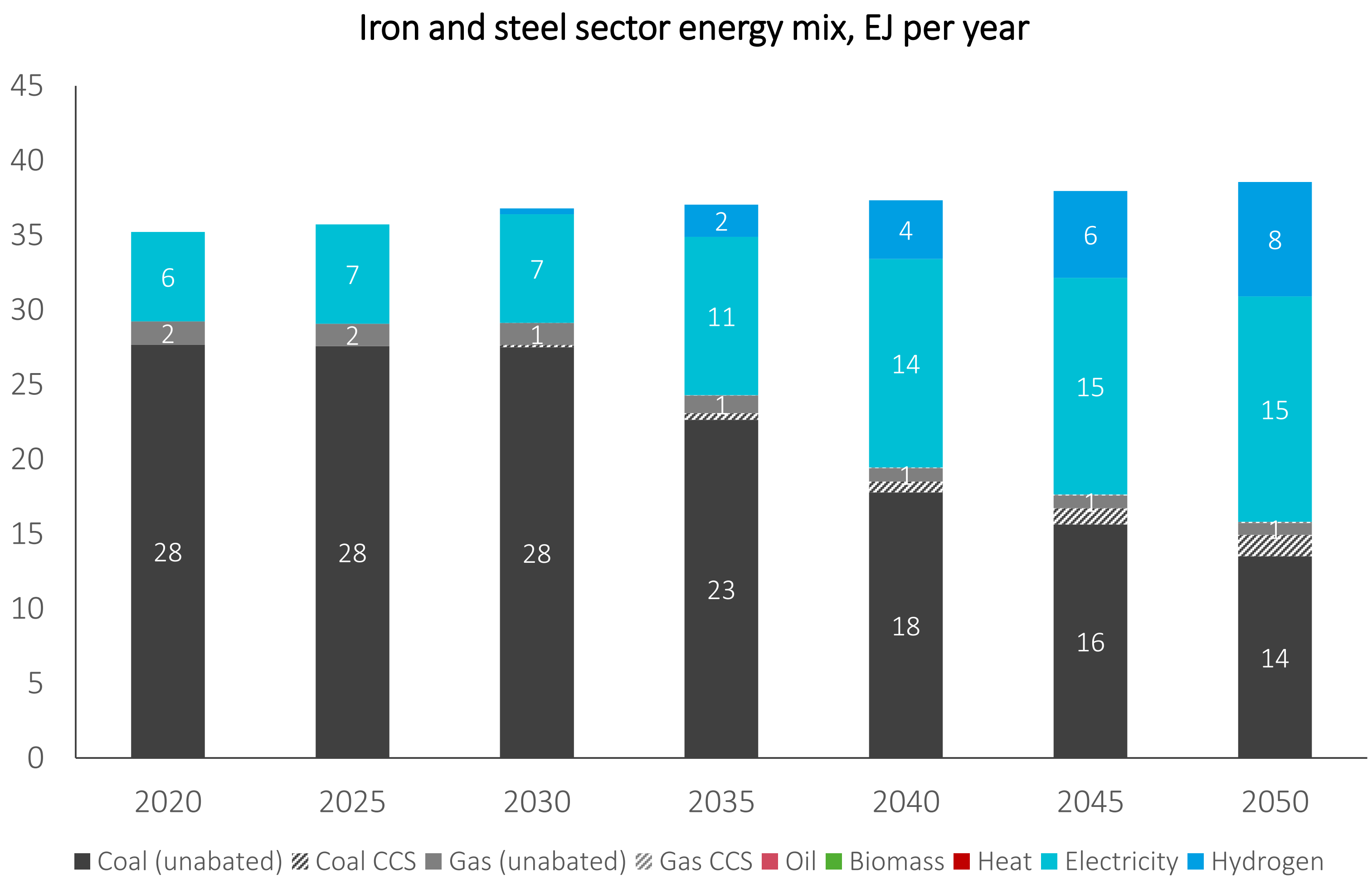


- The IPR FPS low-carbon fuel mix is comparable to IEA scenarios in 2040
- However, IPR FPS has greater industry use of unabated gas as a transition fuel

INEVITABLE POLICY RESPONSE

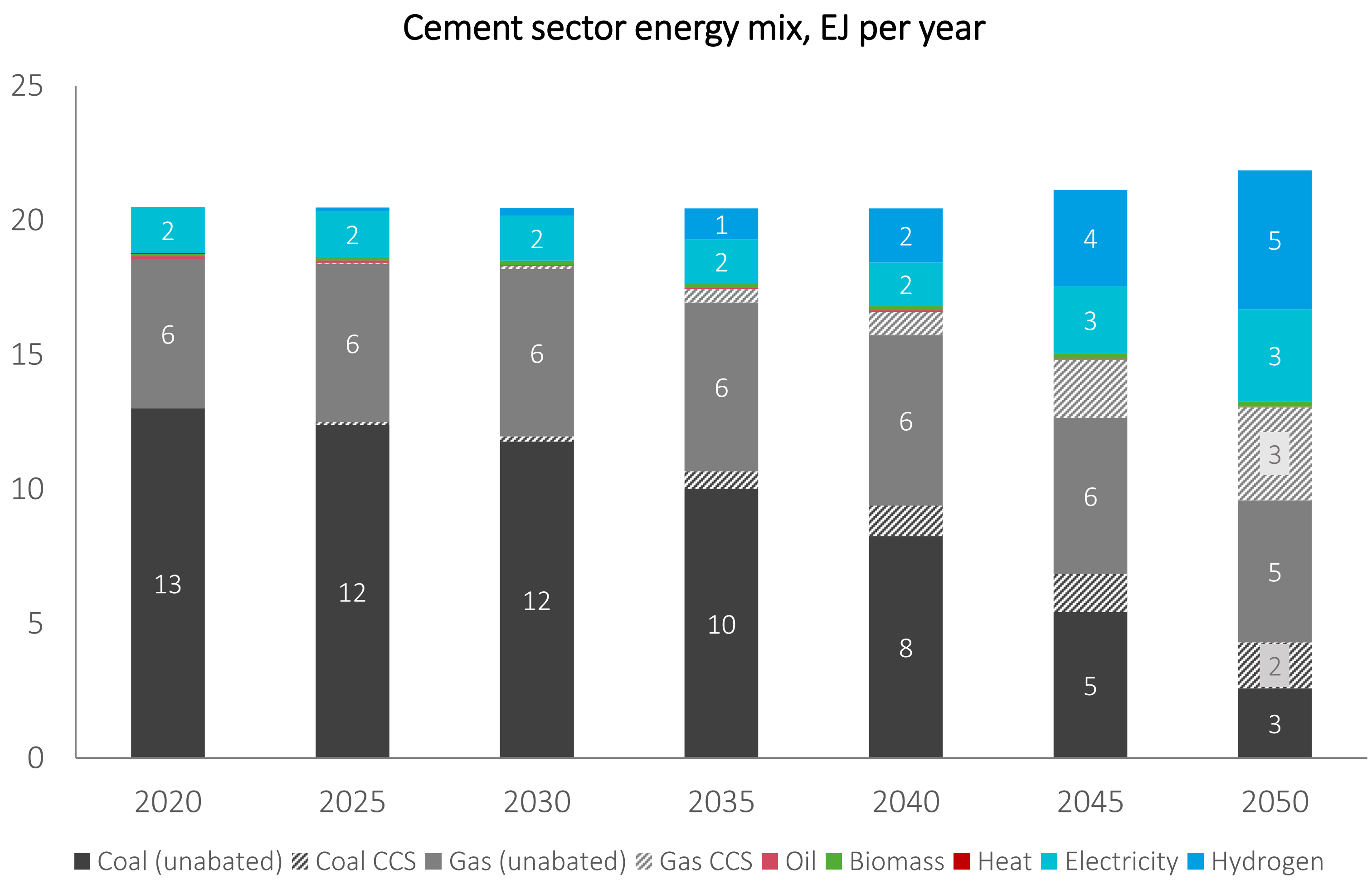
Note: Amount of CCS in industry is not published by the IEA

In steel production, electrification remains the dominant low-carbon solution, but hydrogen begins to play an important role



- Steel demand increases to 2030, but declines 2030-2050 due to improved materials efficiency
- Electric arc furnaces continue to be the primary production method for recycled steel
- Production using hydrogen and CCS begins at small scale in 2030; by 2050 hydrogen accounts for around 20% of fuel used in steel production

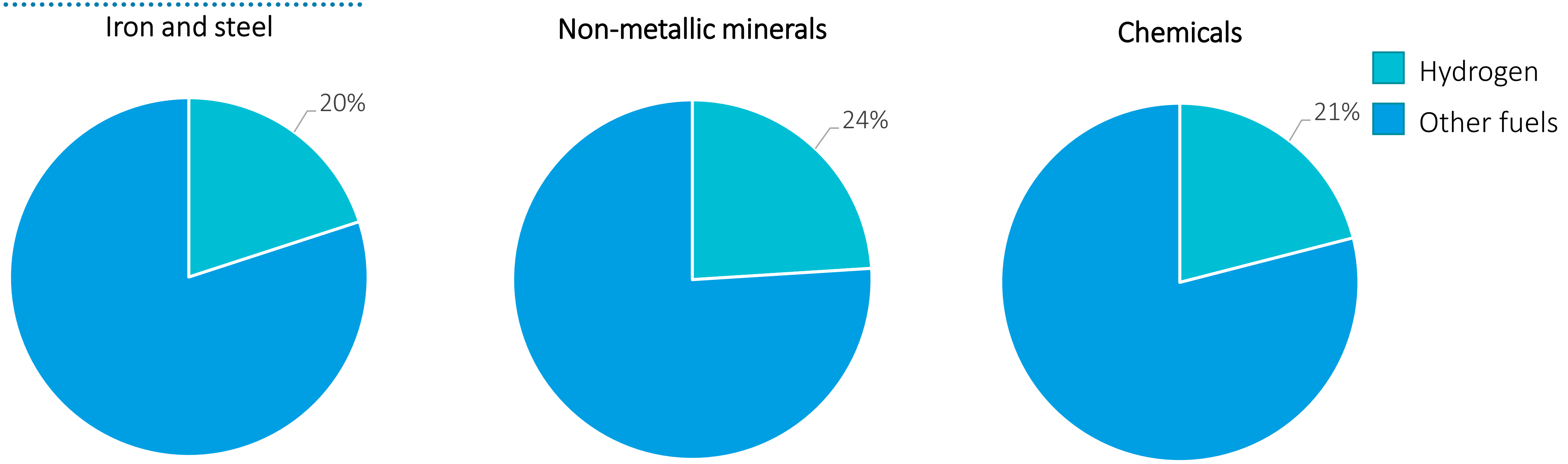
In cement production, hydrogen and CCS emerge as the dominant low-carbon production methods



- CCS plays a more significant role in cement production due to the ability to capture process emissions
- By 2050, around 60% of the energy mix comes from low-carbon sources

INEVITABLE POLICY RESPONSE

By 2050, hydrogen contributes at least 20% of energy demand in hard-to abate sectors

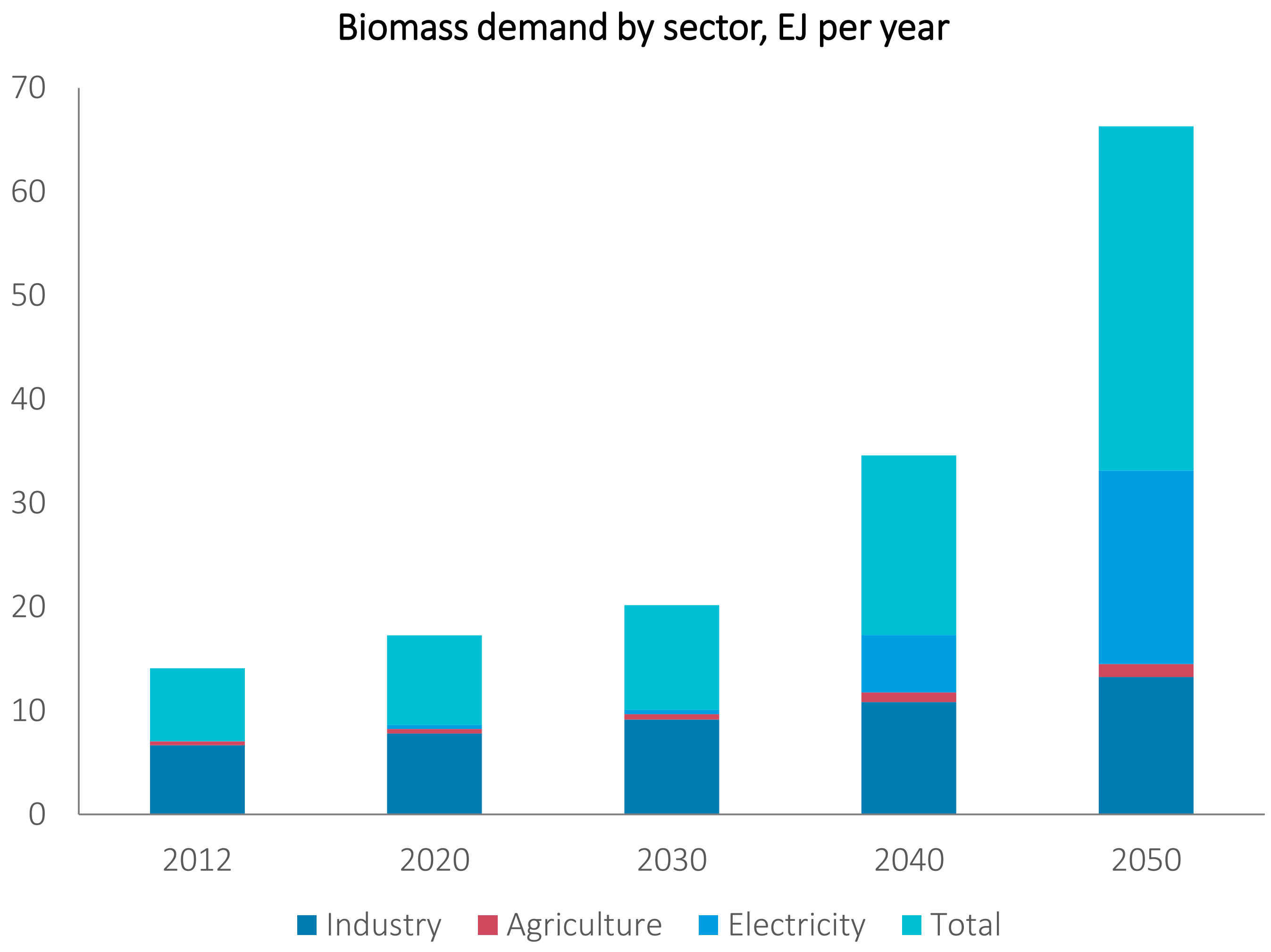


Hydrogen can become a significant energy source in industry. Advantages of hydrogen include:

- Hydrogen is an alternative to electrification technologies. Like natural gas, hydrogen can be burned as a fuel, and less innovation is needed to develop hydrogen burning technologies than many electrification technologies
- Hydrogen is an alternative to carbon capture and storage. Hydrogen allows decarbonisation of industry without fitting capture technologies to individual plant, and without developing new CO_2 transport and storage infrastructure
- Hydrogen can also be used as a reduction agent in steelmaking, potentially eliminating the use of coke as a reduction agent and its resulting process emissions

INEVITABLE POLICY RESPONSE

From 2030, electricity emerges as the largest source of biomass demand



- Bioenergy from energy crops is currently used in industry and transport
- As the supply of sustainable bioenergy grows, it is increasingly used in electricity generation, where it has value as a form of firm power, and in preparation for bioenergy with carbon capture and storage (BECCS)
- Towards 2050, bioenergy is increasingly used in transport. As road transport decarbonises through deployment of ultra-low emission vehicles, bioenergy is used to decarbonise the aviation and shipping sectors.

INEVITABLE POLICY RESPONSE

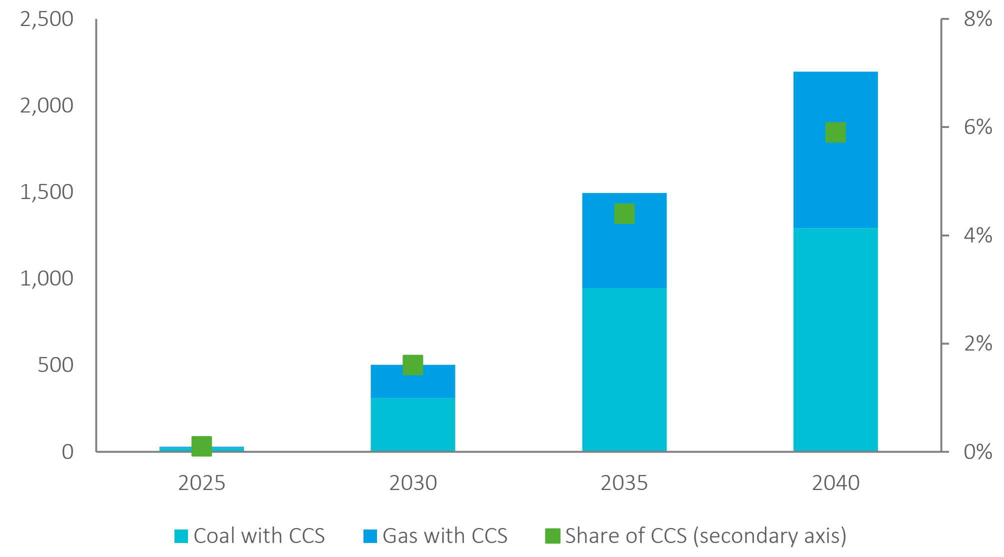
Note: chart shows biomass from dedicated energy crops only; some traditional biomass may also be used in buildings

CCS deployment in the IEA's Sustainable Development Scenario

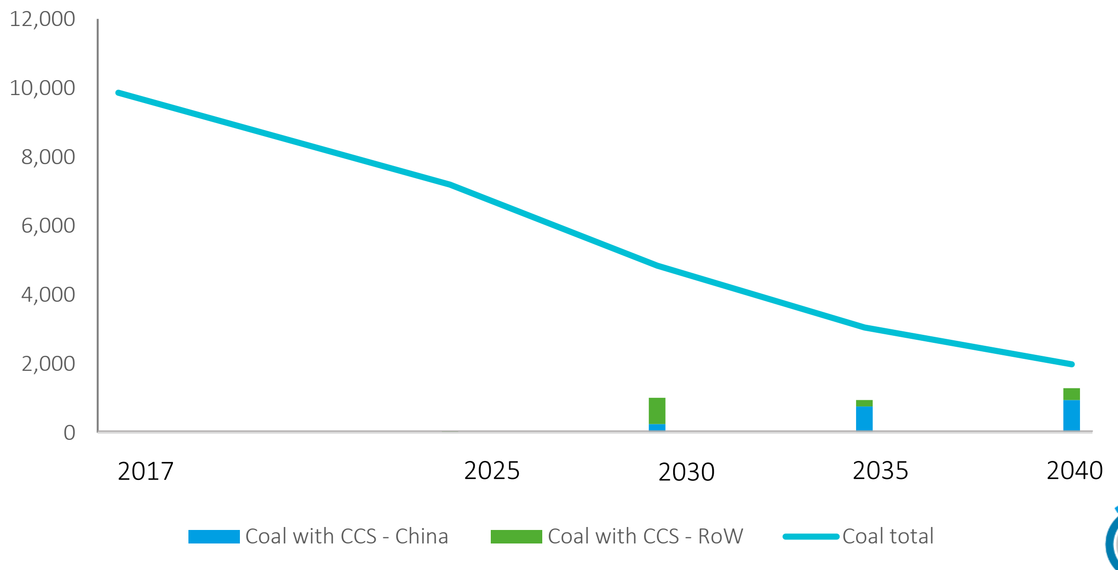
In the IEA' Sustainable Development Scenario (SDS), CCS represents 2,300 Mt of carbon captured each year by 2040 – compared with 30Mt/year currently

- In the IEA's SDS scenario, 2,200TWh of global power are generated with CCS by 2040 – this represents 6% of power generation. Of these 2,200TWh, 60% are generated from coal with CCS
- Most of the power generation from coal with CCS is projected to take place in China – in the SDS scenario, CCS is used to limit emissions from the last operating Asian coal power plants

CCS power generation in the SDS scenario, TWh



Coal-fired power generation in the SDS scenario, TWh



INEVITABLE POLICY RESPONSE

Source: Charts are based on data from the IEA WEO18, available at: https://www.iea.org/topics/carbon-capture-and-storage/power/ Equivalent data for IEA WEO19 has not been found.

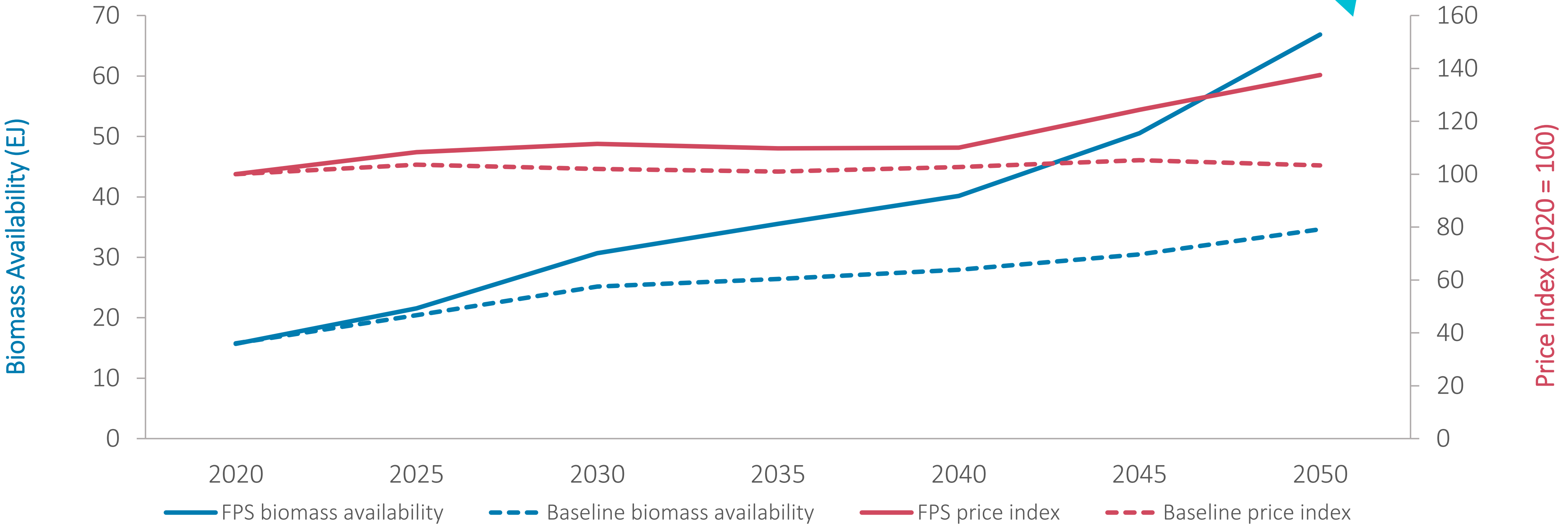
Bioenergy crops produce nearly 67 EJ annually by 2050, with the bulk coming from 2nd generation crops

Literature suggests that biomass availability is unlikely to be sustainable beyond 100EJ by 2100

Widespread adoption of 2nd generation biomass crops in 2030

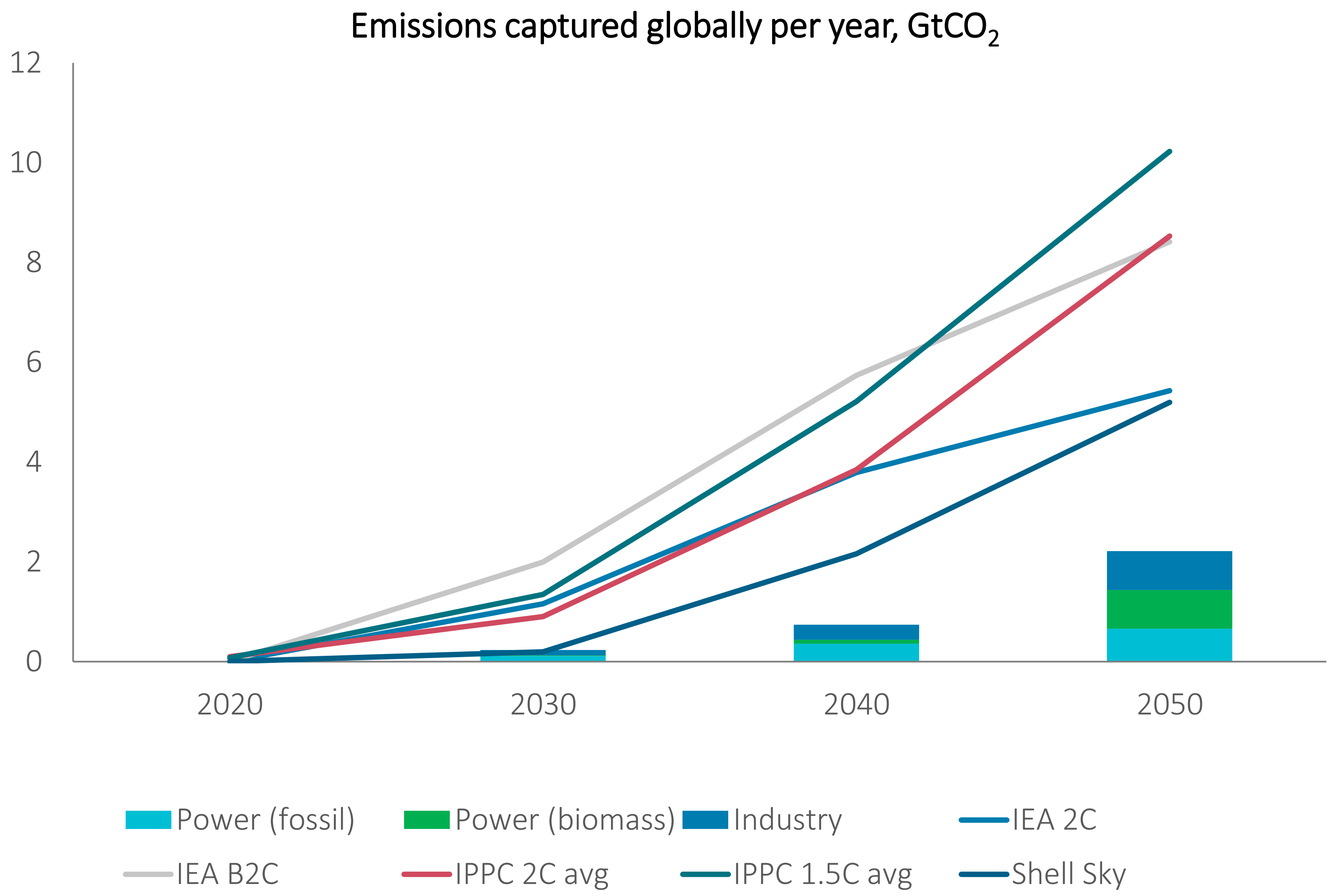
In 2050, the vast majority of biomass used will be 2nd generation or beyond

Bioenergy production and prices



Note: 1st generation bioenergy crops are primarily used for food; 2nd generation bioenergy crops can be dedicated or crop residues

CCS deployment starts later and stays below levels seen in other scenarios



- The IPR FPS scenario uses a moderate amount of CCS especially for Biomass for power
- The level of CCS diverge sharply after 2050 with the levels seem in other scenarios
- CCS is primarily used in hard-to-abate industrial sectors throughout the century
- Fossil fuel electricity declines faster than CCS no fossils can deploy

INEVITABLE POLICY RESPONSE

Land-use results

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RESPONSE

Land-use modelling efforts focus on implementing five major components of a forceful but realistic policy response to climate change

Climate Mitigation

Climate policies fully incorporate land-use by 2030; international payments play a supporting role to national policies

Increasing **bioenergy production**, shifting toward 2nd generation crops by 2030

Large areas of a/reforestation with phase in of payment systems with 30 year investment horizons

Dietary Change

Increased caloric consumption and greater share of animal products **with increasing GDP**

Ruminant meat share of consumed animal products decreases to **75% of baseline by 2050**

Area protection

Areas protected currently remain **effectively protected in the future**

Commitments to expand protected areas consistent with forecast, but serve primarily as additional measure to prevent deforestation

afforestation and reforestation gains depend more on climate action

Economic change

Decreased GDP growth as a result of too-late, too-expensive policy response in wider economy

Maintenance of historic trade self-sufficiency ratios and trading partners–limited or **no aggregate trade liberalisation**

Yield growth

Significant **investment in agricultural productivity** results in improved yields consistent with past growth

Significant gains in productivity come from **expected expansion of existing practices to developing countries**, especially irrigation

Benchmarking IPR FPS results in the land system

The IPR FPS has been informed by existing literature on future emissions trajectories in the land system, and outcomes fall within consensus ranges. Ranges tend to be wide, reflecting the uncertainty and many climate feedbacks associated with land-based sequestration.

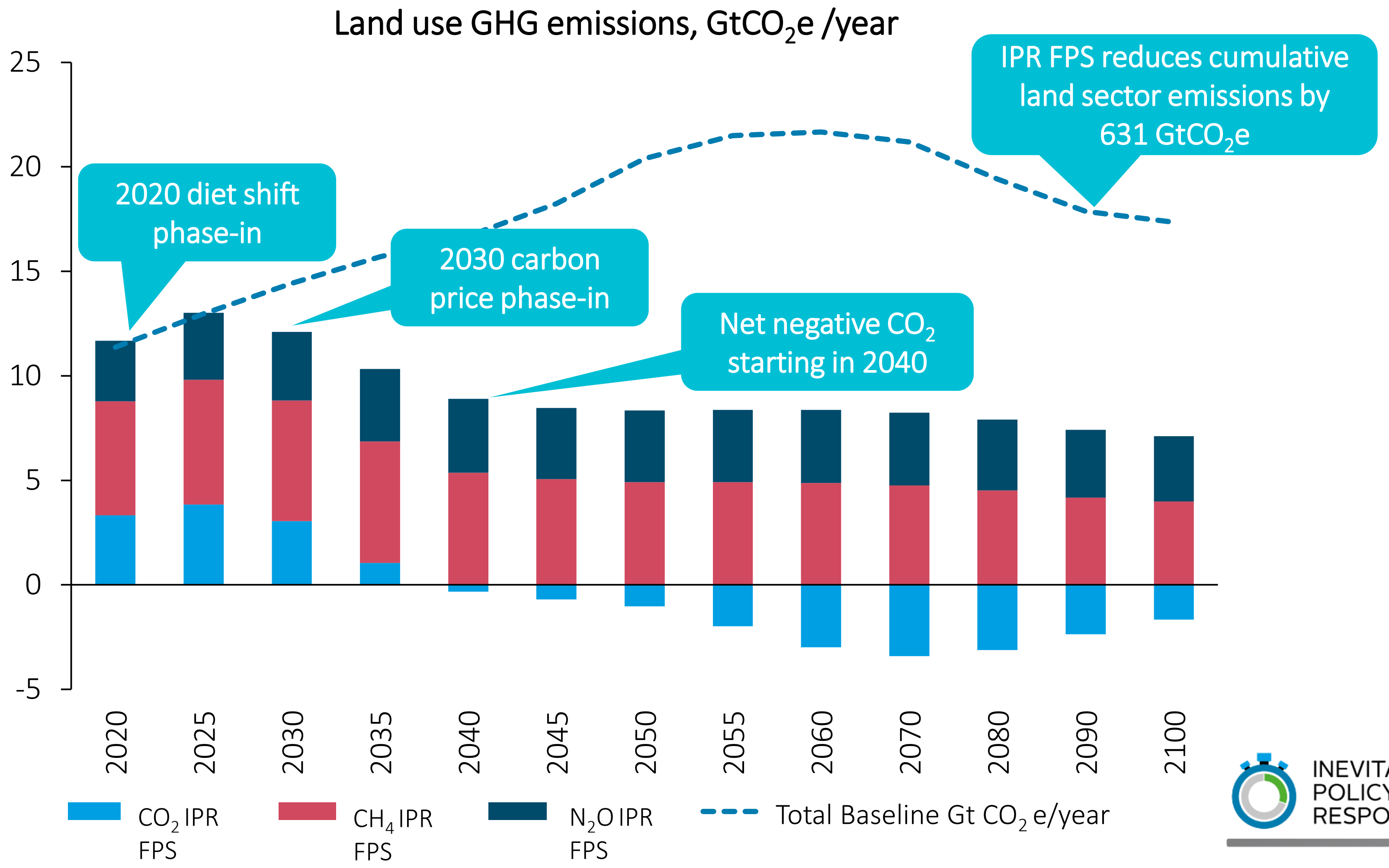
- Re/afforestation potential is thought to range from 350 to 1,780 Mha by 2100, representing 1-18 $GtCO_2e$ annually. IPR FPS expects about 360 Mha of afforestation (excluding restoration of degraded land) in 2050.
- Biomass for bioenergy potential is estimated to range from 3 to 16 $GtCO_2e$ per year, but literature suggests that the sustainable limit in the long term is closer to 3-4 $GtCO_2e$ per year, or 100-150 EJ by 2100. IPR FPS expects 67 EJ of annual biomass availability from the land system in 2050.
- Productivity increases are thought to range from ~25% to ~75% increases compared to current aggregate yields by 2050, but most agree that future productivity gains will come at greater cost. IPR FPS expects for an increase in productivity of ~60% by 2050.

More ambitious climate policy scenarios, such as those required to reach 1.5°C or well-below 2°C targets, most often call for greater levels of re/afforestation or larger dietary shifts. Scenarios that increase either afforestation or bioenergy targets come at higher cost in terms of food price increases.

For benchmarking purposes, a baseline scenario akin to a BAU case is included throughout land use results.

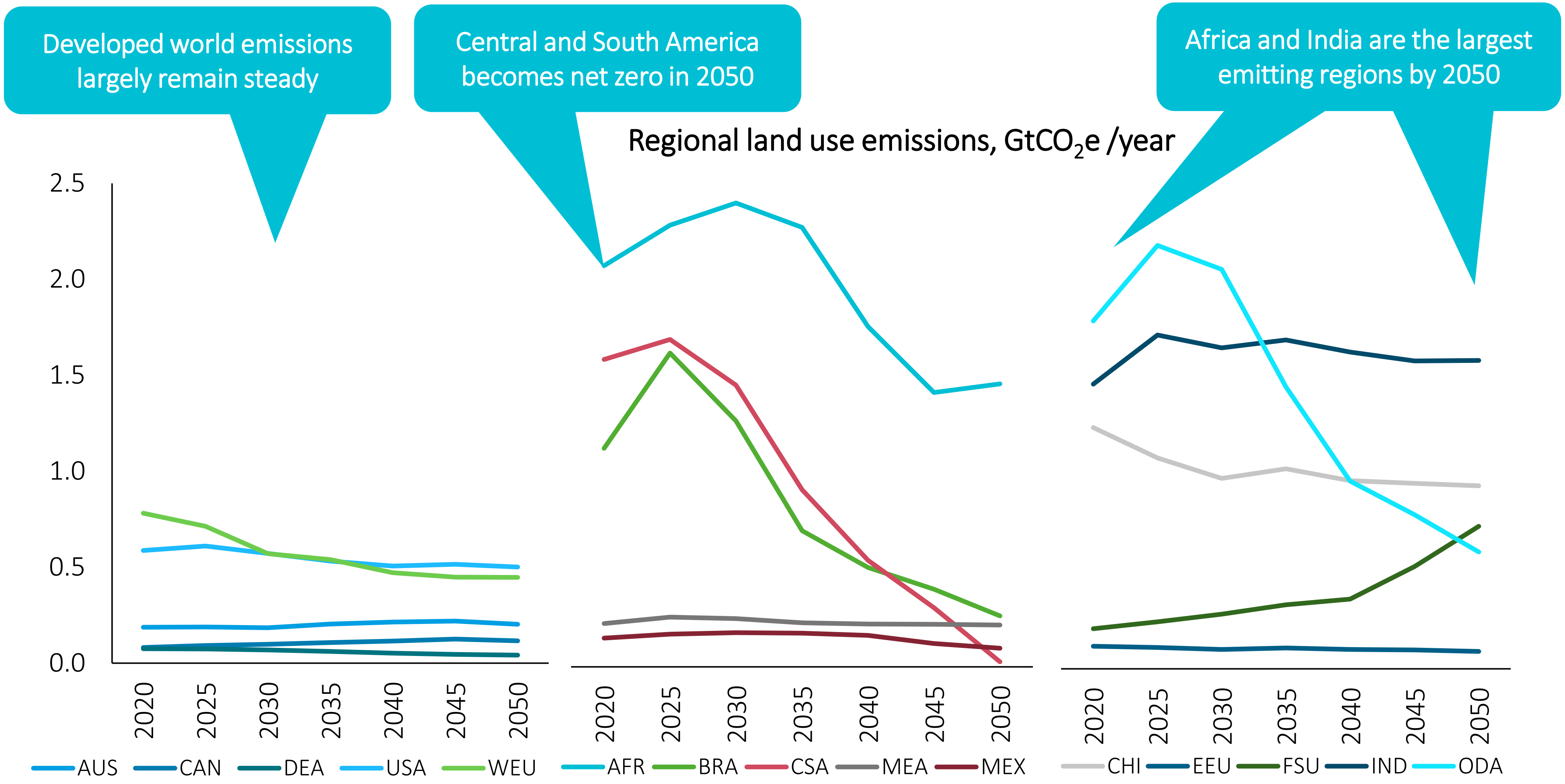
IPR FPS expects substantial reductions in land use emissions, but N_2O and CH_4 persist at high levels through the end of the century

GHG	Primary sources
CO_2	Emissions from land use change
N_2O	Inorganic fertilizers
	Soil organic matter loss
	Animal waste management schemes
CH_4	Enteric fermentation
	Animal waste management schemes
	Rice cultivation



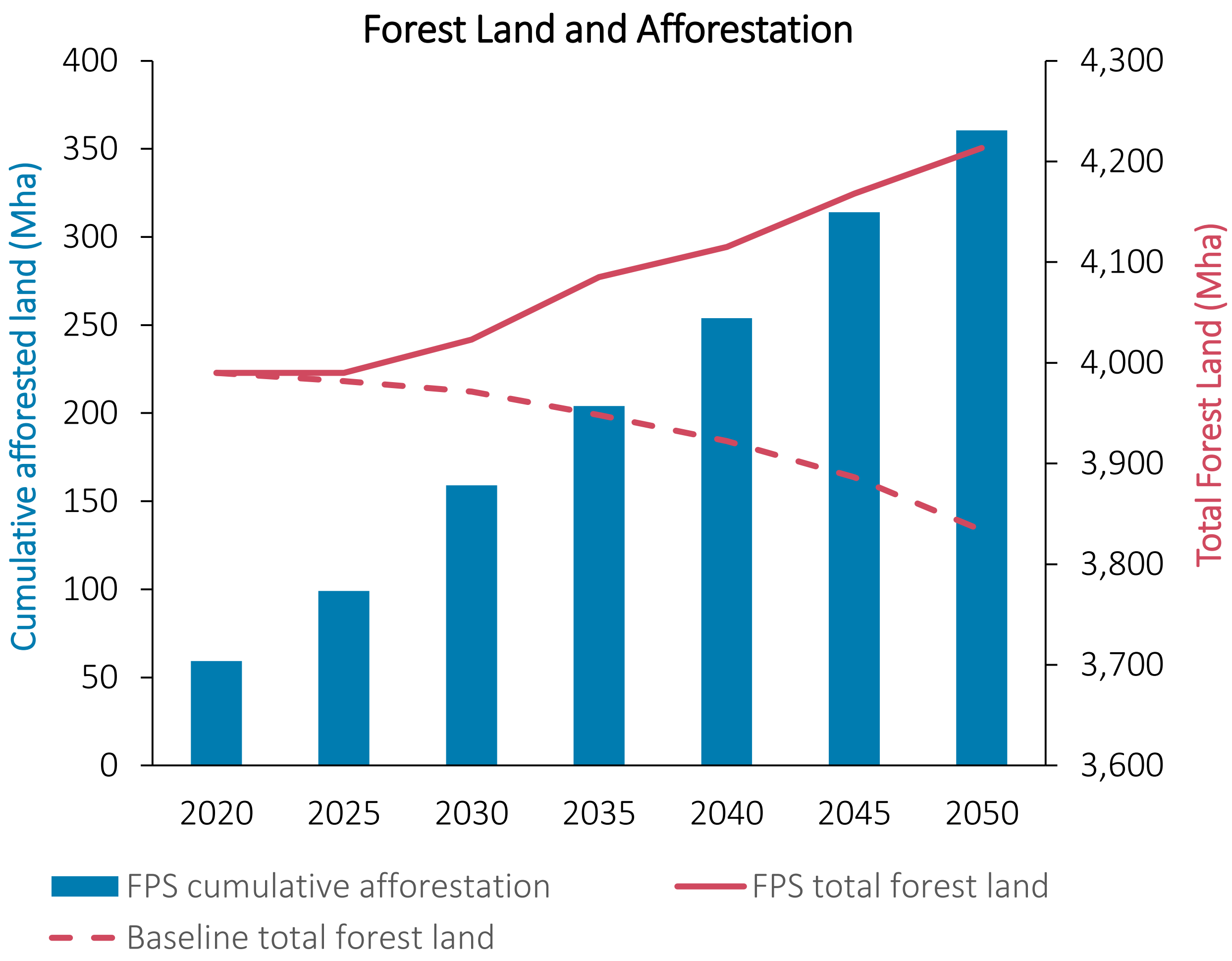
INEVITABLE POLICY RESPONSE

Land-use emissions remain high in much of the world, with CSA and ODA experiencing the greatest declines due to a large increase in forest cover



Notes: DEA = Developing East Asia; WEU = Western Europe; CSA = Central and South America; MEA = Middle East; FSU = Former Soviet Union; ODA = Other developing Asia

Deforestation continues until mitigation policies phase into the land sector, and afforestation and reforestation efforts ramp up substantially



Note: 'Total Forest Land' is defined here as dense, high-carbon stock forest land only

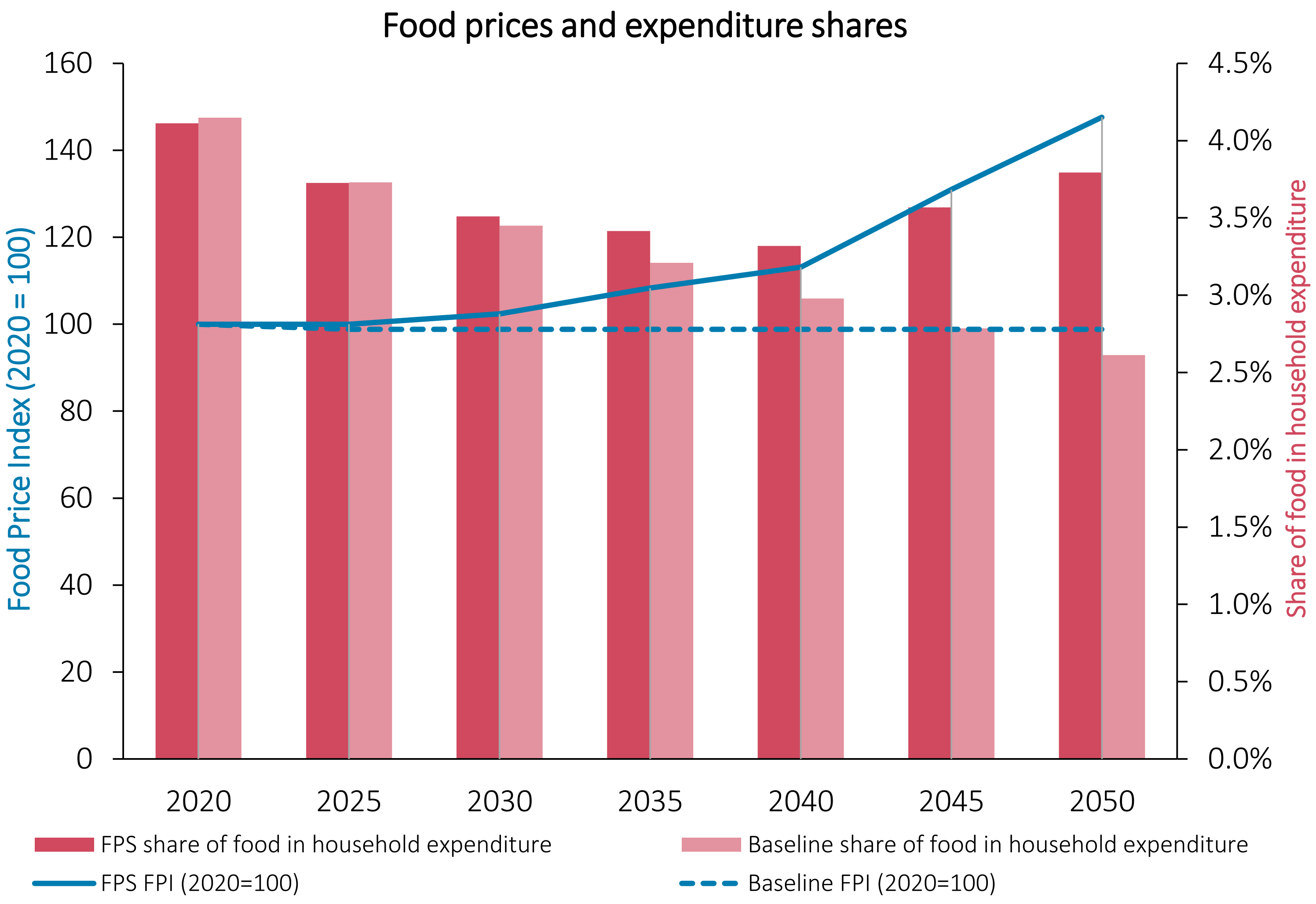
Deforestation practically eliminated by 2030, as domestic climate policies fully implemented, and international payments increasingly introduced

- IPR FPS expects rapid re/afforestation to meet feasible NDC land use targets in coming decade
- Total forest area recovers to 1995 levels between 2030 and 2035, although not all native forest
- Re/afforestation is driven by emerging payment systems – national and international – and impact of increasing prices in carbon markets
- World meets the Bonn Challenge of 350 Mha of land restoration, but well after 2030 target
- Re/afforestation occurs largely in tropical regions: Brazil, Latin America, China and Southeast Asia

Re/afforestation to 2050 draws estimated $780 billion in offsets financing

INEVITABLE POLICY RESPONSE

IPR FPS keeps food expenditure's share in household income near stable



Between 2020 and 2050, the share of food in household expenditures decreases from 4.1% to 3.8%

Wholesale prices from producers (farm gate) increase by 45.5% globally by 2050, with regions experiencing strong land competition observing the highest impact

- These include Central and South America, Mexico, and Brazil
- Food prices in some countries are sensitive to trade pattern changes resulting from shifts

Food price increases are within historical bounds, for example:

- Global CAGR in food price index was 7% between 2005 and 2010
- Maximum IPR FPS CAGR is 3.0%

INEVITABLE POLICY RESPONSE

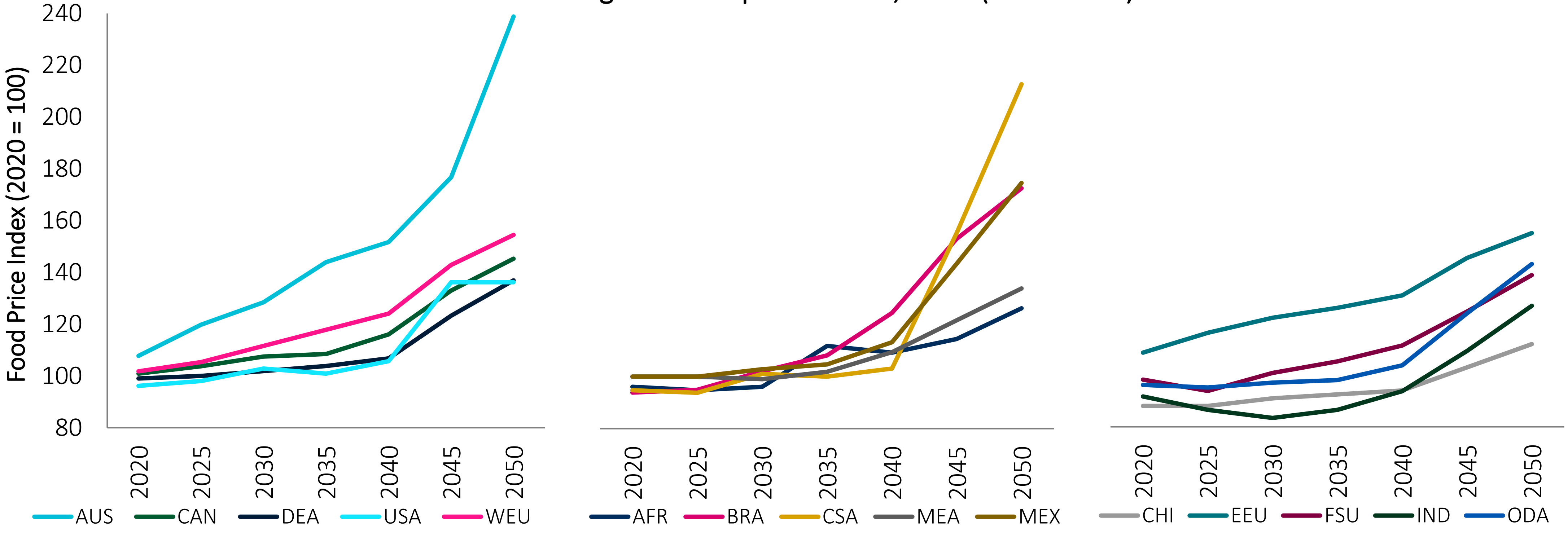
Regions with stronger land competition experience more dramatic food price increases

Binding trade constraints in the model make Australia exposed to substantial increases

Central and South America, Mexico, and Brazil experience food price increases after GHG prices induce greater land competition

Most other countries show relatively small increases in food prices

Regional food price indices, Index (2020 = 100)



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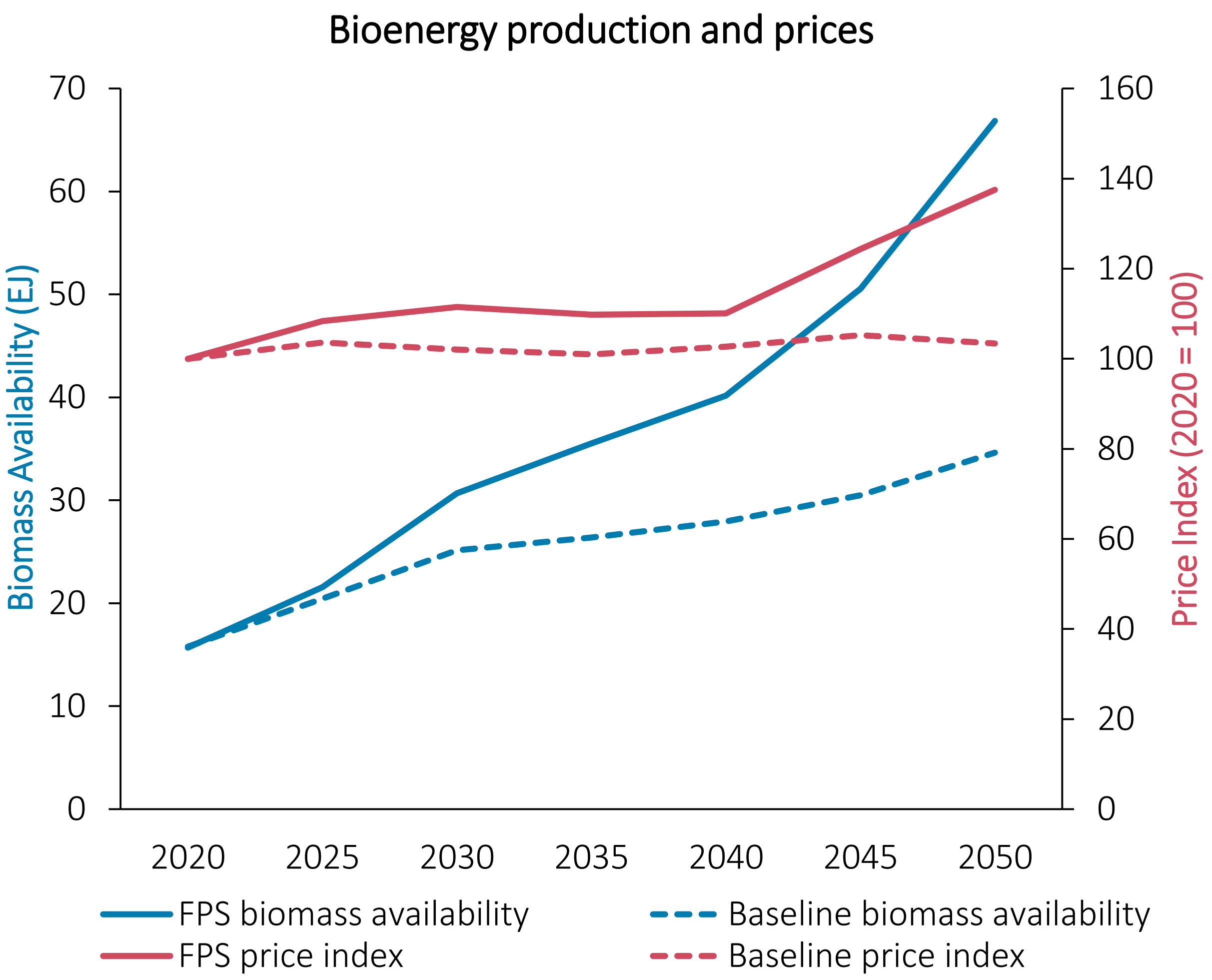
INEVITABLE POLICY RESPONSE

Bioenergy crops represent 65 EJ annually by 2050, with the bulk coming from 2nd generation crops



Bioenergy crops supply nearly 65 EJ annually by 2050

- First generation bioenergy crops continue to dominate in the coming decade
- Second generation crops, such as miscanthus, phase in beginning in 2025, and account for more than two thirds of bioenergy production in 2050

Environmental sustainability and land competition constrain bioenergy production

- Consistent with literature estimates of 100-125 EJ in 2100 of bioenergy as the sustainable limit

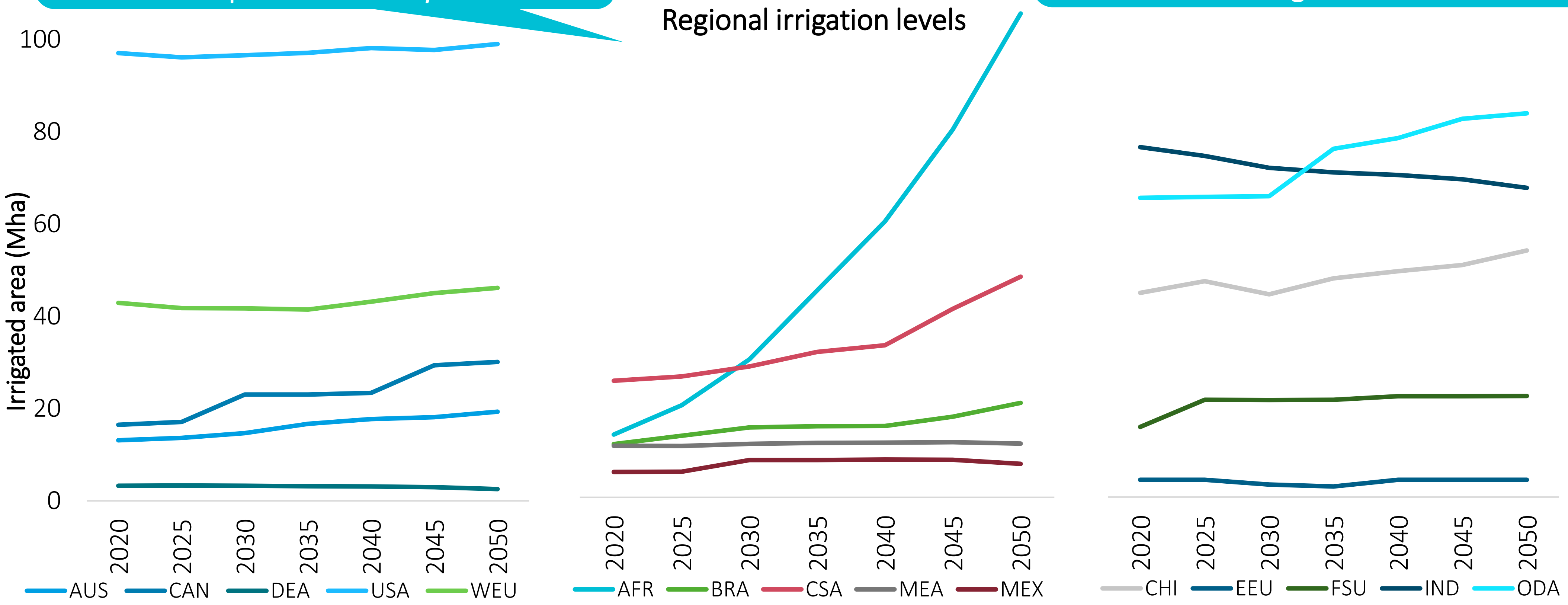
Bioenergy production increases across the globe, although relatively sooner in China, North America and Europe, which have better conditions for sustainable, industrial-scale production. The former Soviet Union emerges later as major producer.

INEVITABLE POLICY RESPONSE

Irrigated area increases in nearly all regions by 2050, but gains particularly large in less developed countries

The forecast expects large, rapid gains in irrigation in Africa and other less developed countries by 2050

39% increase in irrigated area worldwide, with developing world efficiency increasing to manage water stress



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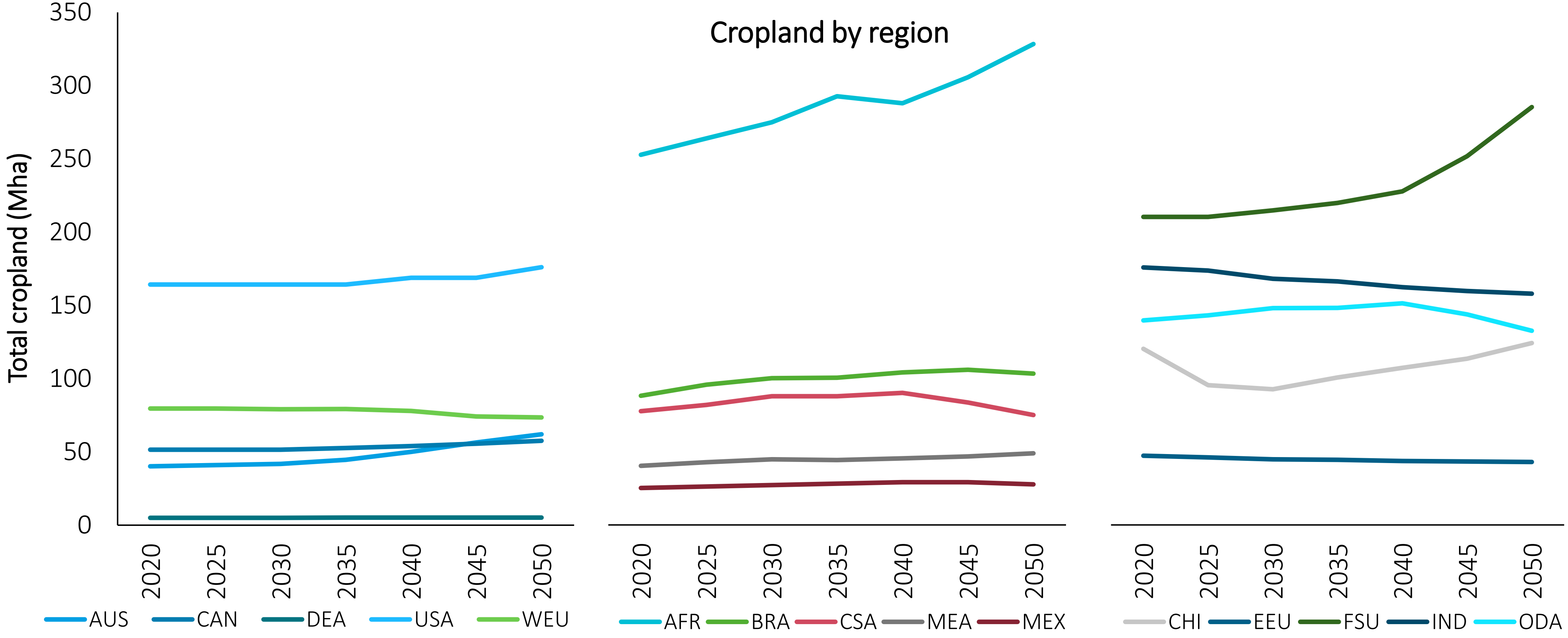
INEVITABLE POLICY RESPONSE

Cropland expands most in Africa and the Former Soviet Union, while other regions remain relatively stable

Total cropland expands from 1,500 Mha in 2015 to 1,700 Mha in 2050

Cropland dedicated to biofuels grows from 9 Mha in 2020 to 146 Mha in 2050

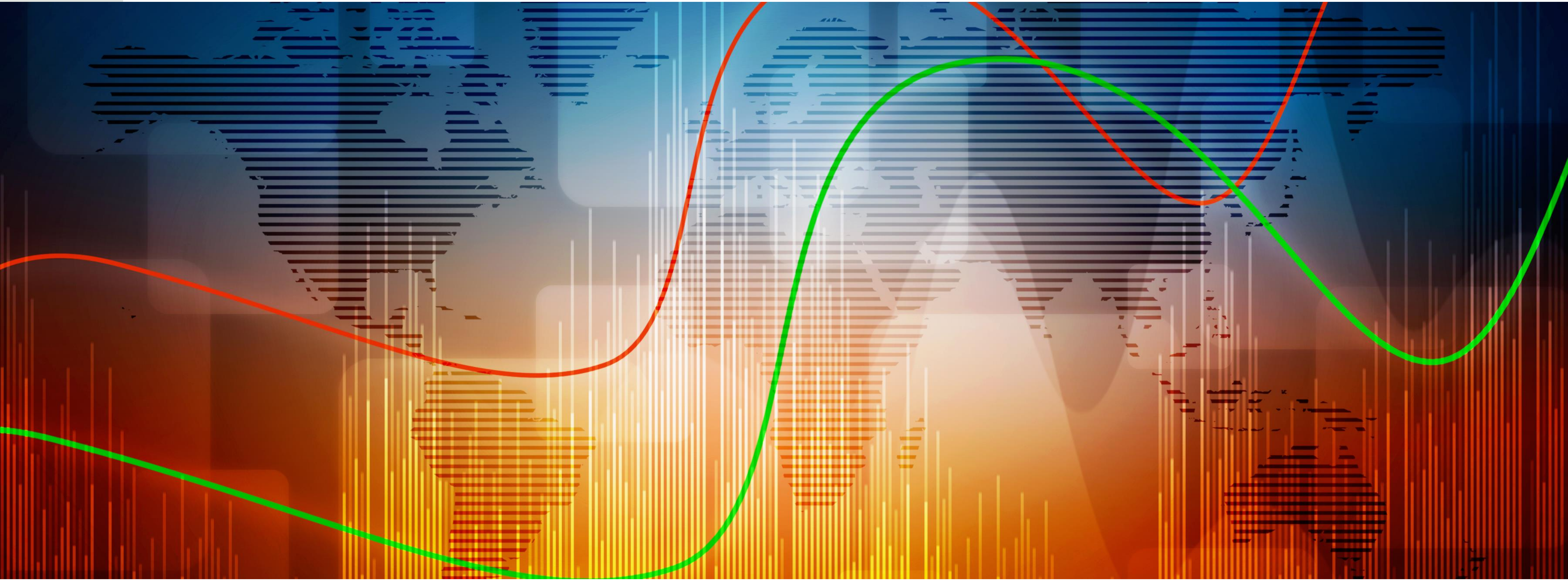
Cropland and forestry expansion comes mostly from recovery of degraded land and increased use of other marginal lands



Notes: DEA = Developing East Asia; WEU = Western Europe; CSA = Central and South America; MEA = Middle East; FSU = Former Soviet Union; ODA = Other developing Asia

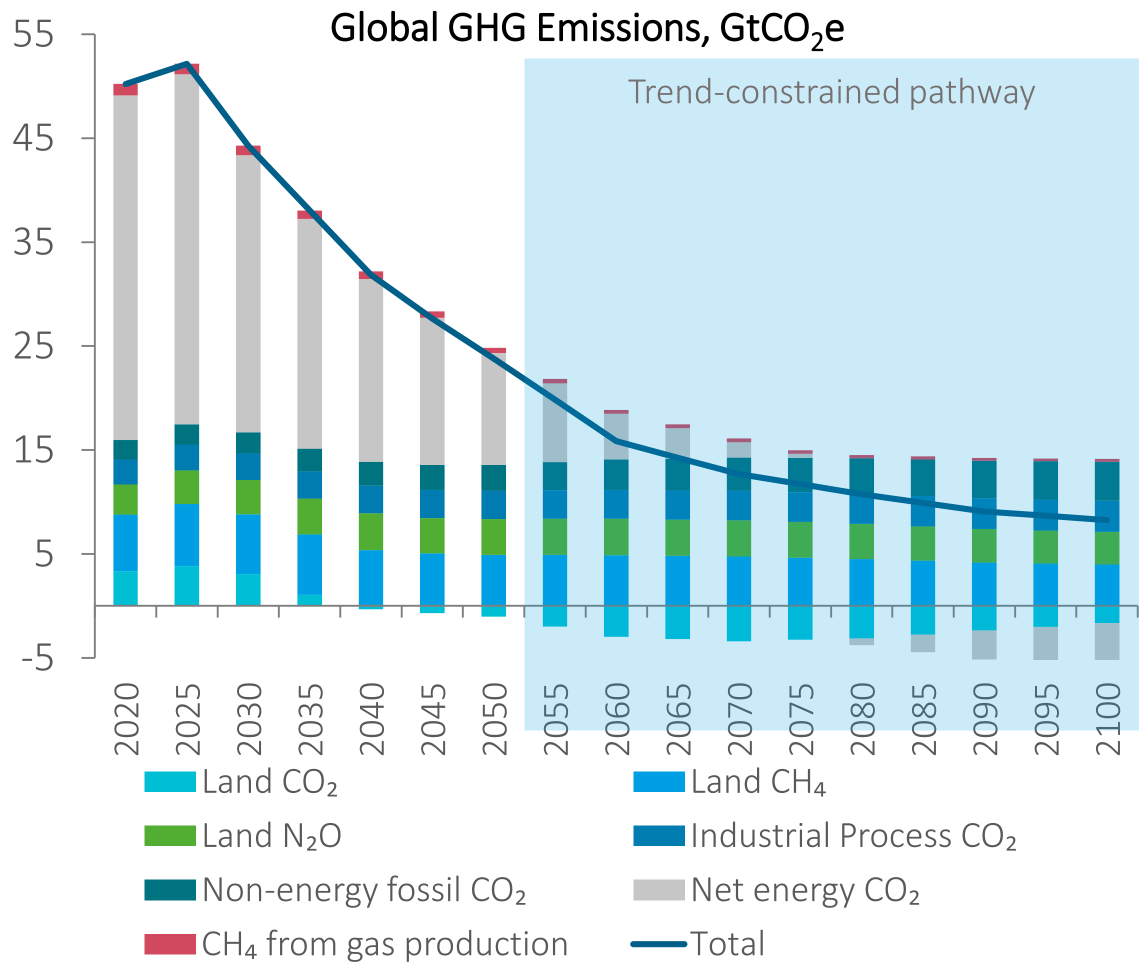
INEVITABLE POLICY RESPONSE

Trend-constrained pathway



INEVITABLE POLICY RESPONSE

The IPR FPS is forceful and combined with the 'trend-constrained pathway' after 2050 leads towards 2°C, but not below*



The IPR FPS is a forceful pathway that leads towards 2°C, but not below*

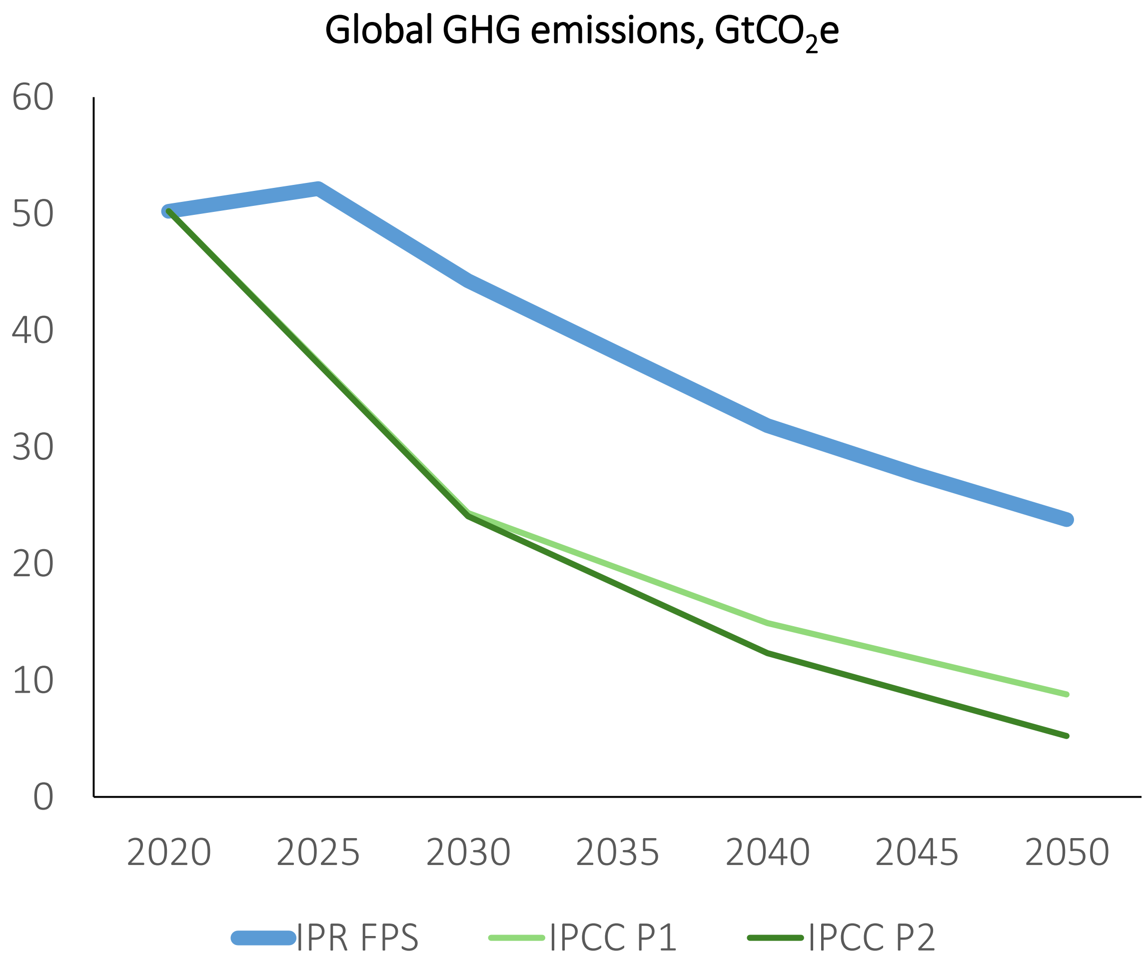
Trend-constrained pathway

- The trend constrained pathway assumes that from 2050 onwards there are no new break throughs in technology and that land use constraints are important in limiting Negative Emission technologies such as BECCS
- Energy-related CO_2 emissions are negative from 2090 onward driven by reductions in emissions and CCS in industry and power
- Hard to abate land emissions for N_2O and CH_4 persist through the end of the century
- IPCC P3 and P4 pathways assume the deployment of large amounts of BECCS in order to reach their optimised temperature goal

INEVITABLE POLICY RESPONSE

Note: The FPS was designed from the policy forecast, and not constructed to meet a specific temperature target. However, the accumulated GHG emissions of FPS to 2050 are consistent with and comparable to scenarios that label themselves as aligned to **2°C. Therefore, FPS can be used alongside (or in place of) 2°C scenarios for investors or corporates seeking to test the impact of a 2°C transition on their portfolios**

The IPCC 1.5°C P1 scenario decarbonises faster than IPR FPS as it does not utilise CCS technologies and has dramatic demand reductions

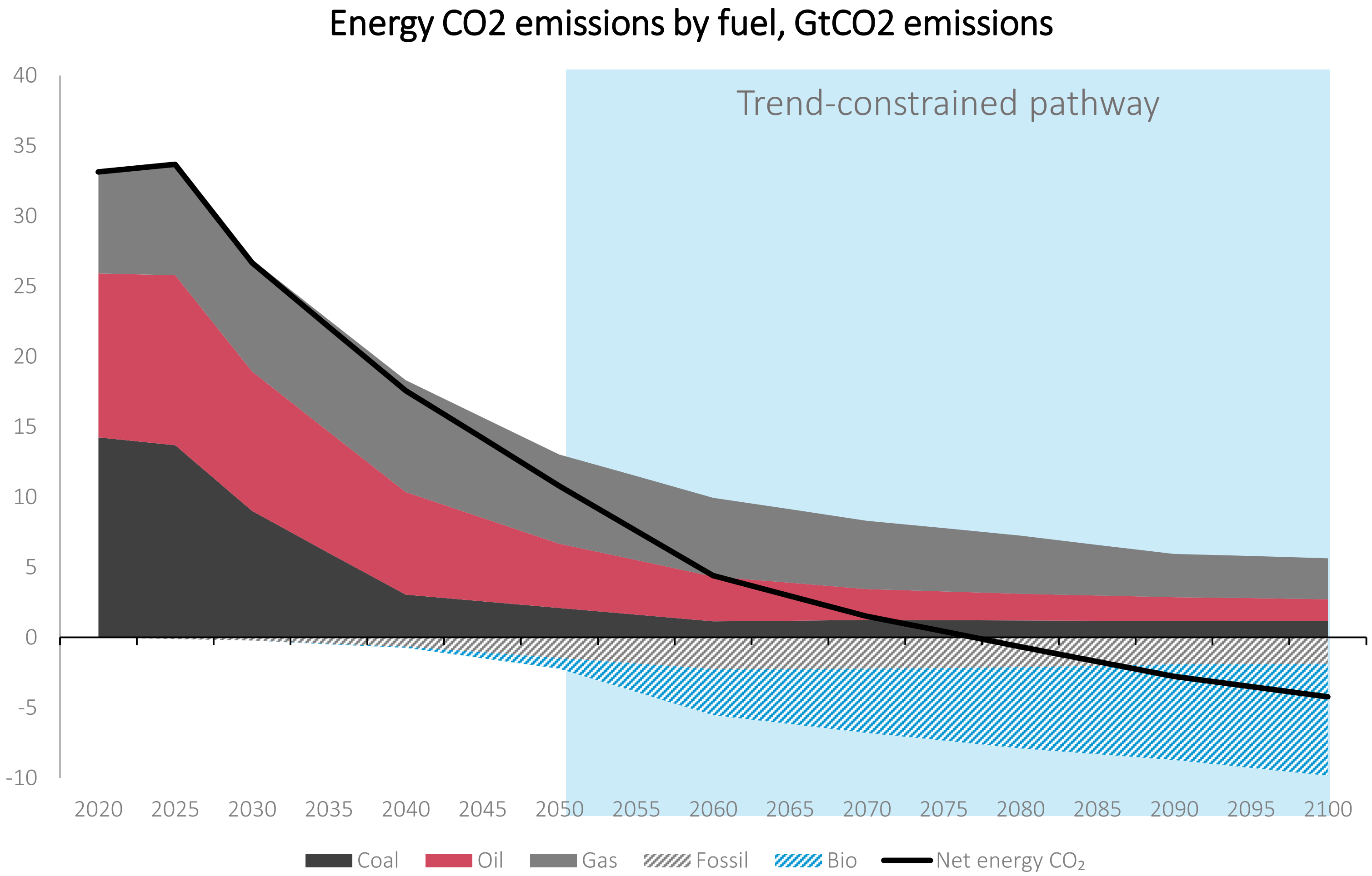


The IPCC 1.5°C scenarios decarbonise faster than IPR FPS

- The IPCC 1.5°C scenarios show a variety of pathways, with particularly important differences in assumptions around the levels of CCS and negative emissions, especially after 2050
- The IPCC P1 1.5°C scenario decarbonises rapidly as it is highly ambitious in its assumptions around demand reductions and does not use CCS
- The IPCC P2 1.5°C scenario also decarbonises rapidly, driven by higher levels of afforestation and CCS
- The rate of decarbonisation needed to meet a 1.5°C target is much higher than IPR in the short term even under a moderate CCS scenario.
- IPPC P3 and P4 are shown on page 94 and include large amounts of Negative Emission Technologies that have yet to be deployed at scale

INEVITABLE POLICY RESPONSE

Bioenergy with CCS is crucial to reduce energy CO_2 emissions below zero by 2100, with CCS in industry mitigating the impacts of remaining fossil fuel use

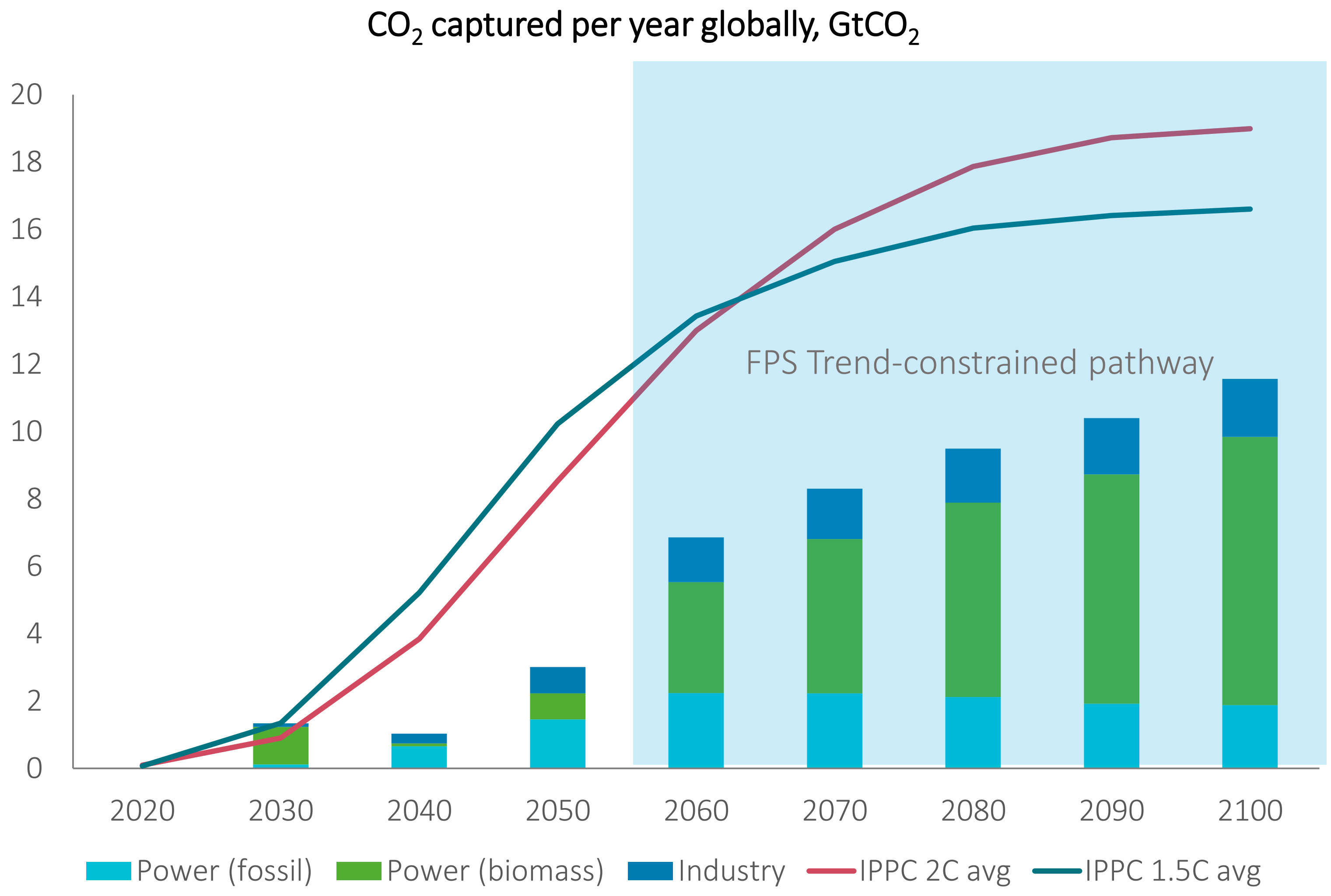


Coal emissions decline rapidly – remain for coking coal and other uses

- CCS on fossil fuels in industry and power and Bioenergy and CCS (BECCS) are needed to reduce emissions rapidly but face constraints
- Oil and natural gas have several uses beyond power and transport – aspirational policies are needed to tackle these remaining emissions
- For ambitious scenarios such as 1.5°C, many assume much more CCS will need deploying than shown here

INEVITABLE POLICY RESPONSE

CCS deployment starts later and stays below levels seen in other scenarios



- The IPR FPS scenario uses a moderate amount of CCS especially for Biomass for power
- The level of CCS diverge sharply after 2050 with the levels seem in other scenarios
- CCS is primarily used in hard-to-abate industrial sectors throughout the century.
- Fossil fuel electricity declines faster than CCS can deploy

Aspirational policies and technologies to bridge overshoot to reach 1.5°C

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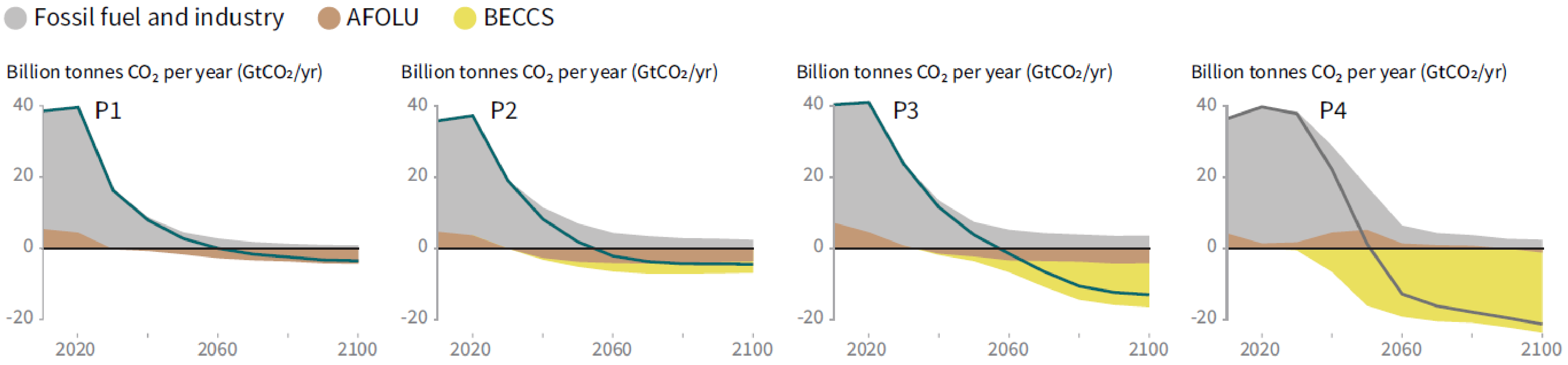
An initial outline

- Tackling the need for highly uncertain and long dated technologies requires much work over coming years
- The key message of IPR has been to be transparent about that and restrict the post 2050 world in particular to a 'trend-constrained pathway'
- Here we start by outlining some of the solutions that have been proposed in this context
- Some are controversial – calls for genetically-modified agriculture, possible geoengineering options as a last resort
- We acknowledge this requires much further research and discussion, so we simply try to set out some of the landscape without definitive judgements about the necessary pathway
- We hope that feasible solutions are accelerated and developed as fast as possible, and that the IPR project will continue to examine emerging options and identify credible pathways over time

INEVITABLE POLICY RESPONSE

Virtually all 1.5°C pathways assume drastic reductions in energy demand or use significant greenhouse gas removal technologies or both

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

INEVITABLE POLICY RESPONSE

Source: Special Report: Global Warming of 1.5°C (IPCC, 2018)

Achieving the 1.5°C target will require accelerated and substantial effort across multiple emerging solutions

Today	2030 –2050	Post 2050

Faster investor and policy action today

ACT NOW
to move more smoothly and cost-effectively to 1.5°C

- Second Ratchet by 2035
- Circular economy
- The agricultural revolution
- Bioeconomy
- Hydrogen economy
- Consumer preferences, such as dietary shifts
- Negative emissions technologies
- AI revolution / future tech
- Last resort measures

INEVITABLE POLICY RESPONSE

A first step toward 1.5°C would involve an immediate ramp up in climate and energy policies with international alignment to move smoothly and at lower cost

Fossil fuels	• More rapid ramp up in carbon prices to c.$60/t$CO_2$ to accelerate low cost fuel switching, energy efficiency, etc. • An immediate elimination of all fossil fuel subsidies, and renewables support – especially in lagging countries • A ban on all fossil fuel exploration activities and on further development of existing resources to avoid stranding • Early retirement of existing fossil-fuel infrastructure that is already costly compared to low-carbon alternatives
Transport	• Widespread and accelerated policy support to shift to ultra low emissions vehicles – such as charging stations, network upgrades, sales subsidies, congestion charge exemptions – especially in lagging countries • Significantly increased state-sponsored research, development and demonstration (RD&D) of low-emissions aviation, marine and heavy-duty vehicle technologies to bring down costs faster
Energy efficiency	• Rapid and widespread roll-out of stronger performance and energy efficiency standards in consumer appliances and industrial equipment to capture low-cost opportunities – especially in lagging countries • Strong new building codes for all new buildings to be carbon neutral or negative, and massive ramp-up of refurbishments in existing buildings to improve energy efficiency
CCS and Industry	• Immediate support for large scale demonstration and deployment of CCS, including storage infrastructure • Significant increase in state-sponsored research, development and large-scale demonstration projects for circular economy, zero-carbon high-grade process heat, and other decarbonisation technologies in industry
Land-use and agriculture	• Rapid deployment of MRV technologies to identify and enable action to eliminate deforestation • Rapid move to incorporate nature-based solutions, and low-carbon agriculture in carbon pricing • Significantly increased state-sponsored RD&D into agtech, and policies to accelerate irrigation infrastructure • Price incentives and behavioural change policies to encourage dietary change away from animal products

INEVITABLE POLICY RESPONSE

Should accelerated and cost-effective action fail to occur in the next 5-10 years, another avenue toward 1.5°C might involve a second disruptive ratchet by 2035

Even if the world were to follow the Forecasted Policy Scenario through to the early 2030s, a significant additional ratchet up in 2035 would be needed to drive deeper reductions and negative emissions by 2050 and beyond. This could occur after the 2033 stocktake as the impacts of climate change are clearer, and would involve:

- A late, more radical increase in carbon prices from the forecasted c.$60/tCO$_2$ to roughly triple this
  - At these levels carbon pricing would accelerate the adoption of next generation technologies: direct air capture, the hydrogen economy, more difficult nature-based solutions and next generation biofuels
- Implementation of carbon capture and storage requirements on power and industrial emissions, even at the cost of accelerated plant retirement and radical retrofitting
- More targeted policies, with higher implicit carbon prices to accelerate the commercialisation of negative emissions technologies to ensure at-scale deployment well ahead of 2050, and then beyond
- Even larger scale state-sponsored development and large-scale demonstration projects for new decarbonisation technologies in industry
- Massive scale up of RD&D funding for speculative, high-payoff technologies, with international collaboration
- Massive direct investment or subsidisation of required infrastructure shift, including ‘war time’ rates of deployment in things like charging stations, network upgrades, hydrogen pipelines, building retrofits, etc.
- More radical incentives for behavioural change related to energy, transport and meat consumption
- Late and more radical shift in land-use incentives toward intensification and nature-based solutions, involving full incorporation of land-use in carbon pricing with international carbon markets

INEVITABLE POLICY RESPONSE

If the world fails to act faster before the 2040s, a set of additional solutions will need to be deployed by 2050 to allow a move to 1.5°C with some overshoot

Failure to act immediately, or to force a more radical ratchet in the 2030s will almost certainly mean overshoot beyond 1.5°C – at this stage, the world will need to:

- Ensure the implementation of technological shifts that should by this time be relatively cost-effective
  - Circular economy across industry and manufacturing
  - Hydrogen technologies, particularly for hard to abate sectors like industry and some transport
  - Fourth agricultural revolution based on emerging clean technologies, and possibly genetic modification
  - Industrial scale biomass for energy and nature-based solutions
- If possible, drive the necessary incentives for behavioural change, beyond what has proven politically feasible up to this point – in particular, significant dietary shifts will remain critical if they have failed to occur by then
- Push the pace of radical solutions, like artificial intelligence
- Rapidly ensure massive negative emissions technologies, combining BECCS, DACs, etc.
- Consider, and potentially implement last resort geoengineering, especially if the implications of climate change prove to be toward the more extreme end of expectations

INEVITABLE POLICY RESPONSE

The Circular Economy can help us to face climate and environmental challenges while safeguarding economic development

The improvement of material efficiency and the management of waste as a resource are expected to facilitate the transition to a circular economy model, in which economies produce less carbon emissions

- Fostering circularity will also create sustainable growth opportunities domestically and reduce countries dependence on raw materials imports
- According to recent estimates, a range of opportunities for circularity in steel, plastics, aluminum and cement could reduce EU industrial emissions by 56% (300 Mt) annually by 2050
- While some shift to a circular economy is incorporated into IPR FPS (in line with action by leading countries), this could be accelerated by removing barriers to the circular economy by appropriate policies and strong government intervention:
  - Making recycling cheaper than other waste disposal options (e.g. waste incineration)
  - Ensuring that the prices of primary raw materials reflect lifecycle emissions
  - Putting in place incentives to boost demand for recycled products

Regulation to support the circular economy has started to emerge:

- The EU's Circular Economy Package (2018), sets clear targets and establishes a programme of concrete actions covering the whole lifecycle of products, from production and consumption to disposal and waste management
- EU Member States' governments now have until July 2020 to transpose these directives into national legislation

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Source: KfW (2019); European Commission (2018); Sitra and European Climate Foundation (2018); Ellen McArthur Foundation and McKinsey (2014)

The Hydrogen Economy

The 'Hydrogen Economy' which first appeared in the 1970s as a response to the first oil crisis, could potentially play a substantial role in the low carbon transition in the medium- to long-term

- There are numerous potential applications of hydrogen across the transport, heavy industry, heating fuel and energy storage sectors
- While IPR FPS includes some deployment of hydrogen, especially beyond 2040s, its role could be accelerated, especially in its application to the main challenges to transition where hydrogen offers most promise:
    - Hydrogen could play a key role in heat decarbonisation strategies, and in the stabilisation of renewables-fuelled energy systems – but the production of low-carbon hydrogen at scale will rely on the deployment of CCS
    - The Hydrogen Economy could be crucial in decarbonising the most difficult parts of industry, including heavy vehicles and high-grade heat processes such as steel and heavy metals manufacturing
- A number of technical, regulatory and institutional barriers will need to be addressed:
    - Enabling policies include direct investments into network infrastructure (e.g. refitting gas piping), subsidies, carbon pricing, demand support (through advertisement and other methods), coordinated supply chain policy from electrolysis to storage and usage, government backed international hydrogen shipping routes, coordination to centre initial infrastructure towards industrial ports (where the majority of demand will come from)
    - To fully develop a hydrogen economy an integrated policy framework and roadmap across the supply chain to demand will be needed, including specialised policies for specific components and regions

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Source: IEA (2019); Bleischwitz and Bader (2010); Policy Exchange (2018); Climate Change Committee (2018)

The Fourth Agricultural Revolution could help address the challenges of meeting rising global food demand while reducing GHG emissions

New agricultural practices and technologies promise to lower the land sector emissions footprint

- The development and acceleration of early stage technologies to reduce non-CO_2 greenhouse gases from agriculture could be pivotal in reducing or eliminating residual land use emissions:
- Improved delivery of nitrogen from fertilizers, through bio-fertilizers or GM crops better absorbing nitrogen, for example, could dramatically reduce N_2O emissions from the manufacture and inefficient application of synthetic fertilizers
- The inorganic fertilizers commonly used today are usually created through the fossil-fuel intensive Haber-Bosch process. Alternatives include a solar-powered version that could cut emissions intensity by 85% or more if demonstrated at scale
- Technical solutions to reduce CH_4 emissions from enteric fermentation in ruminants, such as livestock feed compounds that suppress methane formation, have been successful in lab-scale pilots
- While agricultural productivity growth is already a part of the IPR FPS, more ambitious growth could substantially ease land competition and allow for more afforestation or bioenergy production without increases in food prices. A few examples:
- CRISPR technology could represent a step change in our ability to boost yields through genetic modification, though it still has a variety of legal, ethical, and environmental concerns to address before it could be scaled globally
- Algae-based fish feeds that support scalable aquaculture may present an opportunity to reduce pressure on wild fish stocks, which could replace more emissions-intensive meat production if accompanied by shifts in consumer preferences
- The productivity of oil palm, or the scalable production of bio-engineered synthetic alternatives, could further reduce deforestation pressure and increase opportunities for re/afforestation

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Source: GFI (2018); Tuomisto et al. (2014); Tuomisto and de Mattos (2011); Mattick et al. (2015); World Resources Institute (2019)

The Bioeconomy is crucial to any net-zero emissions scenario

Finding bioeconomy solutions that ease land competition and reduce environmental impacts will be critical to provide new options for negative emissions and decarbonise the energy system

- The bioeconomy covers ultra-low carbon biofuels, bio-based heat, power and cooling and bio-based products and chemicals
- The climate change mitigation potential of the biotechnology processes and bio-based products has been estimated to range from 1 billion to 2.5 billion tons CO_2 by 2030

However, bioenergy and biomass production can drive land competition, replacing land that would otherwise be used for food production or forestry

- IPR FPS is within the consensus view of sustainability limits, but there appears to be limited opportunity for further sustainable expansion without further increases in food prices or reductions in forested land
- Increases in biomass production beyond what is already included in the IPR FPS would require more ambitious improvements in the productivity of bioenergy crops, particularly in 2nd generation crops such as miscanthus or eucalyptus
- Greater utilisation of other sources of biomass, such as natural deadfall and sustainable harvests from forested land or waste materials from industrial and municipal sources could increase biomass availability without driving land competition
- Ocean-based biomass production, such as large-scale seaweed farms could also increase biomass production without driving land competition

INEVITABLE POLICY RESPONSE

Source: Vivid Economics; Environmental and Energy Study Institute (2018); European Bureau for Conservation and Development (2015); Gawel et al. (2019)

Changes in consumer preferences – Dietary preferences

With production, processing and retail of food accounting for 15-30% of all GHG emissions in high-income countries, significant shifts in food consumption patterns will be required as part of the low carbon transition

Clean meats and technologies that reduce food waste give reasons for optimism:

- The uptake of some plant-based meats is already a part of IPR FPS, but many argue that extremely ambitious, rapid uptake of foods such as those produced by Beyond Meats or Impossible Foods is possible
- Synthetic, or lab-grown meats may also offer important alternatives to traditional meat production, but economically-competitive production has yet to be achieved, let alone at scale
- With nearly 1/3 of food produced being lost or wasted at some point in the agricultural supply line, various new technologies that prolong the shelf-lives of fresh fruit and produce, such as thin spray-on films, could help to reduce total food demand

However, achieving a large-scale shift to climate-friendly diets is expected to be challenging

- A study based on five European countries has shown that half of the daily diet (in quantity) should be modified to achieve a 30% reduction in diet-related GHG emissions
- Studies have also shown that large dietary changes are difficult to induce, even by introducing a high carbon tax
- Carbon footprint schemes have started to emerge, but they are not expected to significantly influence consumption in the short-term

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Source: Bjelle et al. (2018); Feucht and Zander (2017); Irz et al. (2019)

Post-2050 Nets – BECCS is one part of the puzzle for greenhouse gas removal past 2050

BECCS is currently the most mature greenhouse gas removal technology and is one part of the puzzle for greenhouse gas removal past 2050

- BECCS combines biomass combustion to generate energy and carbon capture and storage
- There are few examples to date of where bioenergy or biomass combustion has been combined with CCS facilities
  - The majority is located in North America, Europe and Scandinavia
  - Most of these projects capture CO_2 from ethanol production plants, which typically sequester 0.1 – 0.3 Mt CO_2 per year
- The main constraint to future large-scale deployment is land availability, and risk of 'leakage' amplifying deforestation in other parts of land system
- A 50% chance of keeping within 2°C could require land dedicated to bioenergy production the size of India or double

INEVITABLE POLICY RESPONSE

Source: IEA Technology Roadmap: Delivering Sustainable Energy (IEA, 2017); Smith et al. (2016)

Post-2050 Nets – BECCS is one part of the puzzle for greenhouse gas removal past 2050 (Cont'd)

Policy tools which could support the deployment of BECCS include:

- Support technology R&D and innovation in bioproducts
- Promotion of best practices to increase agricultural yields and production efficiency
- Sustainable and/or novel feedstock supply (e.g. algae, aquatic biomass)
- Sufficiently credible and globally widespread jurisdiction-level monitoring and enforcement of zero deforestation

Possible applications of BECCS:

- Dedicated or co-firing of biomass in power plants
- Combined heat and power
- Pulp and paper mills
- Lime kilns
- Ethanol plants
- Biogas refineries
- Biomass gasification plants

INEVITABLE POLICY RESPONSE

Source: IEA Technology Roadmap: Delivering Sustainable Energy (IEA, 2017)

Post-2050 NETs – BECCS could be required in significant amounts, which may impact food prices

BECCS could sequester between 3 and 16 $GtCO_2e$ per year by 2100

- Studies suggest that BECCs deployment will be limited by the quantity of biomass that can be produced sustainably without threatening food security, biodiversity and water supply
- There is a variety of sequestration potential estimates in the literature, ranging from 3$GtCO_2e$ per year to more than 16$GtCO_2e$ per year
  - Estimates within the range vary in terms of the shares of biofuel vs bioelectricity, the underlying crop and feedstock mix, and the assumed land area available – the availability of land is almost always the binding constraint for the lowest estimates
  - The IEA's Technology Roadmap for sustainable bioenergy and suggests a sequestration rate of roughly 7$GtCO_2e$ per year by 2100

According to the IPCC, in pathways with limited or no temperature overshoot, up to 414 $GtCO_2$ of BECCS could be required over the 21st century

- The higher the climate ambition, and the slower the progress in near-term, the more BECCS or other NETs will be needed
- However, there are few clear signals or likely future deployment
- In the 'higher overshoot scenario' (P4) the cumulative amount of BECCS until 2100 reached 1,200$GtCO_2$

INEVITABLE POLICY RESPONSE

Source: IEA Technology Roadmap: Delivering Sustainable Bioenergy (IEA, 2017)

Post-2050 NETs – Direct Air Capture

Negative emissions will require a cocktail approach that diversifies away from BECCS – this will include novel technologies that have not been tried at scale, such as direct air capture (DACs)

- Only a few prototype plants throughout the world – e.g. the Climework factory in Switzerland which was established in 2015
- The costs of the most recent industrial scale project by 'Carbon Engineering' have been put at between US$94 and US$232/tCO_2

Cost estimates in the literature vary significantly

- This is partly due to different underlying assumptions such as the cost of carbon-free energy and technology components
- The costs could fall dramatically over time; one projection based on significant support for RD&D and early commercial deployment has put the costs of low temperature solid sorbent (LT-DACs) systems as 133-222, 60- 105, 40-69 and 32-54 €/tCO_2 in 2020, 2030, 2040 and 2050, respectively
- Such ambitious improvements imply prices in 2030-2050 that are either close to or below the carbon prices under an IPR FPS pathway
- How much DACs will need to contribute depends on the drawdown technology mix and the sequestration needed

Cost Estimate ($/t$CO_2$)	Study
$136	Keith (2006)
$30-200	Lackner (2009)
$297-700	Ishimoto (2014)
$600	American Physical Society (2011)
$400-1,000	National Research Council (2015)
$10-35	Global Thermostat (2016)
$136	Carbon Engineering (2005)

Source: Tollefson (2018); Ishimoto et al. (2017)

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Post-2050 NETs – Bioengineering

DACs could be complemented by both traditional negative emissions technologies (e.g. BECCs) as well as more speculative but promising options, such as the use of bioengineering

Bioengineering could be used to modify or construct organisms that sequester carbon at far higher rates than existing natural alternatives

- Engineering of plants' roots to absorb and fix greater amounts of carbon: Efforts are already being undertaken at the Salk Institute funded by a $35m TED 'Audacious' programme fund and have borne initial fruit. Researchers believe that the approach promises '46% annual reduction in excess CO_2 emissions produced by humans in the future
- Using synthetic metabolic engineering and genetic modification to enhance photosynthesis in plants and ocean organisms. In essence, this involves modification of an organisms metabolism to increase its rate of photosynthesis and hence carbon capture. Existing natural photosynthesising organisms can also be made more resilient e.g. making phage-resistant cyanobacteria

Both these mechanisms will require careful testing before they can be deployed at scale. Early investment and extensive research will be critical

These technologies are early stage and there are few reliable abatement cost estimates, particularly at scale

More futuristic-sounding, but plausible, approaches are also being considered

- For example, the use of nano-technology to construct molecular filters could bring down final capture costs to €13.7/t CO_2 (\$18.3/t CO_2). This involves creating incredibly small (0-20 nanometres) filters which directly capture and sequester carbon (including by discarding them to the ocean floor)

Source: Trudeau et al. (2018); Freitas (2015); Fasihi et al. (2019)

The range of potential applications makes artificial intelligence a powerful tool to reduce GHG emissions

The AI Revolution is expected to unlock a broad set of opportunities for emissions reductions while reducing the costs associated with climate action. Potential use cases of AI in climate mitigation cover the following areas:

- GHG emissions monitoring: Identification of GHG emissions sources, monitoring of CO_2 leaks from wells, monitoring of CO_2 stock sinks (forests, oceans)
- Transport: Better demand forecasts leading to more efficient transportation systems, optimisation of vehicle routing, better integration of modes in the passenger and freight sectors
- Industry: Acceleration of low-carbon materials discovery process, data-based identification of inefficiencies in emission-heavy industries
- Buildings: Monitoring and management of energy consumption through smart control systems, optimisation of urban planning through the identification of district-level consumption patterns
- Agriculture: Precision agriculture (intelligent irrigation systems, disease detection), improvements of crop yield predictions, remote sensing of methane emissions detection, better monitoring of deforestation, estimation of carbon stocks in forest from satellite imagery, automated afforestation through seed-planting drones
- CCS: Identification of potential storage location
- Climate modelling: Improved projections, attribution studies could pave the way for damage litigation claims against fossil fuel companies

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Source: National Geographic (article dated 18th July 2019), Rolnick et al. (2019)

Last resort solutions are not expected to be feasible by 2050 and come with significant risks

Methods not expected to be feasible by 2050

Method	Effectiveness	Comments
Mineral carbonation	Uncertain	• Remains an immature technology • May augment but not replace conventional sedimentary CCS
Ocean alkalinity	Uncertain	• This technology may prove viable in the second half of the century but is unlikely to be employed at scale before 2050 • Public mistrust of technologies that manipulate the oceans
Ocean fertilisation	Uncertain + unlikely to prove useful at scale	• If pursued over large regions, as would be required, fertilisation also carries substantial risk of negative consequences to ocean ecosystems and nutrient cycles • Fertilisation is also currently forbidden under international conventions and unacceptable to much of the public. These include Decision IX/16 of COP 9 under the Convention on Biological Diversity and Resolution LC-LP.1 (2008) under the London Convention and Protocol on the Prevention of Marine Pollution • Public mistrust of technologies that manipulate the oceans
Geoengineering e.g.: • Spraying sulphate particles into the stratosphere • Refreezing parts of the polar regions by pumping salt particles from the ocean into polar clouds	Uncertain + possibly significant secondary effects	• The reduction of solar radiation could create massive changes in weather systems and rainfall patterns (e.g. the Asian monsoon) • Would require global governance • Highly likely to create political conflict • Researching these technologies could create a moral hazard issue as it implicitly encourages delay in putting an end to fossil fuel consumption • Unknown potential negative or catastrophic impacts

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Source: Greenhouse gas removal, Royal Society and Royal Academy of Engineering, (September 2018)

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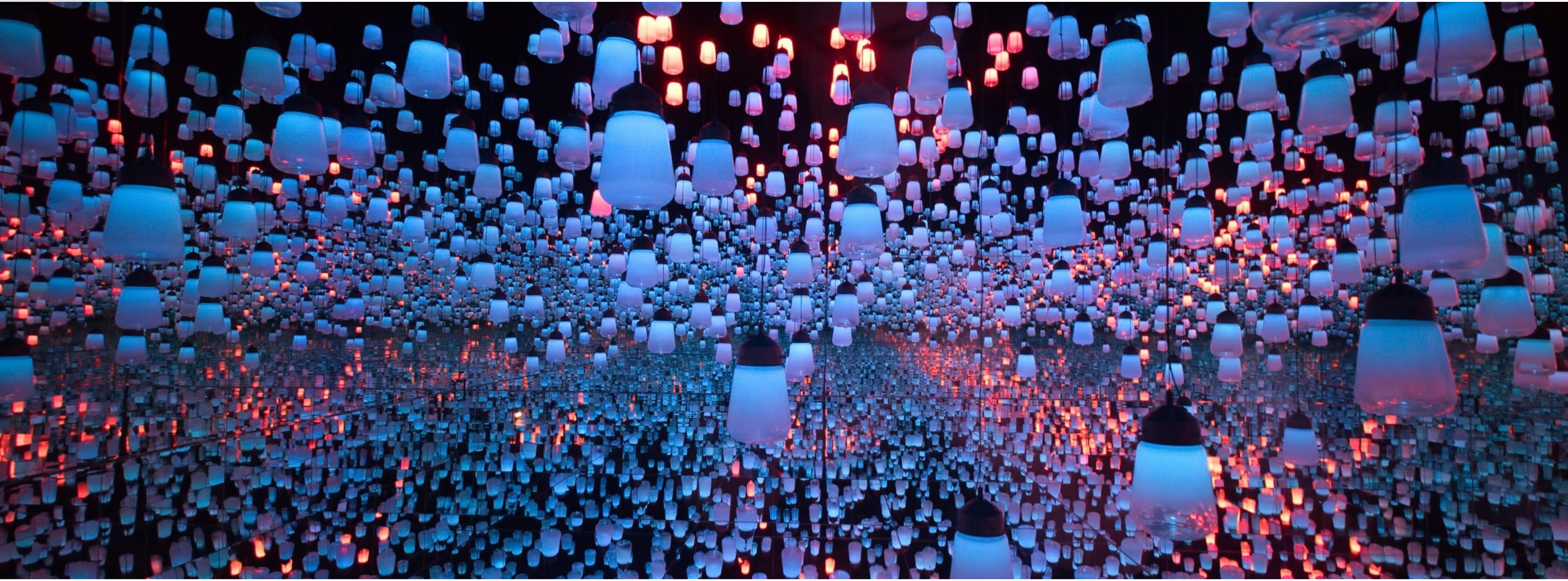
Annex



Summary of results

Sectors	Statkraft Low Emissions Scenario (2018)	IRENA Remap (2018)	IEA Stated Policies Scenario (STEPS) (2019)	IEA Sustainable Development Scenario (SDS) (2019)	Shell Sky Scenario (2018)	BP ET (2018)	IPR FPS (2019)
CO_2 emissions							
Global energy-related CO_2 emissions ($GtCO_2$) in 2040	23.4	15	35.6	15.8	28.7	35.9	**18**
Primary energy							
Average annual primary energy demand growth 2015-2040	0.5%	-0.1% (to 2050)	1.0% (2018-2040)	-0.3% (2018-2040)	1.1%	1.3% (2010 -2040)	**-0.3%** (2017-2040)
Oil consumption: annual average growth 2015-40	-0.80%	n/a	0.4% (2018-2040)	-1.8% (2018-2040)	-0.1%	0.5% (2010 -2040)	**-1.4%** (2017-2040)
Gas consumption: annual average growth 2015-40	6%	n/a	1.4% (2018-2040)	-0.2% (2018-2040)	0.8%	1.8% (2010 -2040)	**0.7%** (2017-2040)
Coal consumption: annual average growth 2015-40	-2.60%	n/a	-0.10% (2018-2040)	-4.3% (2018-2040)	-0.9%	0.0% (2010 -2040)	**-6.4%** (2017-2040)
Transport sector							
Oil share (final, 2040)	70%	33% (2050)	82%	60%	91%	86%	**73%**
% Electric vehicle (EV+PHEV) share of new vehicle sales	77% by 2040	n/a	13% by 2030	14.5% by 2030	n/a	n/a	**90% by 2040**
Power sector							
Demand (annual average growth, 2015-2040)	2.4%	2.0%	2.0% (2018-2040)	1.7% (2018-2040)	3.5%	n/a	**2.2%** (2017-2040)
Wind power (annual average growth, 2015-2040)	8.0%	9.0%	6.7% (2018-2040)	8.9% (2018-2040)	10.2%	n/a	**11.2%** (2017-2040)
Solar power (annual average growth, 2015-2040)	15.0%	11.3%	9.9% (2018-2040)	12.0% (2018-2040)	17.5%	n/a	**14.7%** (2017-2040)
Hydropower (annual average growth, 2015-2040)	2.1%	1.1%	1.7% (2018-2040)	2.3% (2018-2040)	1%	n/a	**1.7%** (2017-2040)
Fossil fuel share in power (% of total 2040)	21%	18%	48%	21%	29%	n/a	**18%** (2017-2040)

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How we translate the Policy Forecast into a modelling framework

We translate the IPR FPS into a modelling scenario using an integrated modelling framework which draw on models which have been extensively used to study global decarbonisation.

Model	Description	Key features
G-Cubed	• A **macroeconomic** intertemporal general equilibrium model of the global economy. The version used for the IPR project has been G-cubed has been developed at Australian National University.	• It includes the monetary side of the economy allowing simulations of exchange rates, nominal interest rates and financial flows over time across regions • The model also incorporates features of neo-Keynesian models allowing for short run wage rigidities
TIAM-Grantham	• A version of the ETSAP-TIAM model, a global **energy system** model developed by the Energy Technology Systems Analysis Programme (ETSAP). The version used for the IPR project is run by Imperial College in London.	• The TIAM-Grantham model covers the full energy chain from extraction of energy resources (e.g. coal mining) through conversion (e.g. electricity generation or oil refining) and to final use to provide an 'energy service' to the end-user (e.g. heating or lighting in a building; mobility etc.)
MAgPIE	• The Model of Agricultural Production and its Impact on the Environment (MAgPIE) is a global **land use** allocation model. It has been developed by the Potsdam Institute For Climate Impact Research (PIK).	• MAgPIE is connected to the grid-based dynamic vegetation model. The model takes into account regional economic conditions such as demand for agricultural commodities, technological development and production costs as well as spatially explicit data on potential crop yields, land and water constraints.

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How we translate the Policy Forecast into a modelling framework

Economic system models

Macroeconomic (G-cubed)

- Production activity, emissions, and abatement costs – in general equilibrium
- Monetary, fiscal and financial adjustments

Land use (MAgPIE)

Production activity, emissions, and abatement costs

Carbon prices

Bioenergy prices and demand

Energy (TIAM)

Production activity, emissions, and abatement costs

Carbon prices

Changes to service demand

Outputs

Economic activity (by sector, country)

Price changes (by product)

Energy use (by fuel and carrier)

Cleantech deployment (by type)

- **Forecast of macroeconomic impacts** of transition across major regions
- **Forecasts of price and quantity metrics** for key commodities/products

Value stream models (asset level)

Predict revenues and profits

Cost & competition model
- Carbon cost competitiveness
- Market power and cost pass-through
- Market share

Demand destruction model
- Change in market size in high-emissions sectors (e.g. O&G)
- Price impacts
- Market share

Cleantech market model
- Change in market size in clean sectors (e.g. electric vehicles, renewable energy)
- Product competitiveness and market share

- **Decomposition of downside and upside exposure** to macro and sector forecasts by asset

Financial implications (asset level)

Financial impacts

Asset class	Metric
Listed equity	Δ market capitalization
Private equity	asset value
Corporate debt	Δ bond yields, credit ratings
Sovereign debt	Δ bond yields, credit ratings
Infrastructure	asset value
Real estate	asset value
Commodities	Δ price

- **Disclosable metrics** at asset or portfolio level
- **Uniform metrics** across business

Financial release December 2019 onwards

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