IEEJ Outlook 2024

Energy, Environment and Economy

Complexity of achieving the energy transition under multiple pathways

Overview

The Institute of Energy Economics, Japan

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Summary

Energy supply and demand outlook

- Under the "Reference Scenario" (REF), in which the prevailing changes from the past continue, energy consumption in 2050 will increase by 1.2 times over 2021. Energy demand in China, which has thus far driven global demand growth, will peak around 2030, with India, the Association of Southeast Asian Nations (ASEAN), the Middle East and Africa becoming the main regions for demand growth.
- Energy consumption under the "Advanced Technologies Scenario" (ATS), in which the introduction of energy and environmental technologies is strengthened to ensure a stable supply of energy and combat climate change, will plateau around 2030, and consumption in 2050 will be roughly 0.9 times that in 2021. It should be noted that this outlook is a forecast-type future projection that is based on assumptions about technology and policy trends, and contrasts with a backcast-type analysis that defines a future "landing point" and charts a path to reach it.
- In the Reference Scenario, global energy-related carbon dioxide (CO_2) emissions will remain roughly flat until 2050, and in the Advanced Technologies Scenario, they will be 14.7 Gt (down 56% from 2021), indicating that the world is halfway to achieving carbon neutrality. Reducing to the point of almost eliminating emissions in the non-power generation sectors and Emerging Market and Developing Economies remains a challenge.
- Electricity generation will double from the current level due to economic growth, electrification, and a boost in demand for green hydrogen. As the expansion of variable renewable energy is expected to continue for the foreseeable future, measures such as electricity storage and thermal power generation (with carbon capture and storage [CCS], hydrogen, etc.) will become extremely important to provide stabilisation and balance between electricity supply and demand.
- Oil and natural gas will increase throughout the Reference Scenario but, in the Advanced Technologies Scenario, they will start to decline in the 2020s and the 2030s, respectively. Still, fossil fuels together account for 73% of primary energy consumption (2050) in the Reference Scenario and 53% in the Advanced Technologies Scenario. Along with efforts to improve efficiency and reduce emissions with technologies such as CCS, securing a stable supply will continue to be an important issue.

Toward fulfilling the role of LNG and natural gas

New investment needed for stable supply of LNG and natural gas

- Cumulative required investments in the natural gas production sector from 2022 to 2050 are $9.8 trillion in the Reference Scenario and $7 trillion in the Advanced Technology Scenario. The liquefied natural gas (LNG) production sector will require an annual capacity addition ranging from 8 Mt/year (ATS) to 18 Mt/year (REF) on average, during the outlook period up to 2050.

- There is also uncertainty over those projects for which investment decision have already been made, with possible delays and failures to materialise.

Cost trends in LNG production projects and challenges in procuring LNG for Japan

- Since 2021, supply chain disruptions triggered by the pandemic have caused delays and rising costs in the construction of LNG production projects. The overall cost pressures associated with the Russo-Ukrainian war are growing. Even after investment decisions have been made, rising instability factors in host countries of LNG production projects have caused delays.
- At the same time, technological innovations in small- and medium-scale liquefaction facilities and the expansion of modular systems ("design-one-and-build-many" strategies) are being introduced to control cost increases.
- In order to secure Japan's necessary LNG procurement in the 2030s and beyond, it will be important to form procurement partnerships such as joint purchasing and volume optimisation between multiple buyers, to make Japanese companies semi-portfolio players, and to provide public-private cooperation and policy support in these areas.

Clarification of LNG role and need for stronger security presented at G7 and at LNG Producer-Consumer Conference

- Whilst the Group of Seven (G7) recognised the importance of natural gas and LNG, it will be crucial to establish standards for acceptable 'abated' LNG in the energy transition. The importance of an internationally aligned approach for measurement and reporting of methane and greenhouse gas (GHG) emissions and their mitigations was emphasised at the G7 Ministerial Meeting and at the LNG Producer-Consumer Conference in 2023.
- The enhancement of the International Energy Agency's (IEA) role in strengthening gas and LNG security, which was presented at the LNG Producer-Consumer Conference, is also noteworthy.
- Furthermore, close dialogue between LNG producing and consuming countries through bilateral government-level consultations, procurement cooperation among consuming countries, and promotion of emergency accommodation cooperation will be important to strengthen gas and LNG security.

Issues for long-term stabilisation and development of the LNG market

- In the international LNG market, LNG investment and construction activities are advancing, especially in the United States, partly supported by LNG offtake commitments under long-term contracts. On the other hand, projects for which investment decisions were made in the past also face uncertainty and delays. Therefore, there is no guarantee that buyers' procurement of LNG with a combination of measures including long-term contracts, as well as suppliers' capability of LNG delivery, are secured yet.
- It is necessary to develop a variety of financial instruments to meet the funding needs of LNG production projects.
- Building partnerships between LNG buyers from the same and/or different countries, including joint procurement, will be effective in light of the buyers' desire for flexibility, especially from emerging LNG markets with the expanding composition of buyers. Such partnership will also contribute to ensuring the stability of Japan's LNG requirements, including long-term contracts.

Growing importance of negative emissions technology

- Interest in negative emission technologies (NETs), which capture GHGs from the atmosphere and store them elsewhere to stay over long periods of time, has increased in recent years both domestically and internationally. It is extremely difficult to achieve carbon neutrality without the contribution of NETs, especially in the industry and long-haul transport sectors, where the use of fossil fuels is certain to continue. Countries should more clearly and specifically position the use of NETs in their emissions reduction plans for long-term carbon neutrality.
- There are a wide variety of NETs, but many will take time to be commercialised. For individual NETs, countries need to take early steps to understand the potential for carbon removal in their countries, consider accurate and transparent methods for measuring removal, reduce removal costs, establish the value chains required for the introduction of each NETs, and assess the impact on surrounding ecosystems.
- International cooperation is also essential to the full-scale introduction of NETs. First, there is a need to widely share international recognition that NETs are an essential means of achieving carbon neutrality, and to accelerate preparatory work towards the establishment of internationally shared measurement, reporting and verification (MRV) systems and carbon removal certification and removal credit systems. At the same time, it is important to deepen discussions at the intergovernmental level in the future with a view to creating a mechanism to realise cross-border removal projects and their reflection in Nationally Determined Contributions (NDCs).

Paths towards ASEAN's energy transition

- ASEAN, with its remarkable economic development, will be at the centre of future global energy demand growth, and of the emission reductions. ASEAN will affect the success or failure of the global decarbonisation. As such, cost reductions are essential for achieving both economic growth and carbon neutrality, while an economically rational energy mix should be pursued.
- Assumptions about future economic growth and energy efficiency improvements will make a big difference in projecting future energy demand. It is not enough to focus only on the 'ratio' of renewable energy, because the total amount of energy demand will significantly change the energy mix we should be aiming for.
- The power generation cost by renewable energy is expected to be low among zero-emission power sources, making it a promising power source. However, it should be kept in mind that there is a possibility of higher electricity costs if the power facilities are spread beyond the suitable area, and that integration costs for stabilising electricity supply and demand will increase if variable renewables account for the majority of the power supply. It is necessary to determine the optimal quantity according to demand, weather conditions and land availability.
- Natural gas plays a major role in reducing emissions in the industry sector (especially for high temperature demand that is difficult to be electrified) and balancing electricity supply and demand. It can be an affordable fuel, especially in reducing emissions during the

transition period toward zero emissions. Expansion of supply capacity and stabilisation of the natural gas supply will contribute to reducing energy transition costs.

The 445th Forum on Research Work

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The Institute of Energy Economics, Japan

IEEJ Outlook 2024

– Complexity of achieving the energy transition under multiple pathways –

Part 1 : Global Energy Supply and Demand Outlook to 2050

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What is IEEJ Outlook 2024 ?

- Quantitative outlook of energy supply and demand in the world, toward 2050.

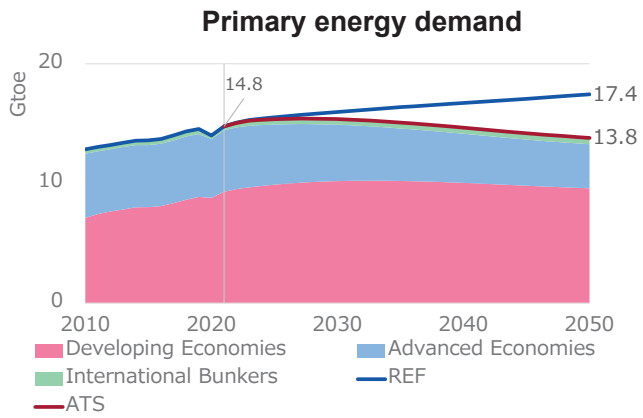
- Has two scenarios;

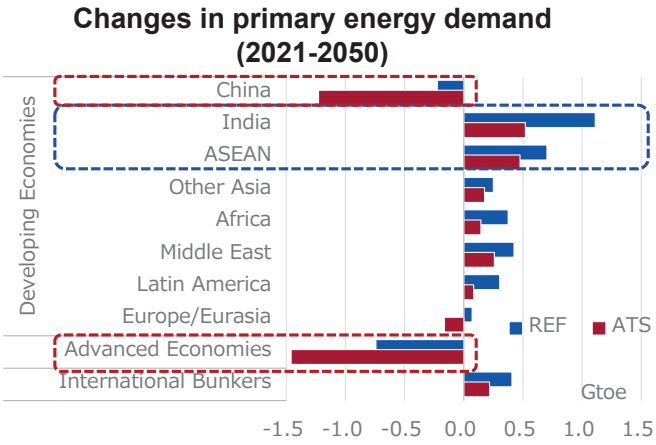
REF: (Reference Scenario)
the prevailing changes will continue against the backdrop of current energy and environmental policies

ATS: (Advanced Technologies Scenario)
Energy/environmental technologies are introduced to the maximum extent possible to ensure a stable supply of energy and strengthen measures against climate change

- **Forecast** analysis using econometric and other models.

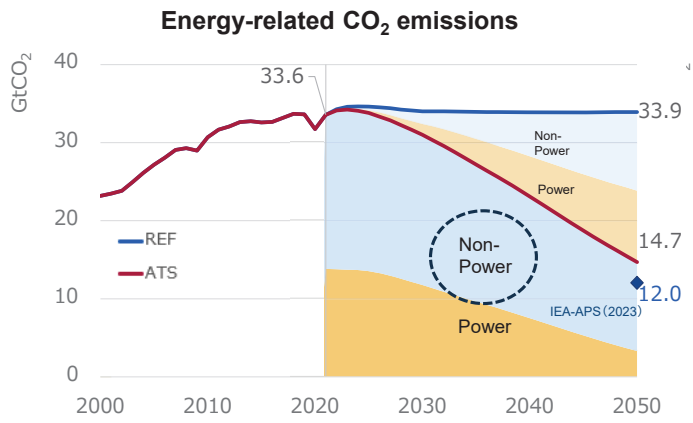
Part 1: Global Outlook
Demand will grow significantly in Asia, Middle East, and Africa

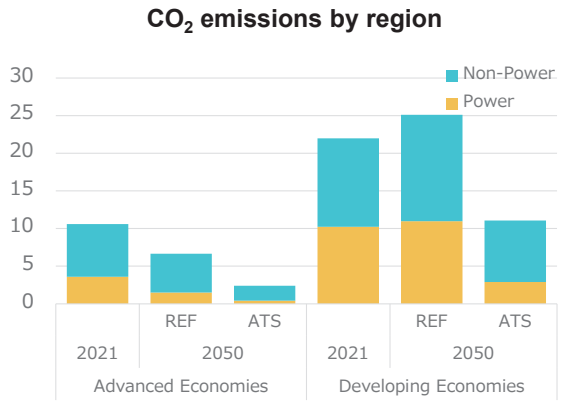




- (**REF**) Demand continues to increase with the current trend, reaching 1.2 times the current level by 2050.
- (**ATS**) Global demand peaks before 2030, however, India, ASEAN, the Middle East, and Africa will continue their demand growth.

Part1: Global Outlook　Power generation moves closer to CN. Decarbonization of non-power is a challenge.



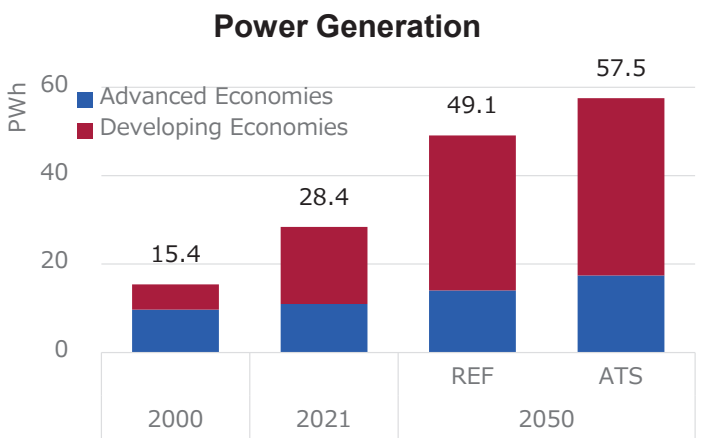


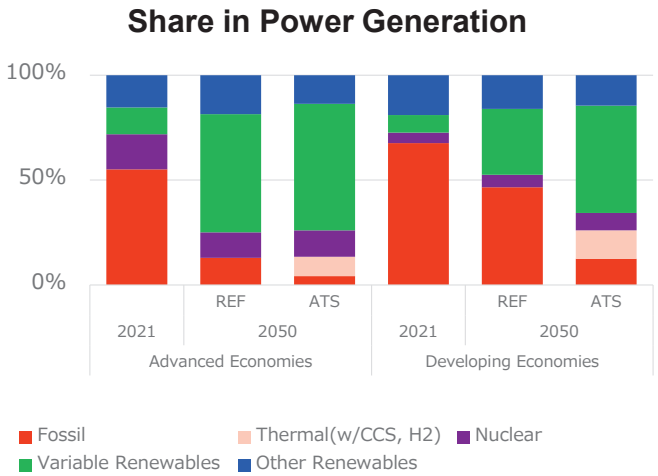
- （**REF**）CO2 emissions are nearly flat as increased demand is offset by lower CO2 intensity.
- （**ATS**）The emission peaks out before 2030 and decline to 14.7 GtCO2 in 2050 (56% below 2021).

It is still far from carbon neutrality, and decarbonization in the non-power sector and emerging and developing countries are significant challenges.

*IEA-APS: Announced Pledges Scenario from IEA "World Energy Outlook 2023"

Part 1: Global Outlook　Power generation will be 1.7 to 2 times. Among them, renewable increase significantly.





- (**REF**) Power generation increases 1.7 times from current levels. Most of the increase is in developing countries, but also in developed countries as electrification progresses.
- (**ATS**) Power generation doubles the current level. In addition to electrification progress, demand for green hydrogen is boosting demand. About 85% of power sources are decarbonized.

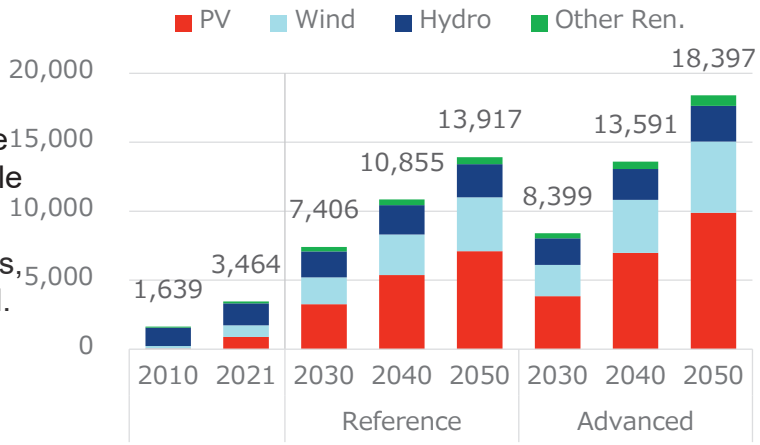
Part 1: Global Outlook Renewable energy capacity will more than double by 2030 and continue the expansion.

- Remarkable penetration of renewables continues. The installed capacity of renewable energy in 2030 is expected to be 2.0~2.4 times that of 2021.
- Increases will continue after 2030 under both scenarios;
- **(REF)** The expansion will slightly slow down due to higher system costs and a decrease in suitable locations.

  (ATS) Renewable energy installation accelerates, increasing capacity to 5.4 times the current level.

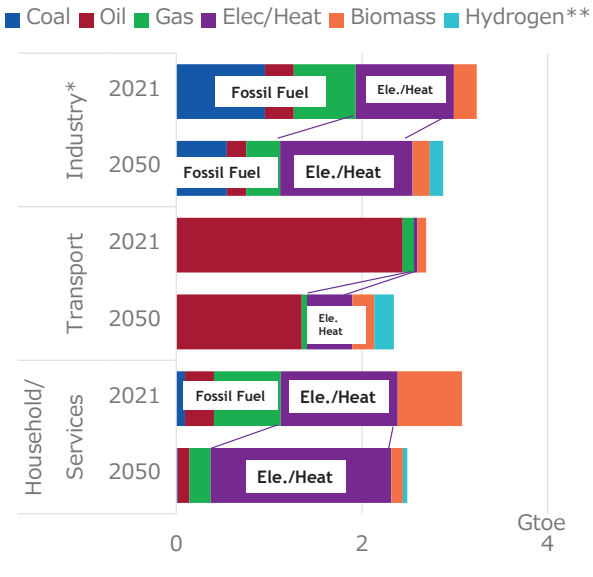
Particularly, solar PV and wind will be nearly 10 times the current capacity. Both daily and seasonal storage will be essential for a stable power supply.

Renewable capacity [GW]



Part 1: Global Outlook While electrification and hydrogenation proceed rapidly, the role of fossil fuels remains

Final Energy Demands (ATS)



**Hydrogen includes ammonia and synthetic fuel from H_2.

- Industry

  Fossil fuels remain due to the difficulty of substitution in heat demand at higher temperatures. (especially for steel and cement).

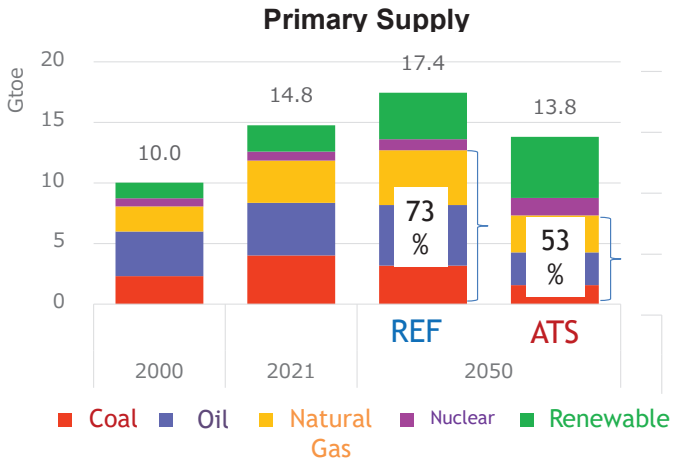
- Transport

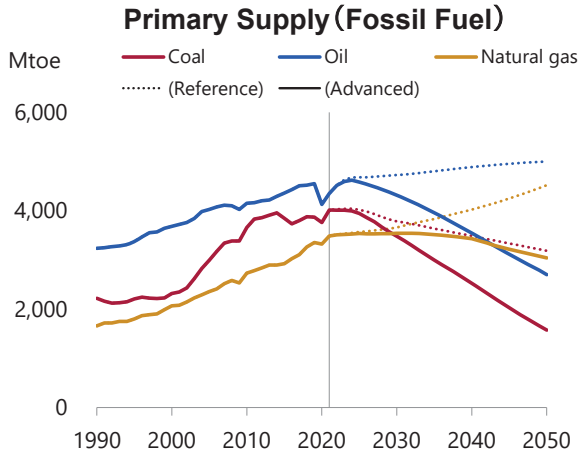
  ZEVs (EVs + H_2 FCVs) are largely penetrating in the automobile subsector. They account for 60% of the passenger cars fleet and 47% of the trucks and buses.

- Others (Household and Services)

  Significant electrification of both service subsectors and homes (often substituting from traditional biomass).

Primary oil and gas supply increases in Reference, and decreases in Advanced Tech..





- **(REF)** Primary supply in 2050 increases 1.2 times that of 2021, 73% of which will be fossil fuels. Oil demand increases 1.2 times and gas 1.3 times, while coal decreases 0.8 times.
- **(ATS)** Half of the primary supply is fossil fuels, and the other half is renewable and nuclear. Oil and coal supply peaks in the 2020s because of a decrease in transportation demand for oil and power generation demand for coal. Gas supplies remains flat until the 2030s and begin to decline before 2040.

Part 1: Global Outlook
Conclusion

- India, ASEAN, Middle East, and Africa will be the center of demand growth in both scenarios.
- Emissions in the Reference scenario remains flat, and those from the Advanced Technologies scenario are halfway from reaching carbon neutrality. The remaining emissions are mainly from the non-power sector and the developing countries. To further cut emissions will remain a difficult challenge.
- Power generation doubles in the next three decades due to factors such as economic growth, electrification, and demand for green hydrogen. As variable renewable covers a large part of electricity, storage and dispatchable power are key to a stable electricity supply.
- In 2050, fossil fuels account for 73% of primary supply in Reference scenario and 53% in Advanced Technologies scenario. The effort for a stable supply of fossil fuels must be continued.

Part 2 (Topic)
ASEAN's Pathways towards Energy Transition

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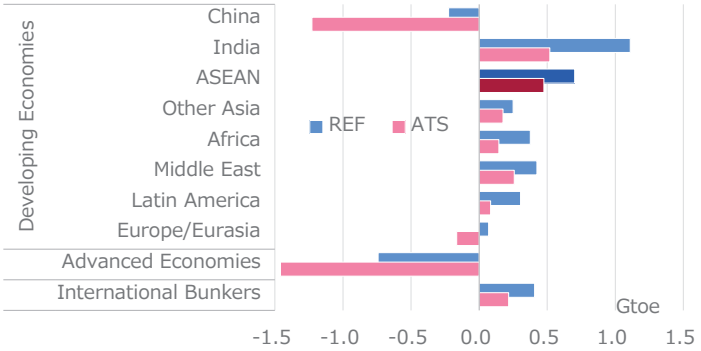
Part 2: ASEAN's Pathways towards Energy Transition
Demand growth in ASEAN is significant; net zero is a significant challenge.

Change in Primary Energy (2021-2050)

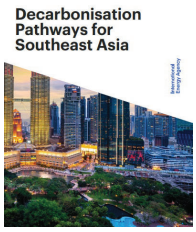


Pledges of ASEAN Countries

	Most recent developments
Brunei	N.A.
Cambodia	CN by 2050 (L/T Strategy, Dec. 2021)
Indonesia	NZ by 2060 or sooner (L/T Strategy, July 2021)
Lao PDR	NZ by 2050 (Climate Ambition Alliance)
Malaysia	CN by 2050 (PM expressed in Sept. 2021)
Myanmar	NZ by 2050 (Climate Ambition Alliance,)
Philippines	N.A.
Singapore	NZ by 2050 (updated L/T Strategy, Nov. 2022)
Thailand	CN by 2050 & NZ by 2065 (PM expressed at COP26)
Vietnam	CN by 2050 (PM expressed at COP26)

- As ASEAN continues to achieve significant economic growth, the region will be the center of energy demand growth in the world.
- Since COP26, eight countries have announced carbon-neutral targets by 2050 or 2060.
- Reducing CO2 emissions while expanding energy supply is a significant challenge.

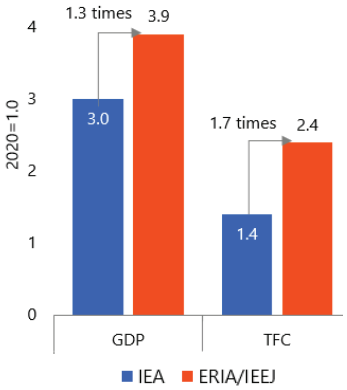
Part 2: ASEAN
IEA G7 Report: comparison of IEA and ERIA/IEEJ pathways



Source) IEA

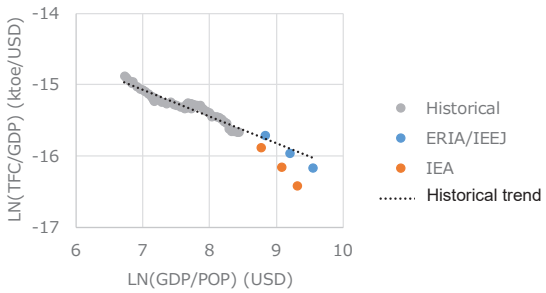
- Future energy demand significantly differs, depending on assumptions of economic growth and energy efficiency improvement.

Growth of ASEAN's GDP and TFC toward 2050



Source: produced from IEA, Decarbonization Pathways for Southeast Asia(2023)

ASEAN's Energy Efficiency Improvement (past five decades and future)



Source: produced from IEA, Decarbonization Pathways for Southeast Asia(2023) and IEA, World Energy Balances

Part 2: ASEAN
IEA G7 Report: comparison of IEA and ERIA/IEEJ pathways

- The optimal energy mix in the future will change depending on the scale of demand.

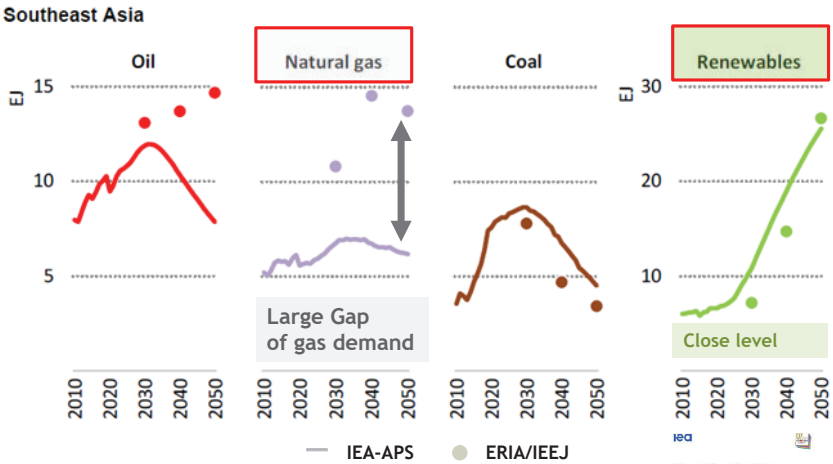
IEA

- The low demand level enables renewable energy and electrification while reducing the supply of natural gas.
- Renewable energy accounts for about 80% of the total power generation in 2050.

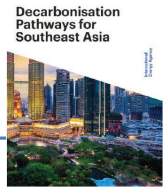
ERIA/IEEJ

- To meet the high demand level, not only renewable energy in the same amount as the IEA; (1) fossil fuels expansion (especially natural gas) (2) decarbonization by hydrogen and CCS, CO2 removal by DACCS and BECCS are required.
- The renewable energy share is about 60%.

ASEAN Primary Energy Demand (IEA, ERIA/IEEJ comparison)



source: IEA, Decarbonization Pathways for Southeast Asia, (2023)



Source) IEA

Part 2: ASEAN
Analysis Framework : Cost-optimal energy mix

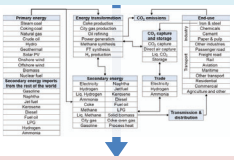
- **Optimal Case** is the energy mix that can meet the net-zero target of each ASEAN country at the lowest cost while meeting the demand of ERIA/IEEJ.
- Under the same demand growth, three cases are simulated; **RE40**: lower penetration of renewable energy, **RE80**: higher penetration of renewable energy, and **gas-cap**: gas supply constraint.

Case Assumptions

Cases	Renewable share in power	Primary supply of gas	CN Year
Optimal	**No limitation** (60% as a result)	No limitation	2050/2060
Gas-Cap	No limitation	Same as 2019	
RE40	40%	No limitation	
RE80	80%	No limitation	

IEEJ-NE Model
(Bottom-up Optimization model)

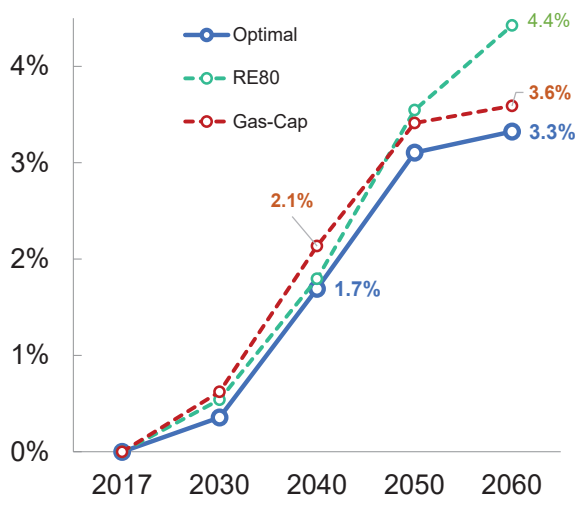
Input:
- CO_2 Reduction Target - Energy Demands
- Tech. Information (Cost, Efficiency, etc.)



Output :
Cost-minimum energy mix which achieve the CO2 reduction target

Part 2: ASEAN RE80 increases costs in the long term, while Gas-Cap increases costs in the mid-term.

Total CO_2 reduction cost* (ASEAN, per GDP)

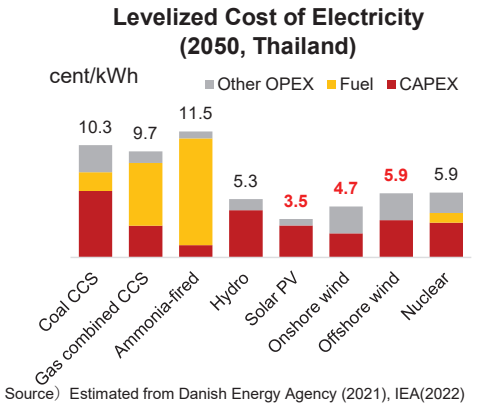


- The total CO2 reduction (abatement) cost to achieve 2060 net zero is US$570 billion/year, equivalent to 3.3% of GDP, in the **optimal case**.
- If the optimal energy mix is not realized, the abatement cost rises further;
  - **RE80** : Cost in 2060 rises to 4.4% of the GDP. The increase in 2050-2060 is especially significant.
  - **Gas-Cap** : The costs during the 2030-2040 are particularly large.

    In other words, the expansion of natural gas supply during the transition period will contribute significantly to cost reductions.

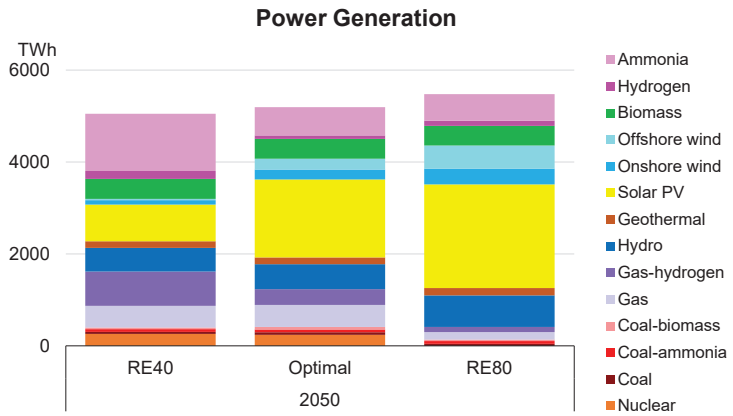
∗ The cost difference between the total cost of energy supply (capital, fuel, O&M, etc.) , compared to the baseline case without emission reductions.
The future GDP is estimated from "Energy Outlook and Energy Saving Potential in East Asia 2020"(ERIA, 2021). 2017 Constant USD.

Part 2: ASEAN Although LCOE of renewable will decrease over time, massive penetration requires additional cost



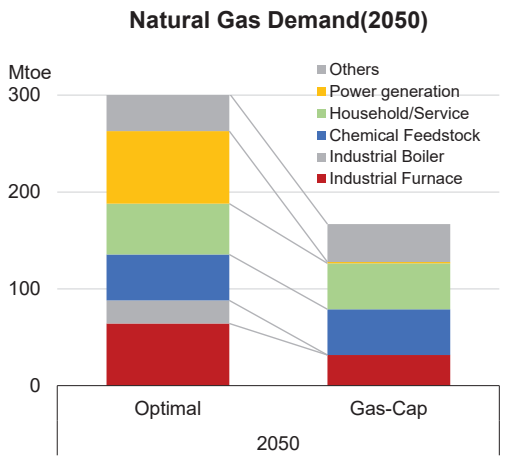
Source） Estimated from Danish Energy Agency (2021), IEA(2022)

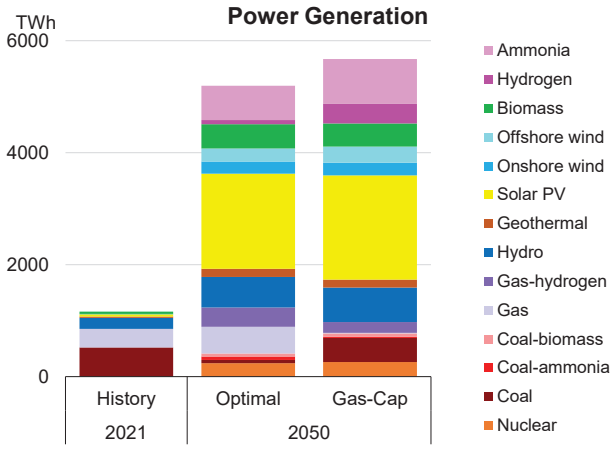
*Costs inside power generation facilities alone; which does not include integration costs.



- The generation cost of renewable energy itself (LCOE) is expected to be relatively low among zero-emission power in 2050. Therefore, if the installation is low, the average power generation cost would increase.[RE40]
- On the other hand, if variable renewable energy (solar and wind) is increased to the level of [RE80], it will be necessary to introduce them to areas with worse weather conditions, and integration costs for dealing with output fluctuations (batteries, etc.) will increase, leading to higher overall system costs.

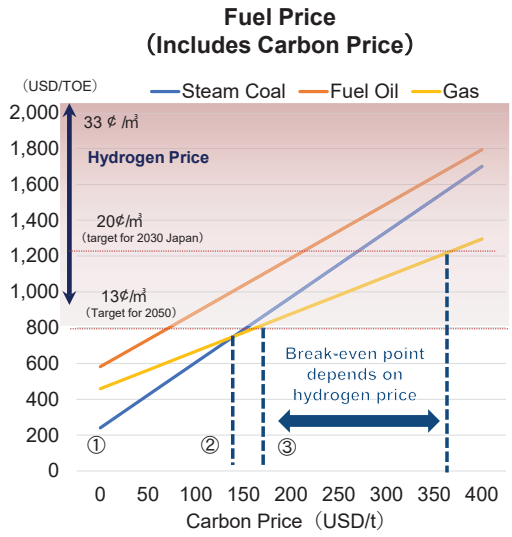
Part 2: ASEAN Gas plays an important role in heat demand and power generation, during the transition period





- In the **optimal case**, natural gas is primarily a fuel for industrial furnaces, which are difficult to electrify. In the **gas-cap** case, the shortage must be offset by oil and coal, which have higher emission factors.
- In the optimal case, gas-fired power generation is introduced to balance supply and demand.

Part 2: ASEAN
On the way to net-zero, gas is competitive among fossil fuels



Source) Advanced Technologies Scenario, 2050

- In demand sectors where electrification is difficult, fossil fuel use is expected to continue until a low-cost hydrogen supply is realized.
- The cost advantages among fuels will change as follows.

  (1) **Coal has the smallest price** per calorific value of fuel alone.

  (2) As ASEAN moves toward net zero, some external cost is expected to be attached to CO_2 emissions.

  If the carbon price increases to around $100/t, **gas would be affordable**.

  (3) If the carbon price increases significantly and the hydrogen price is reduced to about 13 cents/m3, the **H_2 price may fall below the gas price**.

  Gas could become competitive where the carbon price falls between (2) and (3).

* The MAC (marginal abatement cost*) calculated from this analysis is around 200$/t-$CO_2$ in 2040 and 370$/t in 2050, a level at which gas use has some advantage.

Part 2: ASEAN's Pathways towards Energy Transition
Conclusion

- For ASEAN, with its remarkable economic development, **cost efficiency of energy transition is essential** to achieve both economic growth and CN.
- Depending on future assumptions for growth and energy efficiency improvements, there will be significant differences in the outlook of future energy demand. It is not sufficient to simply focus on the share of renewable energy, as the **optimal energy mix will vary depending on the total amount of demand**.
- **The cost of renewable energy is expected to be low** among zero-emission power sources, making it a promising power source. However, it should be noted that suitable sites are limited, and the **integration cost may increase when variable renewable covers a large part** of the electricity supply.
- **Gas will mainly play a role in reducing industrial emissions** (especially hard-to-abate sectors) and **in dispatchable power generation**. It can be an important energy source for emission reductions, especially during the transition toward zero emissions.

An IEEJ Outlook 2024 Discussion Topic
To Achieve the Important Role of LNG and Natural Gas

November 2023

The Institute of Energy Economics, Japan - IEEJ

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Abstract

- ✓ **Additional investment is required to ensure stable supply of LNG and natural gas**
  - Amount of required investment in natural gas production (from 2022 to 2050)
    Reference Scenario (REF): USD 9.8 trillion; Advanced Technology Scenario: USD 7.0 trillion
  - Significant addition of LNG production is required
  - Uncertainty remains over realization of LNG production projects with potential suspensions and delays
- ✓ **Trend of LNG production project costs and issues of LNG procurement**
  - Upward trends due to supply-chain disruptions, the Russian war, and inflation
  - On the other hand, innovations are underway to contain cost increases, including small and mid-scale liquefaction trains, modularization
  - To meet Japan's LNG requirement after 2030, joint procurement and partnerships between national and international companies, portfolio strategies for Japanese larger LNG buyers and trading houses, and optimisation of mixtures of LNG procurement (long-term and short-term contracts and spot purchases) should be further considered
- ✓ **Longer LNG transportation distances and needs of transportation optimisation**
  - While the expansion of the Panama Canal has provided significant merits with some bottlenecks and the market has seen longer shipping distances, streamlining LNG transportation is important
- ✓ **G7 and LNG Producer Consumer Conference emphasize the role of LNG and supply security**
  - Importance to define "abated" LNG compatible to energy transition
  - Enhancing gas security through dialogues involving IEA as well as its non-member countries
- ✓ **Toward LNG market stabilisation - long-term challenges**
  - Securing appropriate LNG supply through long-term commitment
  - Variety of financial measures should be developed to meet diversified needs of LNG production projects
  - As the market expands including emerging buyers, collaboration between buyers of different markets is also effective

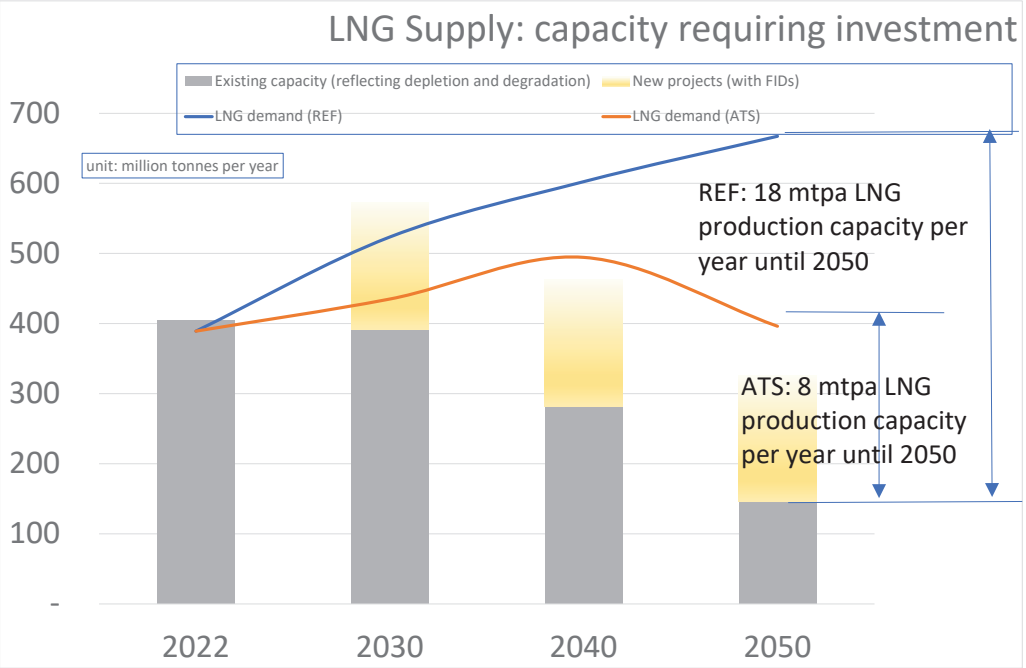
Investment is needed to meet incremental LNG demand, as well as replace depleting existing LNG production capacity

Investment is needed in 8 - 18 mtpa LNG production capacity per year until 2050

Required additional capacity investment means the gap between projected LNG demand and decreasing existing production capacity, to be filled by the followings:

1. Greenfield project investment
2. Alternative new field development (backfill) investment (the yellow stack indicates already sanctioned projects)
3. Investment in existing fields to offset production decline
4. Rejuvenation of existing liquefaction facilities

✓ *Those projects already greenlighted (included in the yellow stacks) may entails uncertainty with possible delays and failures to materialise

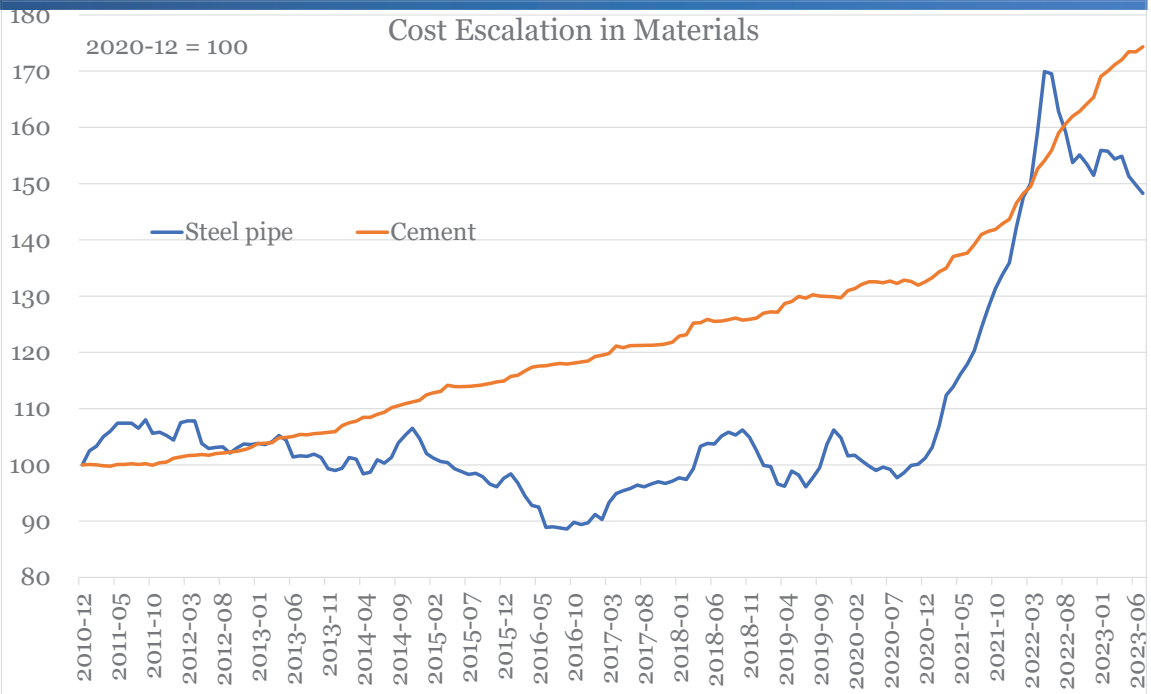


Trends of LNG production projects - development and costs

	Major trends	Factors to promote projects and cost reductions
2010-2014	• Responding to Northeast Asian LNG demand surge, Australian LNG production projects proliferated, leading to concentration of construction activities and cost escalarions	• Cost escalations in Australia stimulated LNG production development activities in other regions
2015-2020	• LNG production project development activities shifted to the United States with moderated cost escalations in both upstream and liquefaction sectors • As feedgas supply for the U.S. LNG shares the same network as the U.S. gas consuming market, the gas is not necessarily cheap but is expected to be stable on the long-term basis	• Conversion of underutilised LNG receiving infrastructure into LNG export facilities is a factor leading to overall cost reductions in the United States • Separated gas production and transportation sectors in the United States have led to lower risks and costs for individual players • Floating liquefaction (FLNG) has become a competitive options to develop remote gas sources
2021-2023	• Logistical constraints caused by the pandemic delayed construction acrtiviities, leading to cost overruns • The Russia-Ukraine war has led to general cost escalations • Instability in those countries where LNG production projects have been sanctioned has caused delays	• Innovative small and mid-scale liquefaction applications bring cost reductions • Modular and design-one-and-build-many strategies lead to cost reductions • The phasing out from Russian gas has stimulated LNG production development activities in other regions
	• Prices of steel, concrete, and other materials are on the rise (as well as an end of zero-interest) • CCS and electrification (renewables) add costs	• LNG production developers competing for market windows in the late 2020s pursue cost reductions

Higher material costs likely result in increases in LNG production project construction costs

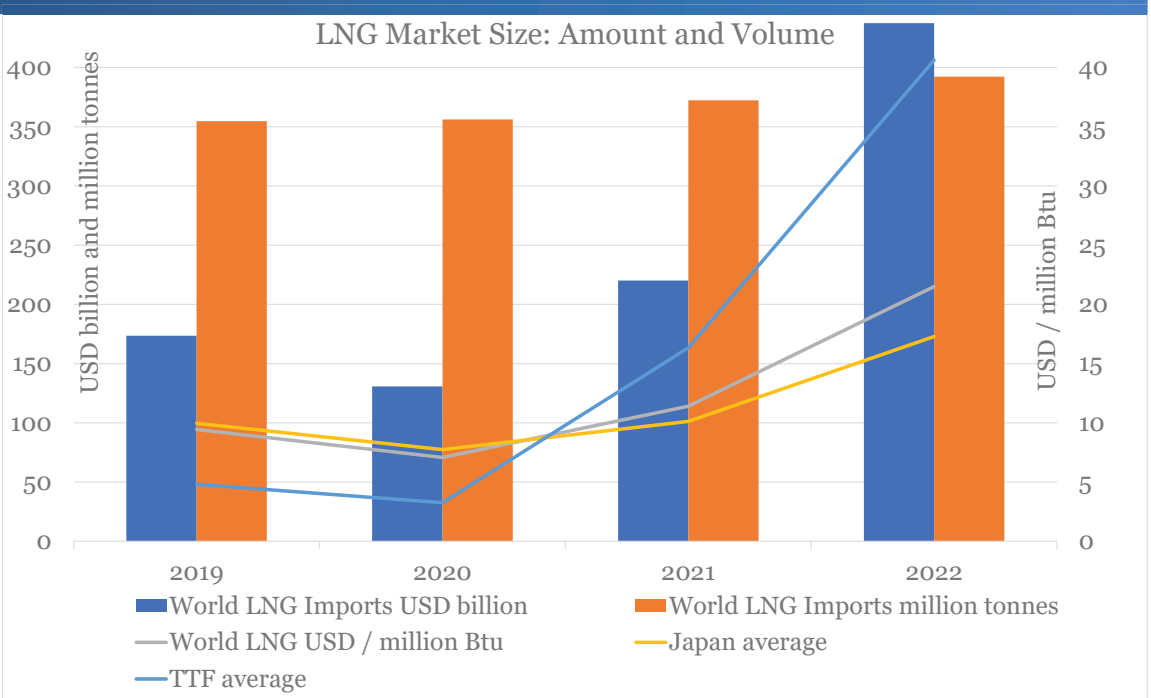
- ✓ Cost escalations have accelerated since late 2021 in steel, cement and other construction materials
- ✓ The higher material costs likely result in increase in LNG production project construction costs



Source: Based on data of Federal Reserve Bank

The rapid rise in prices resulted in a more significant expansion of the LNG market in terms of the total amount than the volume

- ✓ The LNG market experienced a steady growth in the volume wise in 2022
- ✓ The paid amount doubled in 2022, in a stark contrast against 2020 when the amount decreased significantly
- ✓ The economic value of the market is expected to shrink in 2023 due to lower LNG prices



Source: based on data of GIIGNL, Global Trade Atlas, Trade Statistics, and ICE

Selected Cases of Risks Facing LNG Production Projects After FIDs

	Current status	What to watch
Mozambique	• FLNG started exports in 2022 • The first onshore project suspended construction due to instability, facing a delay of more than 2 years	• The first onshore project needs security in the area and faces potential additional costs - negotiation continues with contractors
Russia's Arctic LNG 2	• After the first module completion, uncertainty persists on the second and third modules	• Economic sanctions impose difficulties in technological and logistical aspects
Mauritania's and Senegal's offshore Greater Tortue Ahmeyim FLNG	• The delayed delivery of FLNG unit pushes back commercial operation to 1Q 2024	• Cost pressures due to the delay
Australia's Barossa development	• Resumption of drilling activities in 2023 should enable 2025 start of gas supply • The operator maintains cost estimates	• A delay in the resumption of activities could prolong suspension of Darwin LNG • Costs may be higher even if the schedule is maintained
Australia's Scarborough development	• The operator maintains cost estimates and production target of 2026 • Environmentalists challenge procedures	• Pipeline laying may be delayed due to procedural issues of environmental permit
Australia's other LNG projects	• Uncertainty over the implementation of the safeguard mechanism • Labour relation issues at the operating projects	• The day-one GHG net-zero requirement may pose difficulties on greenfield projects • LNG production projects may need to measures to avoid labour disputes

Securing greener LNG production projects

	Electrification and greener power sources	CCS
General Trends	• Electrification of liquefaction processes • Higher reliability and lower maintenance costs • More efficient liquefaction, better GHG management, and less gas consumption	• Capturing CO2 native to feedgas and generated from compression and liquefaction processes • Integrating CO2 captured in neighbouring industrial facilities could enhance economics
Challenges	• Securing greener power sources • Securing baseload and backup power supply • Installing renewable power sources within vicinity of the LNG production site • Securing flexibility in load and supply management of renewable power, with neighbouring industrial facilities, if there are any • Likely larger initial investment amount	• Securing suitable carbon storage sites in the neighbourhood • Creating sizable CO2 demand sources • Likely larger initial investment amount • Required time for integrating existing LNG facilities • Ensuring stable operation of the CCS • Greater technical challenges to capture CO2 from the process than from feedgas
U.S. Gulf Region	• Gradual progress has been observed in electrification with greener power sources partly as measures to reduce air pollutions	• CCS projects are developed by LNG production project developers partly helped by preferential tax treatment
Canada's West Coast	• Utilization of hydro-power from the grid	
Qatar	• In parallel with the NFE and NFS expansion projects solar power sources are developed	• CCS plans are combined with the NFE and NFS • A jetty boil-off gas recovery facility recovers BOG and reliquefy BOG

Major Current and Future LNG Supply Sources

- ✓ Projects advance around the world to increase LNG supply
- ✓ Risks are here and there with development
- ✓ Projects become more difficult in frontier areas as relatively accessible ones have been already developed
- ✓ Expansion at existing sites (brownfield) and feedgas supply replacement projects (backfill) are considered economically advantageous

Russia
- **Sakhalin 2 is one of the biggest supply projects in the Asia Pacific LNG market even with uncertainty**
- New projects have even mor uncertainty

Canada
- **Opening up the West Coast of North America as major LNG supply sources along with Mexico in 2025**
- Claiming one of the cleanest LNG supply sources in the world

Algeria
- As continue being a major supply source of pipeline gas and LNG to Europe, its stable supply is another key of stability of the global market

East Mediterranean
- As a potential major supply source to the European market, the region could have a role to balance the global market

United States
- The largest LNG exporter in 2023
- **More FIDs and development activities underpinned by increasing offtake commitments**
- Long-distances from GOM to Asia
- Troubles at large-scale projects could have big impacts globally

Tanzania
- Partnership with international partners could pave the way to be a major LNG supply source

Iran
- Once economic sanctions are lifted, it has a huge potential of further development of gas resources, including export options

Papua New Guinea
- Existing PNG LNG project has potential to be expanded with additional gas sources
- **Papua LNG project proceeding FEED work**

Qatar
- North Field East (NFE) and North Field South (NFS) expansions are expected to start delivering LNG in 2025 and 2027
- With 21 million tonnes per year out of 48 has been sold to international partners under super long-term deals, likely sale of the remaining volumes and potential additional international partners are to be watched

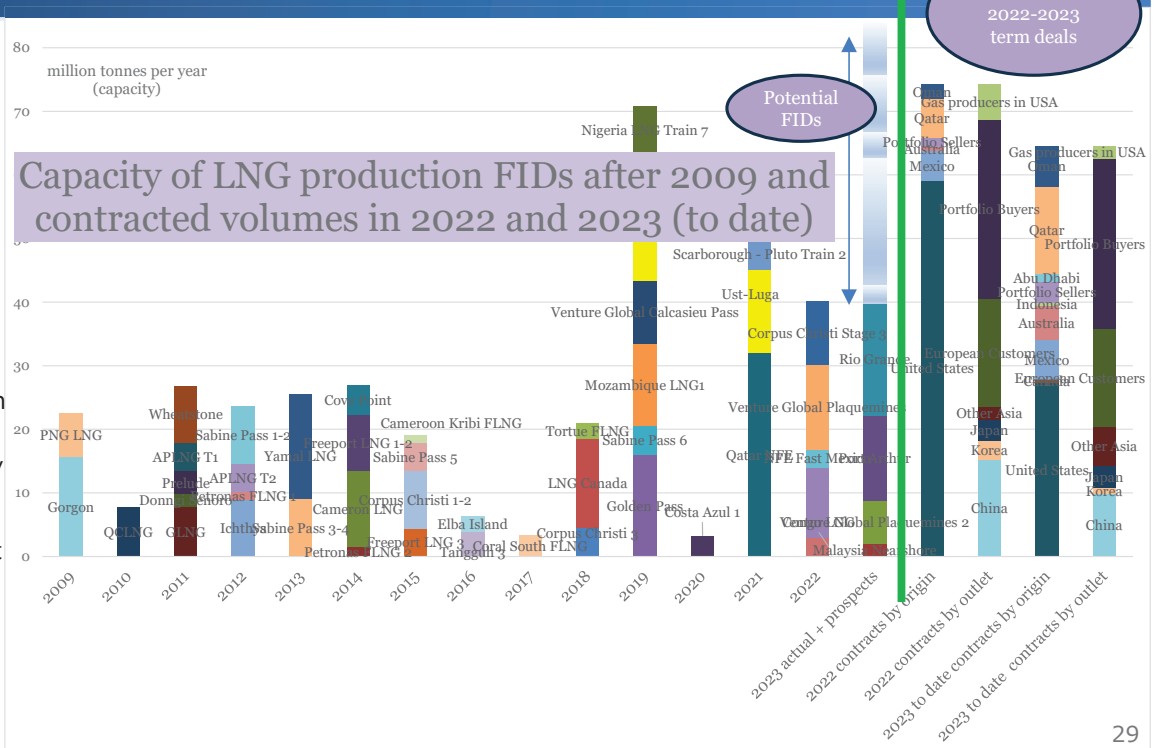
Mexico
- Altamira FLNG is expected to produce first LNG shortly
- The West Coast is also expected to start LNG exports in 2025

Australia
- The largest and most diversified LNG supply sources with brownfield and backfill opportunities
- **Labour issues could disrupt stable LNG delivery**
- **Climate and fiscal policy changes (reforms) could have impacts on future and existing LNG production projects and could discourage investors in those projects especially witnessing rule changes after investment decisions are made**

Mozambique
- A floating LNG production project opened up the huge natural gas resources offshore East Africa to the global market
- Onshore construction activities have been stalled for two years due to the unstable local conditions
- **East Africa is expected to be a major and flexible LNG supply sources with its strategic location**

LNG Production Investment and Term Contracts Are On The Rise

- ✓ LNG FIDs and construction activities are on the rise after the Ukraine war
- ✓ The project boom leads to construction cost escalation
- ✓ A clear definition of "abated LNG" is required to encourage investment under the long-term perspective of energy transition
- ✓ Russian projects, even though they have been with FIDs, are uncertain
- ✓ The United States as supply sources, China, other Asia, Europe, and portfolio players as buyers represent majority of term-contract parties in 2022 and 2023

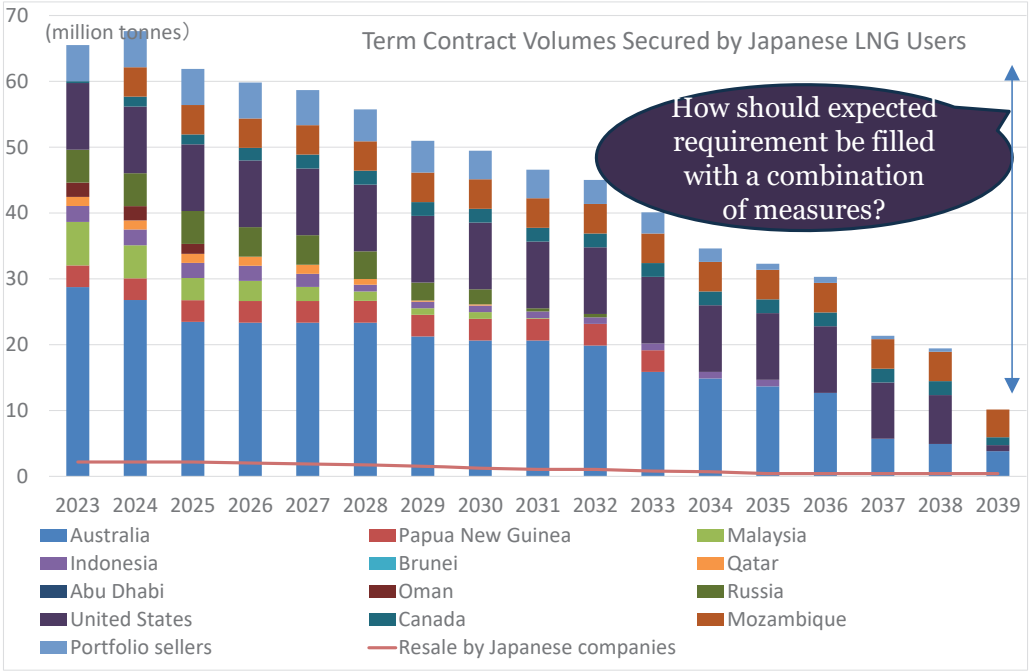


Japanese LNG Procurement Tends to Rely on Partnerships and Portfolio Players

- ✓ Volumes procured so far go down from 60 million tonnes of 2025 to 50 million tonnes by 2030
- ✓ Requirement is expected to maintain the 60 million tonnes per year level until 2050 according to the IEEJ's Reference Scenario
- ✓ For future procurement:
  - ➢ Large volumes under long-term contracts are difficult for individual buyers
  - ➢ Share of short-term and spot procurement grows

↓

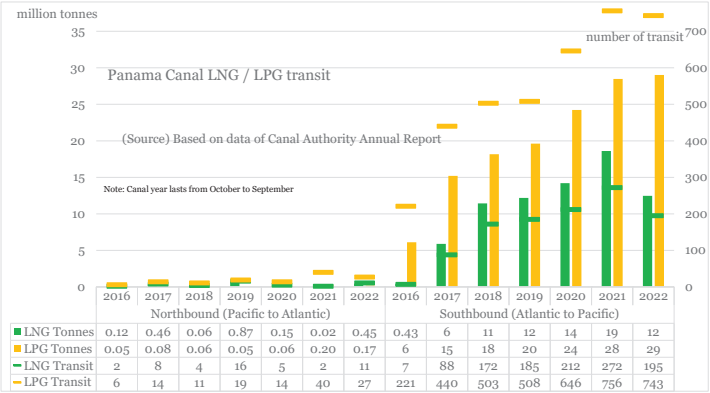
- ✓ Cooperation between companies and the government and policy supports are essential
  - ➢ Procurement from portfolio players of Japan and other international portfolio players
  - ➢ Encouragement for Japanese larger buyers and trading houses to undertake portfolio activities
  - ➢ Partnerships with international companies, including joint procurement and optimization
  - ➢ Partnerships between fellow companies – including joint purchase



Huge Benefit of the Panama Canal - As Well As Bottlenecks

<Benefit of the expanded canal>

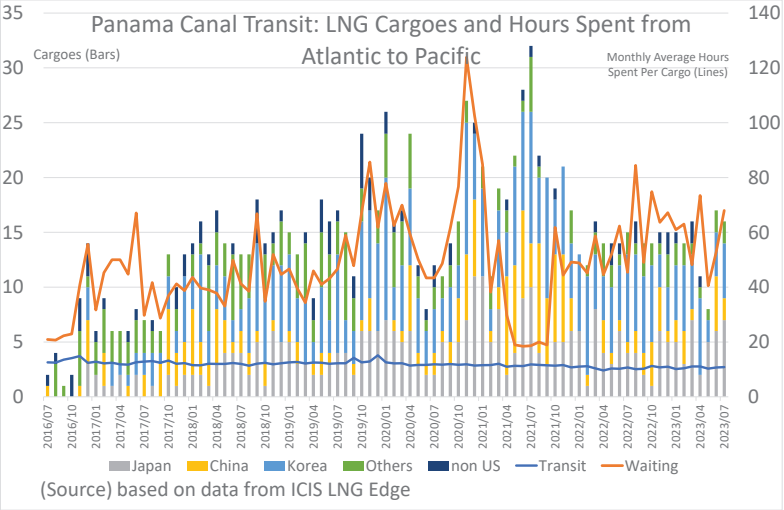
- ✓ As 2016 expansion of the Panama Canal enabled transit of LNG carriers, more LNG can be transported from the United States mostly the Gulf of Mexico to Northeast Asia
- ✓ Thanks to the shale revolution, more LLPG is also transported through the canal



	Northbound (Pacific to Atlantic)							Southbound (Atlantic to Pacific)						
	2016	2017	2018	2019	2020	2021	2022	2016	2017	2018	2019	2020	2021	2022
LNG Tonnes	0.12	0.46	0.06	0.87	0.15	0.02	0.45	0.43	6	11	12	14	19	12
LPG Tonnes	0.05	0.08	0.06	0.05	0.06	0.20	0.17	6	15	18	20	24	28	29
LNG Transit	2	8	4	16	5	2	11	7	88	172	185	212	272	195
LPG Transit	6	14	11	19	14	40	27	221	440	503	508	646	756	743

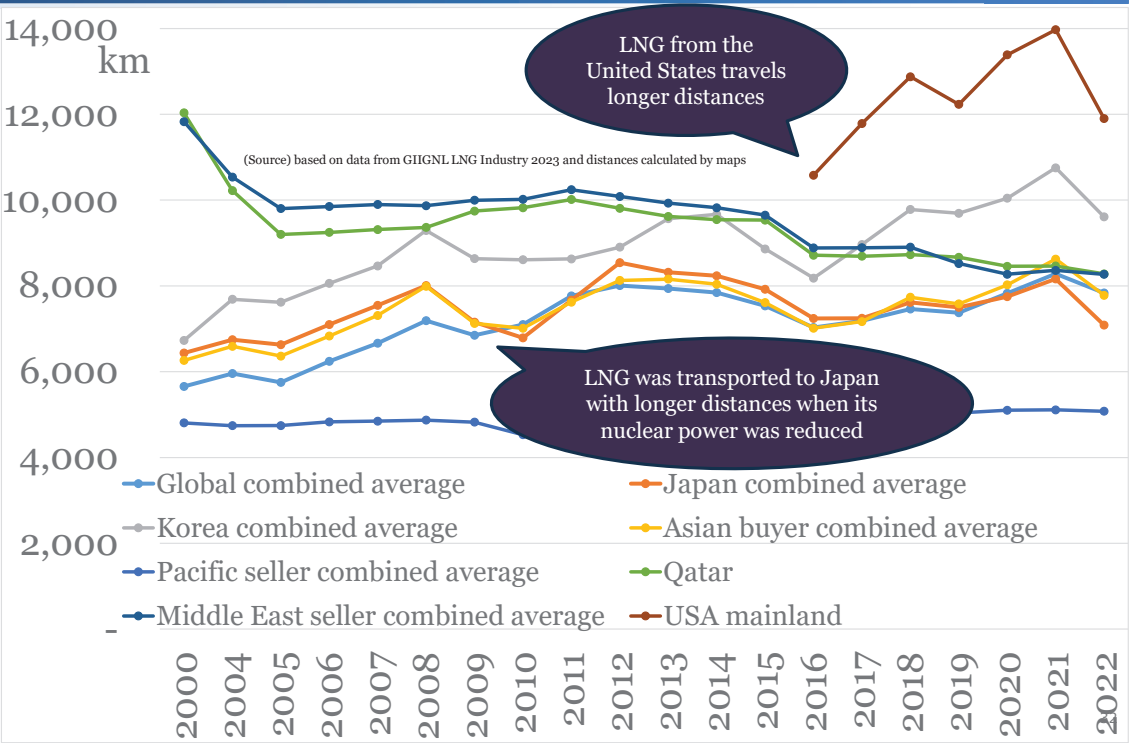
<challenges>

- ✓ Due to larger volumes transported, waiting times are longer to transit
- ✓ Drought lowers water levels leading to restrictions of number of large vessels to transit



Longer Transportation Distances and Bottlenecks Make Optimization Essential

- ✓ Along with supply sources, transportation routes and distances are diversified
- ✓ Distances have been longer when LNG demand surged in Japan and Asia unexpectedly
- ✓ Long-distance transportation has increased notably from the U.S. Gulf Coast to Northeast Asia
- ✓ In 2022, the shift of U.S. LNG to Europe lowered the overall average transportation distance
- ✓ The West Coast of North America and East Africa are expected to contribute to optimization of LNG transportation



G7 Ministerial Communique Underwrites Importance of Natural Gas

Relevant articles related to LNG and natural gas	Note
49. Energy security and clean energy transitions: . . . commitment. . . to accelerate the **phase-out of unabated fossil fuels**	Definition of "abated" will be the key
61. Methane: . . . **an internationally aligned approach for measurement, monitoring, reporting, and verification of methane and other GHG** emissions to create an international market that minimizes GHG emissions across oil, gas, and coal value chains, including by minimizing flaring and venting, and adopting best available leak detection and repair solutions and standards.	International standards of emission measurement and international cooperation are important
69. Natural gas and LNG . . . **investment in the gas sector can be appropriate** to help address potential market shortfalls provoked by the crisis, subject to clearly defined national circumstances, and **if implemented in a manner consistent with our climate objectives** and without creating lock-in effects, for example by ensuring that projects are integrated into national strategies for the development of low-carbon and renewable hydrogen.	Great recognition of the importance of natural gas and LNG Also important is to establish the standard of transition compatible LNG

Outcomes of the LNG Producer Consumer Conference 2023

- ✓IEA member, LNG-producing and -consuming countries expressed respective approaches of LNG utilization toward net-zero goals and expectations on LNG and natural gas in their energy security
- ✓Japan emphasized the importance of green transition. It also pointed the necessity of securing emergency reserves and mutual cooperation. Japan also presented its plans of SBL (Strategic Buffer LNG) and support of LNG trading. Japan also expressed its support for abolishing destination restrictions.
- ✓Japan and EU announced cooperation in the LNG area, including enhancement of LNG supply security, cooperation with international organisations (specifically IEA), transparency of the LNG market information, and cooperation in methane emission mitigation measures

LNG Supply Security To Be Enhanced Through International Cooperation

- ✓Provisions and transparency of gas market information by IEA, covering member and non-member countries, and its advisory functions should be enhanced as indicated in the Chair's summary of the LNG Producer Consumer Conference 2023
- ✓To ensure sufficient supply, stable procurement and deliveries of LNG and natural gas, enhanced mutual dialogues and cooperations between producing and consuming countries, as well as among consuming countries are necessary, paving the way toward smooth energy transition and energy security.

Toward Long-Term Stability and Further Growth of the LNG Markets

	Notable issues to be considered from the perspective of LNG consumers
Supply issues	Steady realisation of LNG projects in the United States as the mainstay supply sources Maintain stability and enable expansion of LNG production in Australia, Canada and Mexico Realization of LNG production projects in Africa's frontier regions Effective utilisation of existing - amortised - LNG production projects in enhancing flexibility of the global LNG market
Demand issues	As LNG demand centers shift to developing economies, support from traditional LNG consuming countries may be effective As flexibility in the LNG market is valued, efforts are needed between the public and private sectors to secure stable demand and enable some forms of long-term commitments. Demand aggregation, utilization of portfolio players and joint procurement are necessary
Pricing issues	Increasingly greater fluctuation of prices due to increasing volatility and increasing gas-on-gas pricing make it important to consider appropriate balances between different pricing arrangements
Climate change challenges	Clarification of LNG project standards that are compatible with decarbonized energy transition (methane and GHG emission mitigation measures) is necessary Promoting CC(U)S and green electricity in LNG liquefaction contributes to greening LNG
Financial challenges	Financing arrangements that can accommodate shorter LNG sale contracts are needed As the market expands, it is also important to ensure the creditworthiness of new buyers entering the market

Significance and the roles of Negative Emissions Technologies (NETs)

The Institute of Energy Economics, Japan

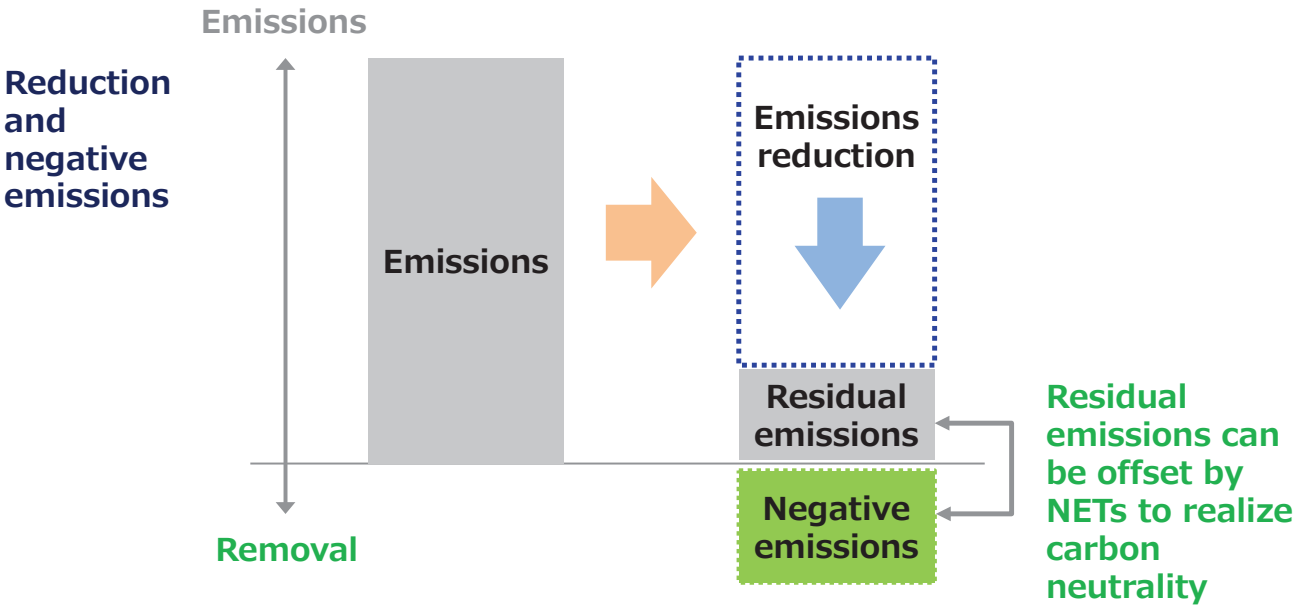
Yoshikazu Kobayashi,
Assistant Director, Research Strategy Unit
Executive Analyst, Clean Energy Unit

Summary

- It is very difficult to realize carbon neutrality without negative emissions technologies (NETs). The Roles and contributions of NETs should be more clearly specified in the long-term emissions reduction plan.
- Various types of NETs exist with different degrees of technological maturity. Understanding the potential of carbon removal volume each NETs, establishment of the methods to accurately measure the removal volume, cost reduction, and assessment to potential impacts to ecosystem by NETs need to be pursued as immediate actions.
- International cooperation is also important. Based on the shared understanding about the values and the roles of NETs in various pathways toward carbon neutrality, countries need to cooperate to establish internationally acceptable MRVs system, certification system, and removal credit system.

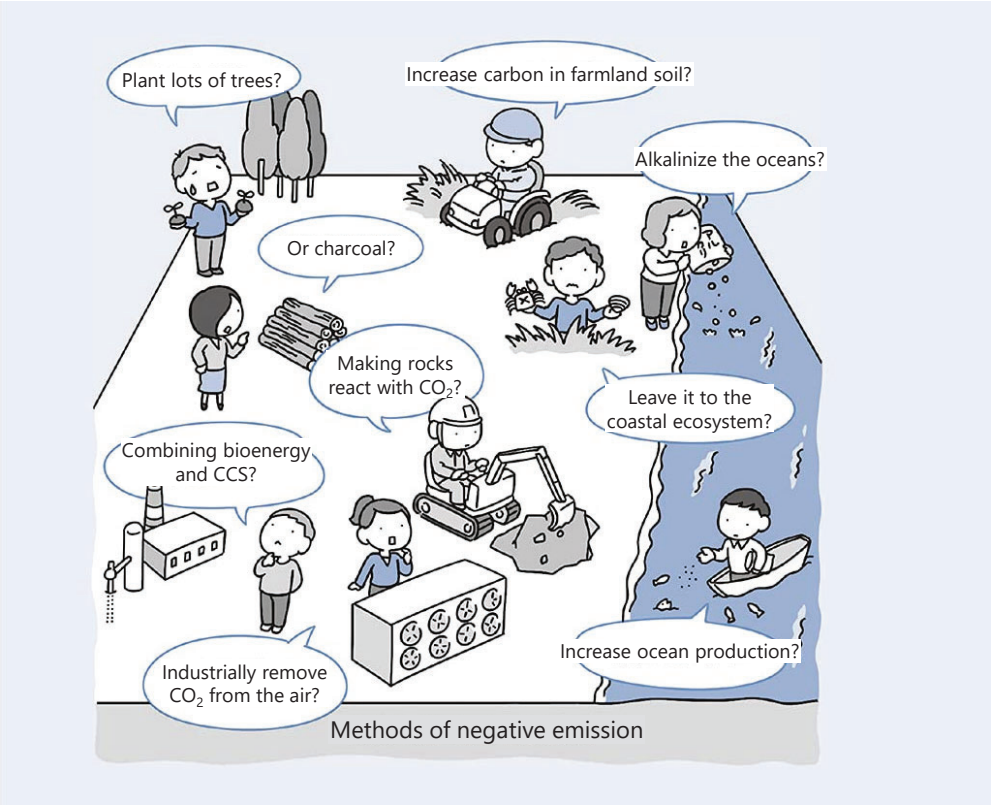
What is negative emissions technologies?

- Negative emissions technologies (NETs) : technologies that capture greenhouse gas from the atmosphere and store it for a long term.
  - NETs is a means of carbon dioxide removal (CDR).
- NETs can offset the residual emissions that cannot be eliminated to realize carbon neutrality.



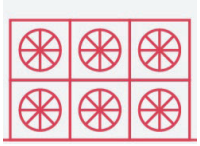
Various types of NETs

- Various NETs can be deployed to capture CO2 and store it.



Source: Institute of Applied Energy (2021)

Various types of NETs (cont.)



Direct Air Carbon Dioxide Capture and Storage(DACCS)

Capture CO2 directly from the atmosphere and store it underground

Bioenergy with carbon dioxide capture and storage (BECCS)

Capture CO2 emitted from bio-energy and store it underground

Afforestation and forest management

CO2 absorption by forests through large-scale afforestation, reforestation, adoption of agroforestry methods, and active prevention of deforestation.

Soil carbon sequestration

Promote carbon storage in the soil through no-till cultivation, growing crops that cover the soil surface, and using compos。

Sources: Institute of Applied Energy (2021); J Wilcox, B Kolosz, & J Freeman (2021) CDR Primer

Various types of NETs (cont.)

Bio char

Carbon contained in biomass is fixed for a long period of time by carbonizing biomass through pyrolysis or other means.

Enhanced weathering

CO2 from the atmosphere is absorbed and fixed (mineralized) by reacting with materials such as basalt, peridotite, and serpentinite.

Blue carbon

Promote carbon storage by improving vegetation and soil in coastal areas, and CO2 absorption by large-scale seaweed cultivation

Ocean alkalization

The amount of CO2 absorbed at the sea surface is increased by increasing the alkalinity of seawater by adding calcium carbonate and other substances.

Sources: Institute of Applied Energy (2021); J Wilcox, B Kolosz, & J Freeman (2021) CDR Primer

Various negative emissions technologies (NETs)

- NETs can be broadly divided into two categories: technology-based and nature-based ones.
- While each NET has its own advantages and disadvantages, DACCS and BECCS (both of which utilize CCS) have relatively high technological maturity, large removal potential, easy measurement of removal volume, and long CO2 fixation periods.

Overview of major NETs

NETs	Type	TRL*	Removal cost (US$/tCO2)	Removal potential (GtCO2/yr)
DACCS	Technology	6	100-300	5-40
BECCS	Technology	5-6	15-400	0.5-11
Afforestation/Forest managemnet	Nature	8-9	0-240	0.5-10
Soil carbon sequestration	Nature	8-9	-45-100**	0.6-9.3
Bio char	Nature	6-7	10-345	0.3-6.6
Weathering enhancement	Nature	3-4	50-200	2-4
Blue carbon	Nature	2-3	N/A	<1
Ocean alkalization	Nature	1-2	40-260	1-100

＊TRL (Technology Readiness Level) is a measure to type of measurement system used to assess the maturity level of a particular technology. TRL9 is closest to commercialization.
** Soil carbon sequestration can generate profits (negative cost) by improving the soil productivity.

Source：Babiker *et al.* (2022) Cross-sectoral Perspectives.

Policy actions for NETs introduction

- Incentives such as tax credits, setting introduction targets for individual NETs, and integrating removal credits into existing emissions trading systems are being considered for NETs introduction by major countries.
- In Japan, R&D for DAC technologies are provided by the government, and policy options to create the market for NETs are being discussed.

Country	Incentives	Numerical target	Credit
US	• Tax benefit (130-180$/t-$CO_2$) for DAC project • 3.5$ billion is provided for 4 DAC hub developments	• Carbon dioxide removal by giga-ton scale • Cost reduction to below 100$/t-$CO_2$	-
UK	• 100 million GBP provided for R&D of NETs incl. DACCS	• 5 million t-CO_2 removal by 2030 and 75 to 80 million t-CO_2 removal by 2050 through technology-based NETs	• Integration of removal credit to the UK-ETS
EU	• Plan to expand incentive for NETs (details are under discussion)	• 310 million t-CO_2 removal by LULUCF and 5 million t-CO_2 removal by tech-based NETs by 2030.	• Integration of removal credit to the EU-ETS

Japan's policy actions

- In May 2023, the Study Group on Market Creation for Negative Emissions Technologies released a summary framework, which provides the following seven options for market creation of NETs.
  - Which options will be adopted will be discussed at the Study Group.

Option	Outline
Compensation	The government compensate if a reference price linked to market will be below a strike price based on cost plus margin.
Public procurement	The government procure negative emission arrangement made by business actors at a specific price.
Purchase of excess credit	The government purchase surplus removal credit which a business actor could not sell at market.
Tax benefit	The government provides tax benefits for adoption of NETs
Support for CAPEX and Pilot Tests	The government supports pilot testing, FS, FEED, project development, and EPC
R&D support	The government supports R&D of NETs to reduce costs.
Allocation of obligatory purchase	The government obliges high-emission sectors to purchase removal credit for a certain volume.

Source : METI (2023) "Summary framework for market creation of negative emissions technologies"

Expected carbon removal by NETs in major countries

- Carbon neutrality scenarios made by government / research institute in major countries assume that 10% to 20% of the existing emissions will be offset by carbon removal, necessitating NETs as a means to achieve carbon neutrality.

	Reference year	LULUCF	Other NETs	Total	Removal volume (mil t-CO_2e)
Japan	2015	No assumption	14%	—	185
China	2020	6%	6%	12%	1,553
EU	2020	13%	6%	19%	593
Germany	2018	No assumption	9%	9%	72
France	2015	14%	3%	18%	78
UK	2020	4%	12%	16%	64

Scenarios colored by yellow are those made by the government.
LULUCF: Land Use, Land Use Change, and Forestry

Carbon neutral scenarios by governments and research institutes

- References of each country's scenario in the previous slide

Country	Source	Remarks	Base year
Japan	Research Institute of Innovative Technology for the Earth (RITE) (2021), "Scenario Analysis of Carbon Neutrality in 2050 (Interim report)," Advisory Committee on Energy Resources, Sub-Committee on Basic Energy Policy	Reference case	2015
China	Project Report Editorial Team (2020) "China's Long-Term Low Carbon Development Strategy and Transformation Pathway Research Report", *China Population, Resources and Environment*, Vol. 30, No. 11 (Analysis by a team led by Tsinghua University)	1.5℃ scenario	2020
EU	European Commission (2020), Stepping up Europe's 2030 climate ambition.	Average of four scenarios	2015
Germany	Prognos, Öko-Institut, Wuppertal-Institut (2020), Klimaneutrales Deutschland (Agora Energiewende, Agora Verkehrswende und Stiftung Klimaneutralität). Prognos, Öko-Institut, Wuppertal-Institut (2021), *Klimaneutrales Deutschland 2045* (Stiftung Klimaneutralität, Agora Energiewende und Agora Verkehrswende).（CN2045の分析）		2018
France	Direction Générale de l'Energie et du Climat (2020), *Synthèse du scénario de référence de la stratégie française pour l'énergie et le climat*.)	Additional Measures Scenario (AMS)	2015
UK	Committee on Climate Change (2020), The Sixth Carbon Budget .	Balance Net Zero Path Scenario	2020

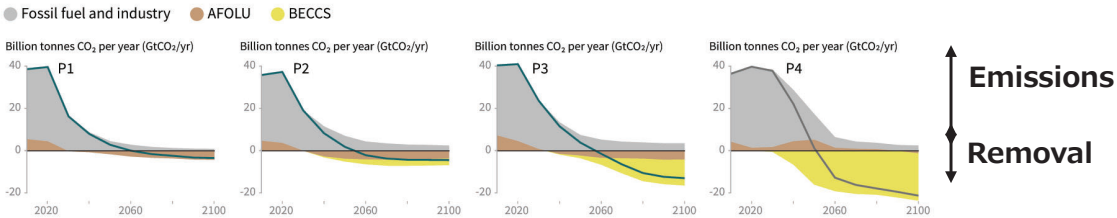
Roles of NETs in the pathways to carbon neutrality

- It is very difficult to achieve carbon neutrality without NETs.
  - Adoption of NETs is assumed in almost all scenarios referenced in the IPCC report.
- The use of NETs should be more clearly and concretely positioned in long-term emission reduction plans by each country.

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

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.

Source: IPCC (2018), Special Report: Global Warming of 1.5 ºC. Figure SPM 3b.

R&D for NETs

- Existing actions to develop DAC technologies and to secure domestic CO2 storage sites by the Japanese government should be accelerated.
  - The possibility to combine biomass fuel (including co-firing at thermal power) with CCS should alto be explored as a type BECCS operation.
- For nature-based solutions, the first goal is to achieve the forest absorption targets set forth in the current NDC. The possibility of soil carbon sequestration and biochar then should be examined.

NETs	Type	Major challenges
DACCS	Technology -based	• Cost reduction (CO2 capturing, energy input) • CCS capacity development (transport infrastructure, storage capacity, etc.)
BECCS	Technology -based	• Ensuring stable supply sources of biomass • Maximization of co-benefits (such as power supply) • CCS capacity development
Afforestation / Forest management	Nature-based	• Securing sites to adopt NETs • Promoting the logging of aging forest • Utilization of wood products by cut-down trees
Soil carbon sequestration	Nature-based	• Potential impacts to the existing agricultural activities • Accurate measurement of carbon removal volume • Maximization of co-benefits

R&D for NETs (cont.)

- Some nature-based solutions such as blue carbon and enhanced weathering are suitable for Japan's geographical conditions, and actions for these NETs, such as establishment of methods for measuring the removal volume and securing application sites) should be promoted.

NETs	Type	Major challenges
Bio char	Nature-based	• Securing sites for the NETs application • Accurate measurement methods for the volume and duration of removed volume • Value chain development from production to utilization • Management of the impact to the atmosphere and water
Enhanced weathering	Nature-based	• Pilot testing and data accumulation • Securing proper sites (including public acceptance) • Value chain development
Blue carbon	Nature-based	• Accurate measurement methods for the volume and duration of removed volume • Securing proper sites (including public acceptance) • Cost reduction
Ocean alkalization	Nature-based	• Pilot testing and data accumulation • Accurate measurement methods • Management of the impacts on ecosystem

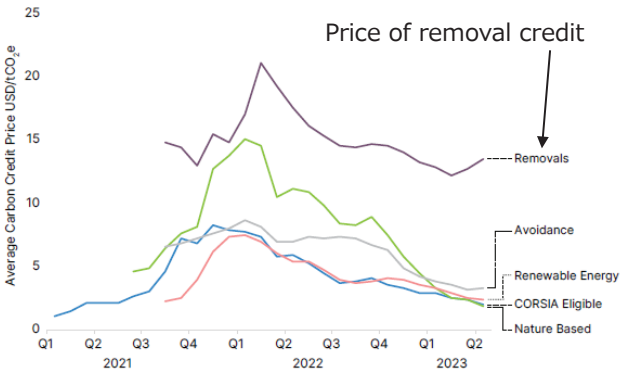
Development of removal credit system

- Offsetting residual emissions by NETs requires removal credit system.
- Removal credit has different characteristics from reduction credit.
  - Removal credit is already traded in the voluntary credit market at a higher price than reduction credit.
- MRV system of removed volume, certification system of carbon dioxide removal, and transaction rules for removal credit need to be established.

Reduction credit and removal credit

	Reduction credit	Removal credit
Traded CO_2	Reduced CO_2 volume from base case or pre-determined emissions quota	Reduced CO_2 volume from base case
Characteristic of traded CO_2	CO_2 that will be emitted	CO_2 that already exist in the atmosphere
Major means to generate credit	Efficiency improvement, renewable, nuclear	NETs
Time horizon	Relatively short-term	Relatively long-term

Price of different credits

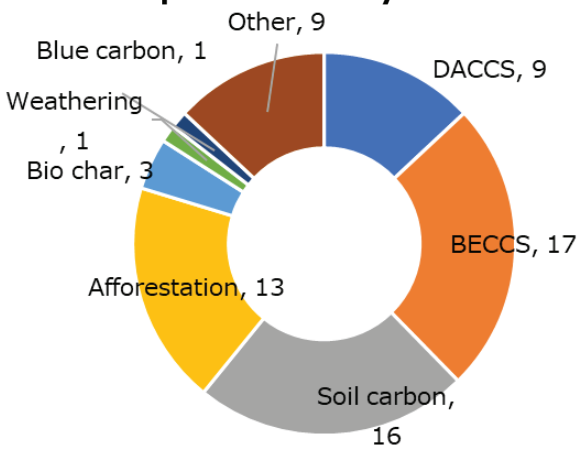


Source: World Bank, State and Trends of Carbon Pricing 2023

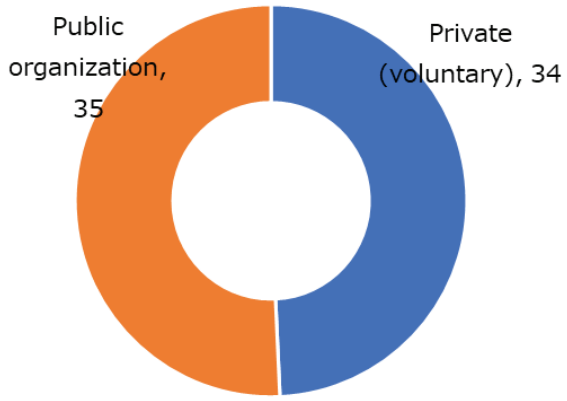
Measurement, Reporting, and Verification

- Currently, various MRV procedures for NETs coexist.
  - As of May 2023, there are 69 MRV procedures related to NETs worldwide.
- Establishment of MRV methods that are shared internationally is still a long way off, and future multilateral efforts (e.g., setting minimum standards, understanding the amount of removal over the lifecycle, etc.) are needed.

Number of MRV procedures by NETs



Number of MRV procedures by its owner



Note : "Other" includes Peatland rewetting, Wetland restoration, Woody biomass burial, and Bio oil.
Source : Leo Mercer and Josh Burke (2023) Strengthening MRV standards for greenhouse gas removals to improve climate change governance.

International Cooperation

- Shared international recognition of the values and the roles for NETs
  - Currently, only afforestation/forest management and BECCS are listed as NETs in the IPCC report.
  - Common understanding and the method of measuring the removal volume and the carbon fixation period of each NET need to be established.
- Development of MRV system
  - Accumulation and sharing of data on removal effect of each NET
  - Standardization of MRV methods (or agreement on minimum conditions)
  - Development of a method for measuring removal effect on life cycle basis
- Development of international certification and credit systems
  - Development of certification systems for carbon removal in each country and integration into international certification systems
  - Establishment of a cross-border removal credit system
  - Development of a mechanism to enable the counting of removal volume toward NDC
- Formation and promotion of international NETs projects
  - Pursue opportunities to apply low-cost NETs overseas and count the removal volume to NDCs
  - Establishment of rules for the use of NETs in the ocean

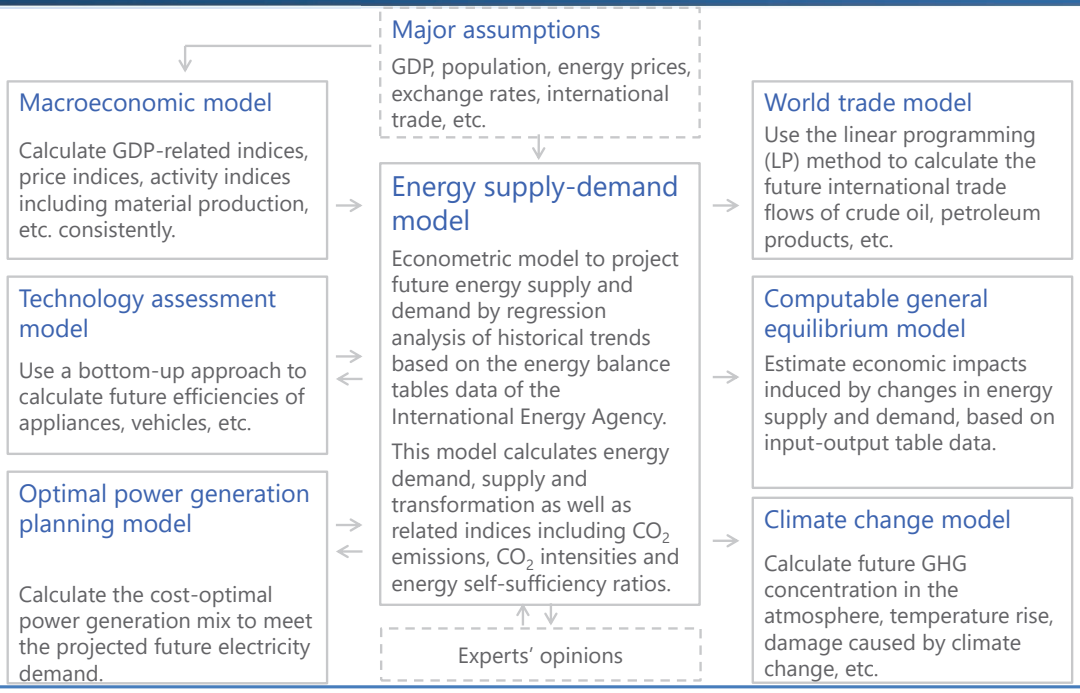
Reference materials

Geographical coverage

- Countries/regions in the world are geographically aggregated into 42 regions.
- Especially the Asian energy supply/demand structure is considered in detail, aggregating the area into 15 regions. That of the Middle East is also aggregated into eight regions.

Source: [Map] www.craftmap.box-i.net

Modelling framework

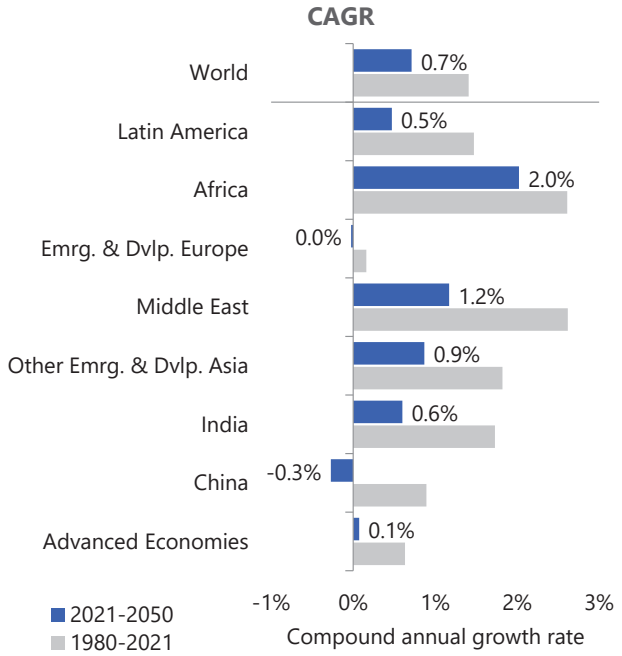


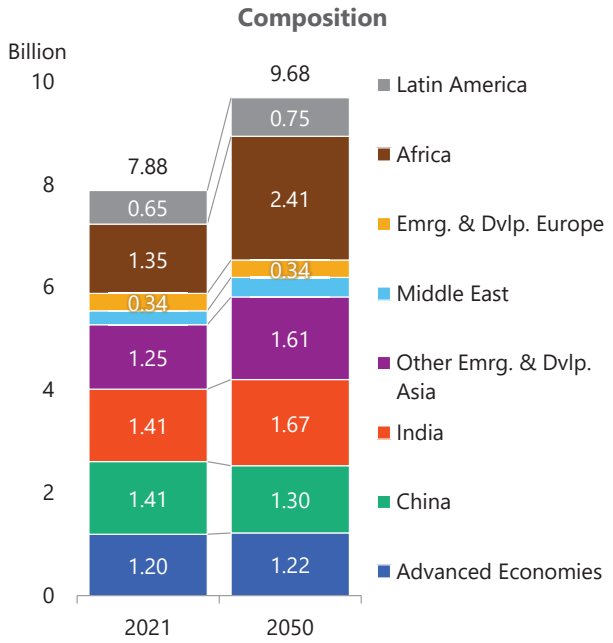
Basic scenarios in IEEJ Outlook

	Reference Scenario	Advanced Technologies Scenario
	Reflects past trends with technology progress and current energy policies, without any aggressive policies for low-carbon measures	Assumes introduction of powerful policies to address energy security and climate change issues with the utmost penetration of low-carbon technologies
Socio-economic structure	Stable growth led by developing economies despite slower population growth. Rapid penetration of energy consuming appliances and vehicles due to higher income.	
International energy prices	**Oil** supply cost increases along with demand growth. **Natural gas** prices converge among Europe, North America and Asia markets. **Coal** price decreases due to request for decarbonization.	All prices decrease along with decrease in demand due to progress in energy saving and request for decarbonization
Energy and environmental policies	Gradual reinforcement of low-carbon policies with past pace	Further reinforcement of domestic policies along with international collaboration
Energy and environmental technologies	Improving efficiency and declining cost of existing technology with past pace	Further declining cost of existing and promising technology

Assumptions

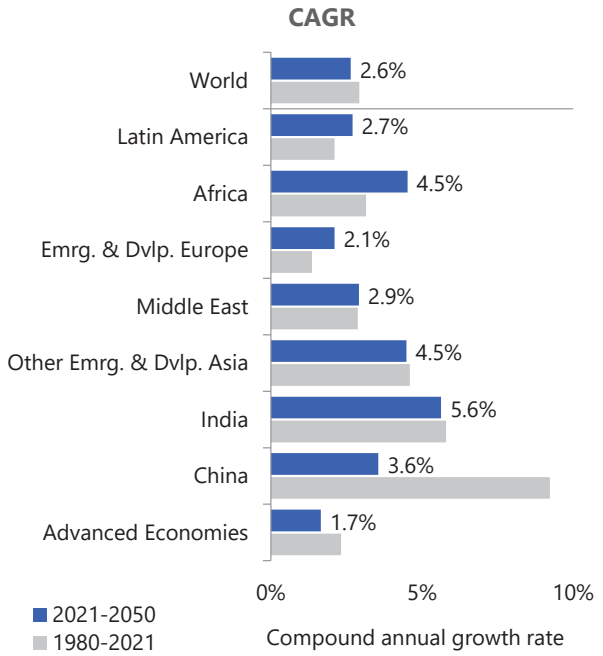
Population

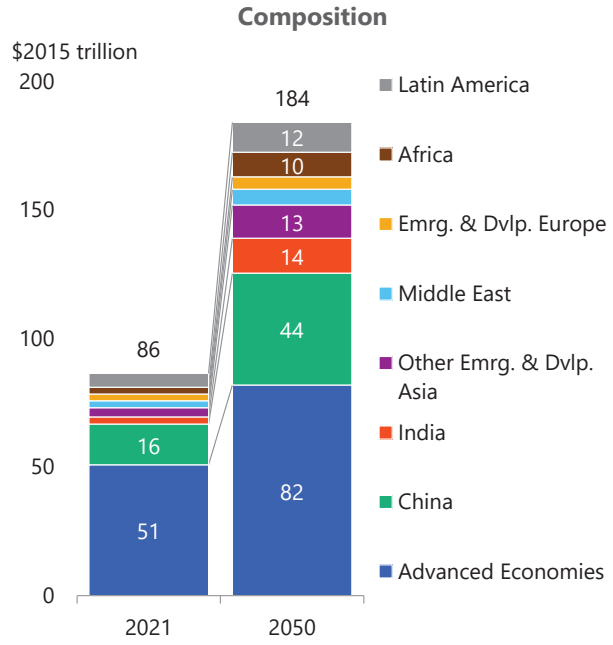




Assumptions

Real GDP

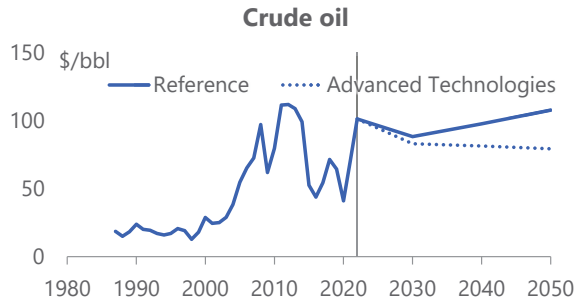


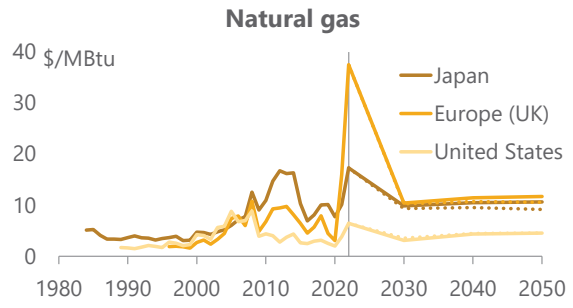


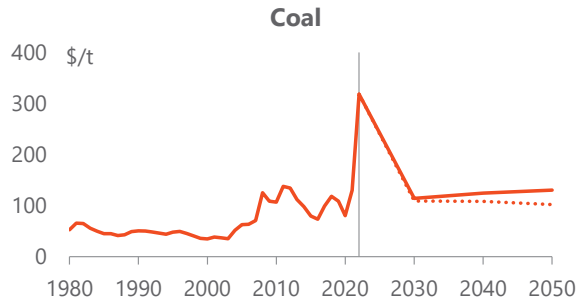
Assumptions

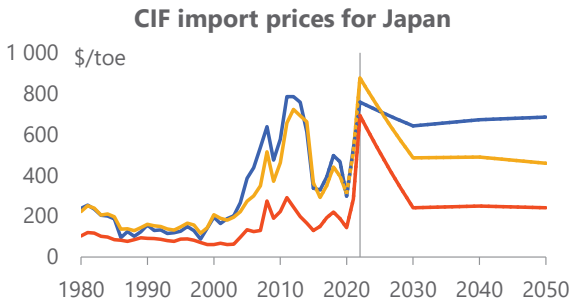
International energy prices

Reference : ———
Advanced Technologies : ·····









Note: Historical prices are nominal. Assumed future prices as real in $2022.

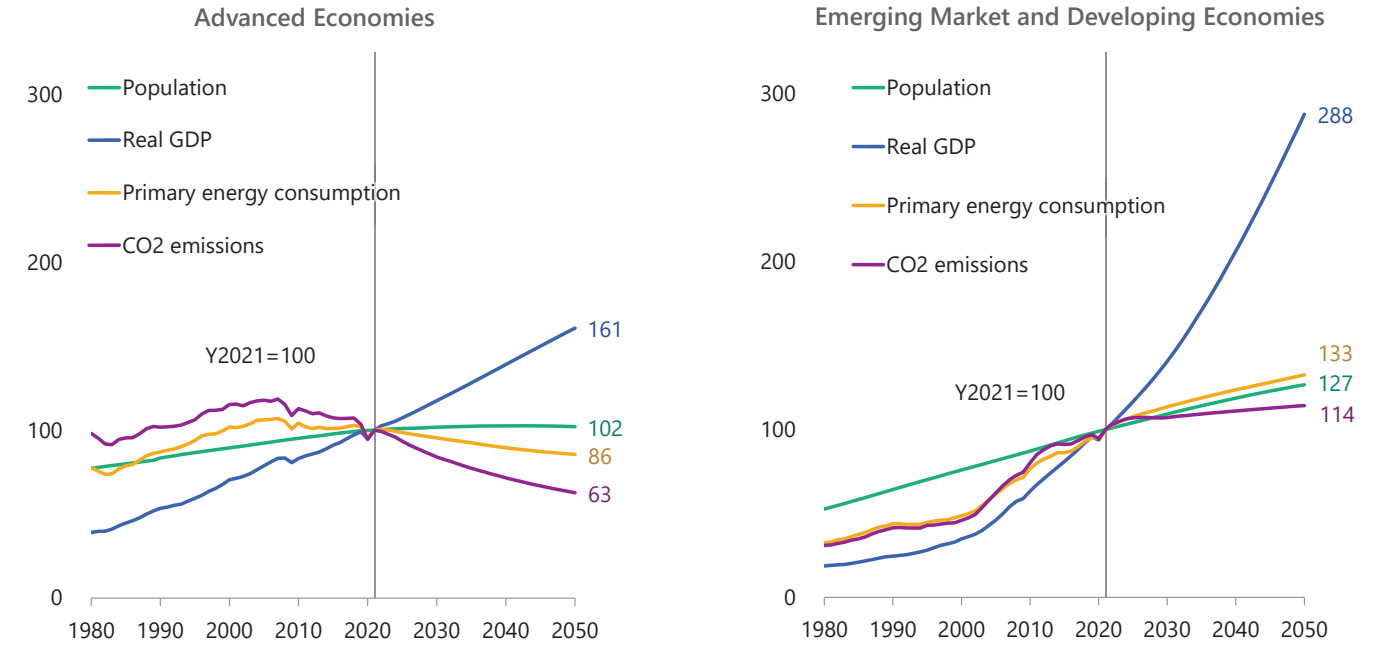
Assumptions

Energy and environmental technology

			2021	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency	Industry	Intensity in steel industry (ktoe/kt)	0.261	0.254	0.202	100% penetration of Best Available Technology by 2050.
		Intensity in non-metallic minerals industry	0.091	0.070	0.055	
	Transport	Electrified vehicle share in passenger car sales	12%	66%	96%	Cost reduction of electrified vehicles. Promotion measures including fuel supply infrastructure.
		Average fuel efficiency in new passenger car (km/L)	15.0	27.4	46.6	*electrified vehicle includes hybrid vehicle, plug-in hybrid vehicle, electric vehicle and fuel-cell vehicle
	Buildings	Residential total efficiency (Y2021=100)	100	154	202	Efficiency improvement at twice the speed for newly installed appliance, equipment and insulation.
		Commercial total efficiency	100	153	204	Electrification in space heating, water heater and cooking (clean cooking in developing regions).
	Power	Thermal generation efficiency (Power transmission end)	37%	44%	49%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology	Biofuels for transport (Mtoe)		94	138	236	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
	Nuclear power generation capacity (GW)		429	506	802	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
	Wind power generation capacity (GW)		842	3 904	5 170	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
	Solar PV power generation capacity		883	7 104	9 883	
	Thermal power generation capacity with CCS (GW)		0	0	1 110	Installing CCS after 2030 (regions which have storage potential except for aquifer).
	Zero-emission generation ratio (incl. CCS)		38%	59%	88%	Efficient operation of power system including international power grid.

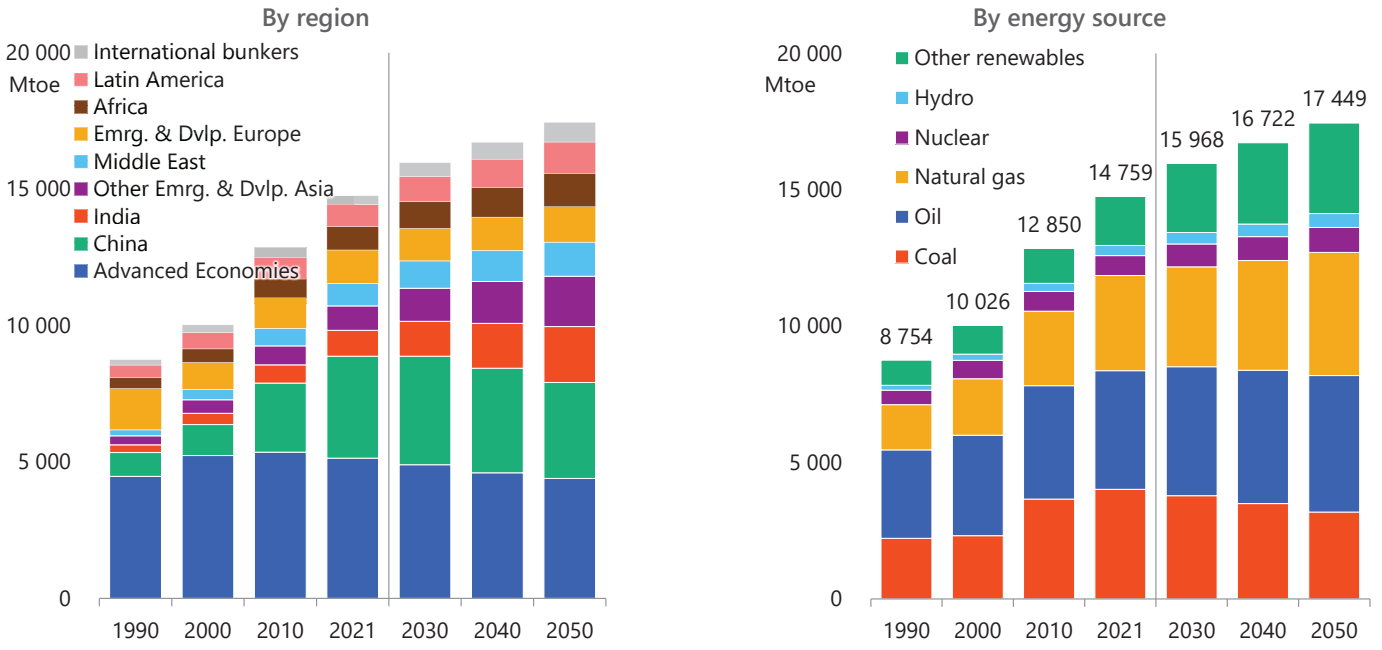
Reference Scenario

Population, GDP, energy and CO_2



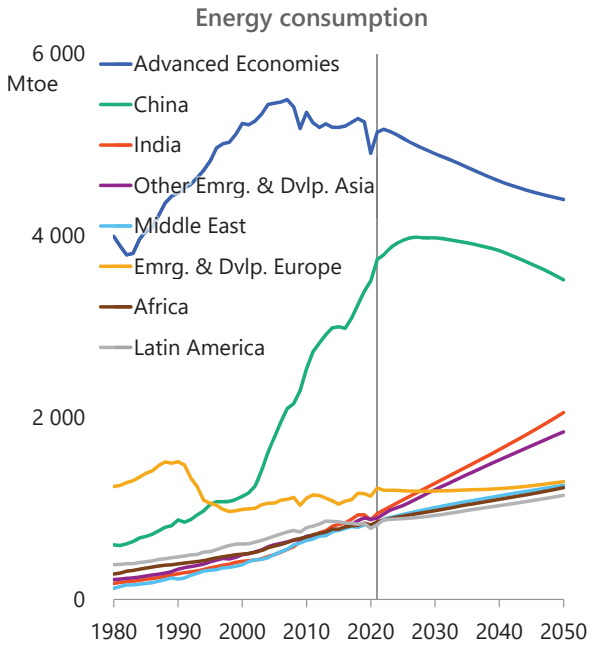
Reference Scenario

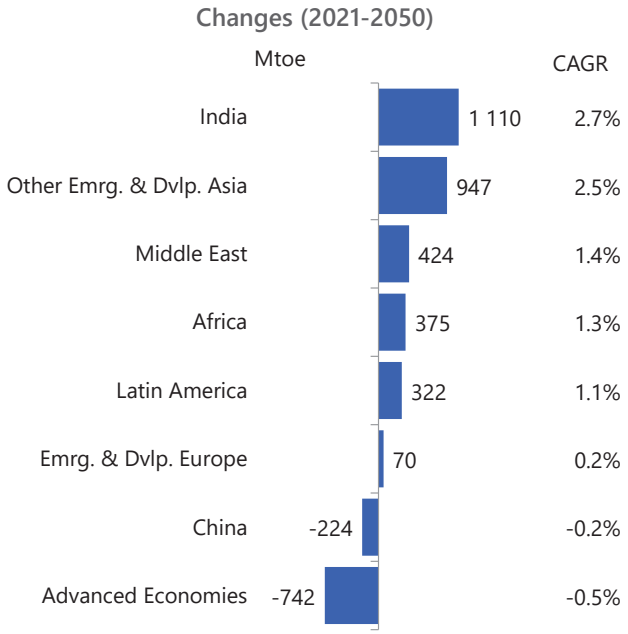
Primary energy consumption



Reference Scenario

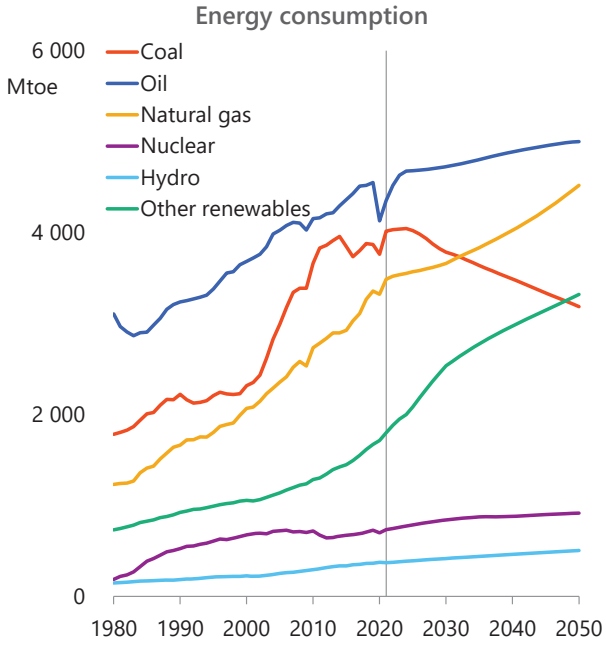
Primary energy consumption (by region)

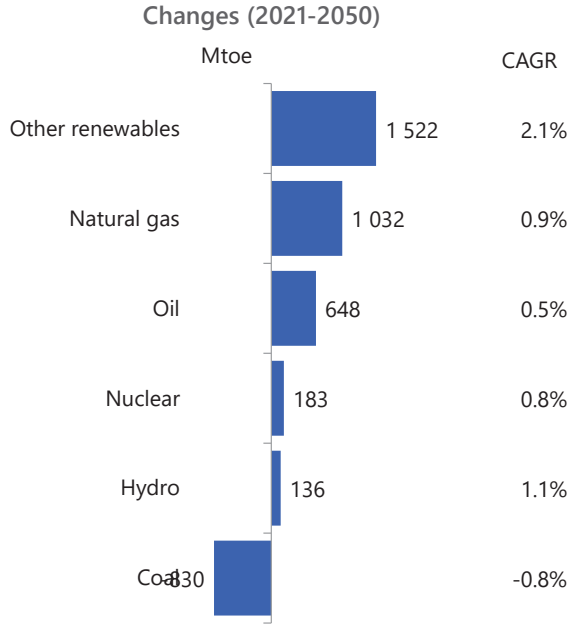




Reference Scenario

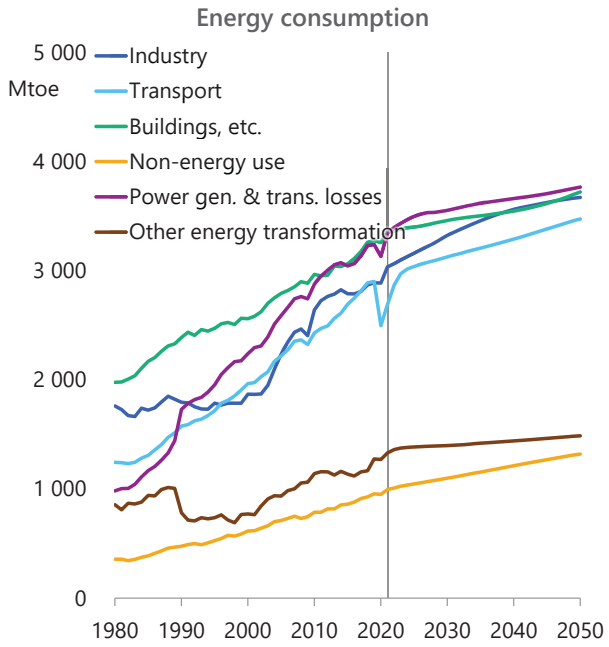
Primary energy consumption (by energy source)

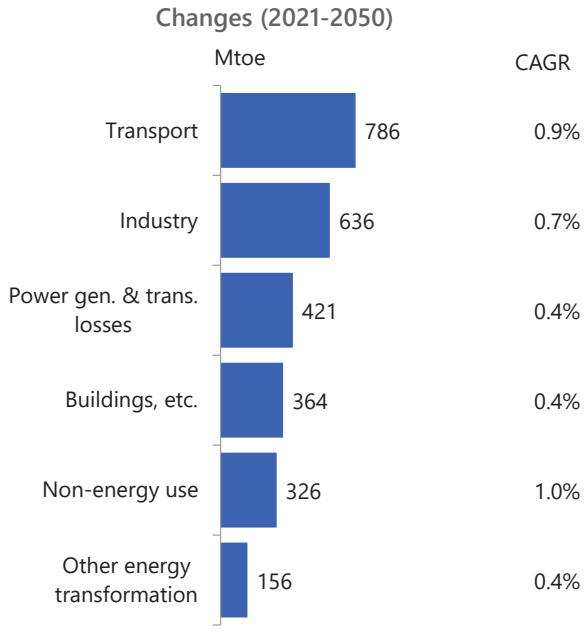




Reference Scenario

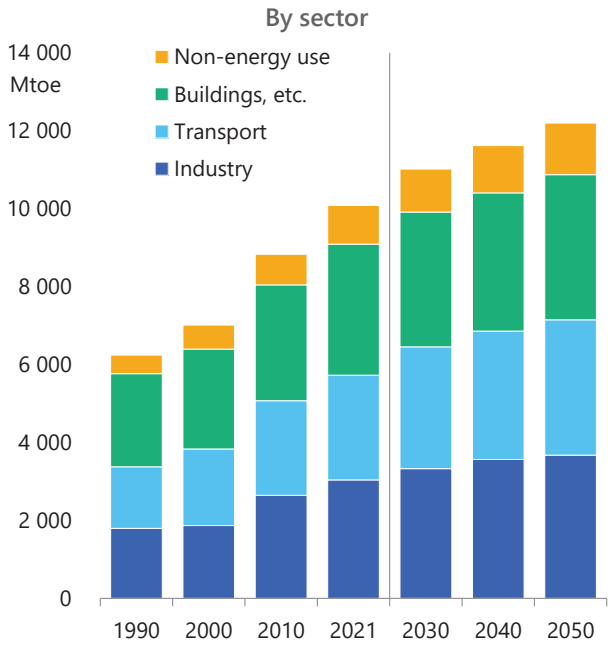
Primary energy consumption (by sector)

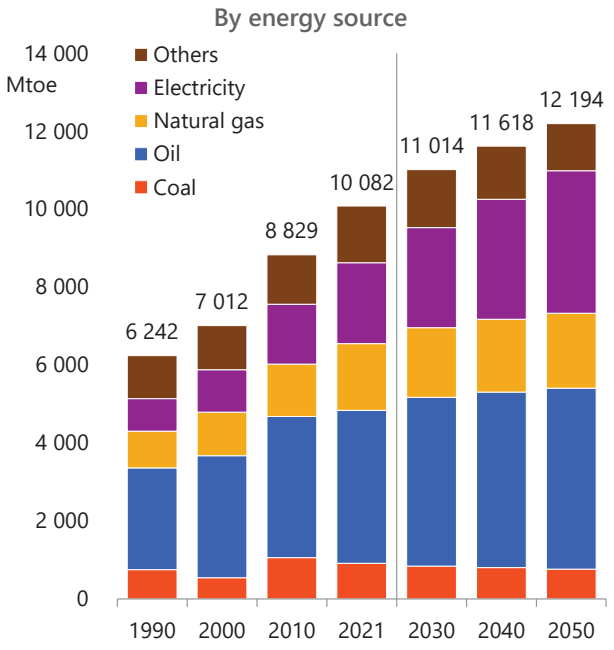




Reference Scenario

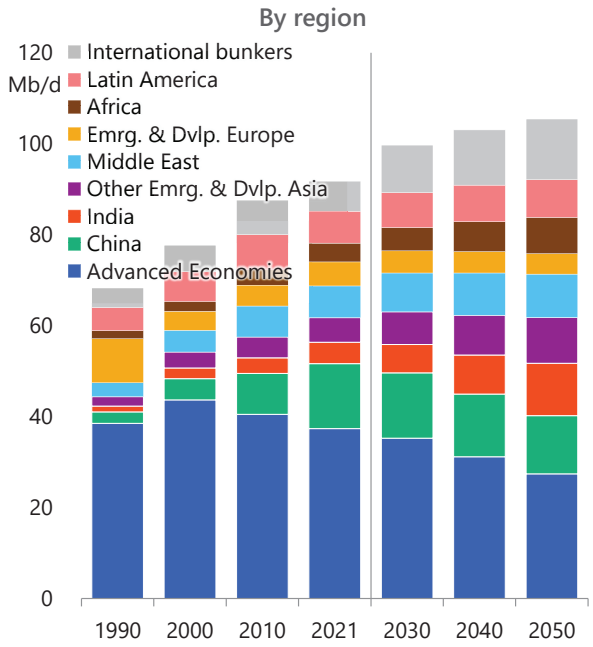
Final energy consumption

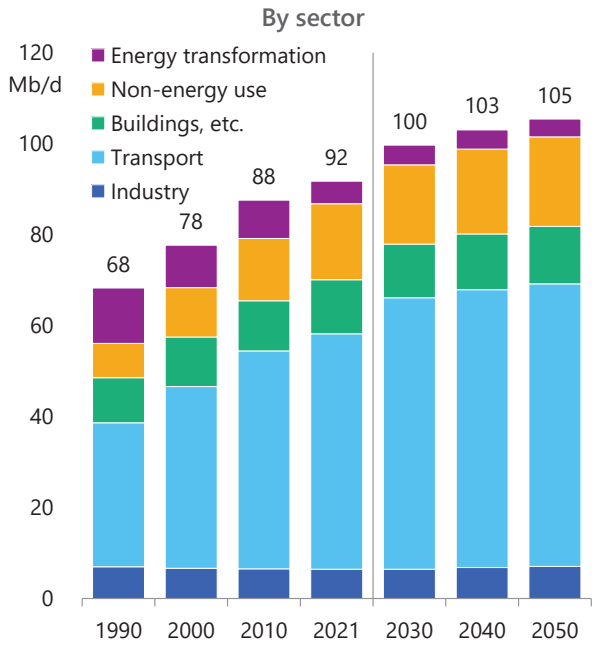




Reference Scenario

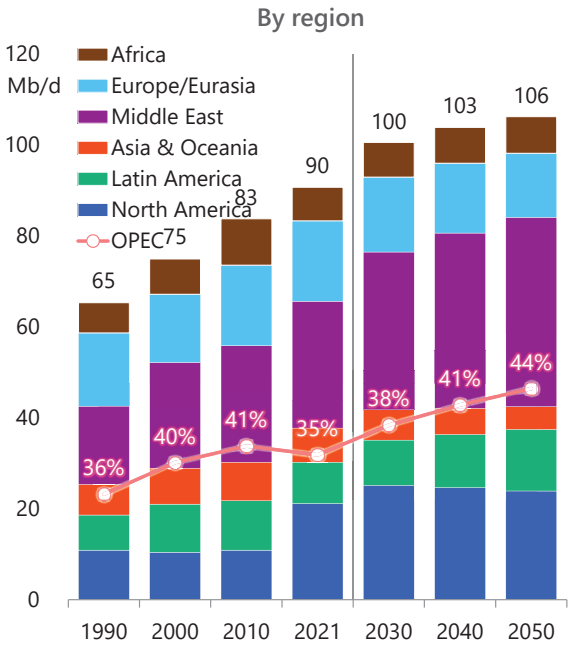
Oil consumption

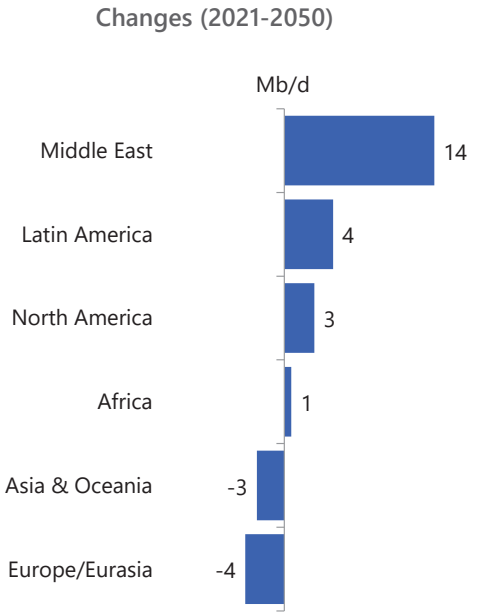




Reference Scenario

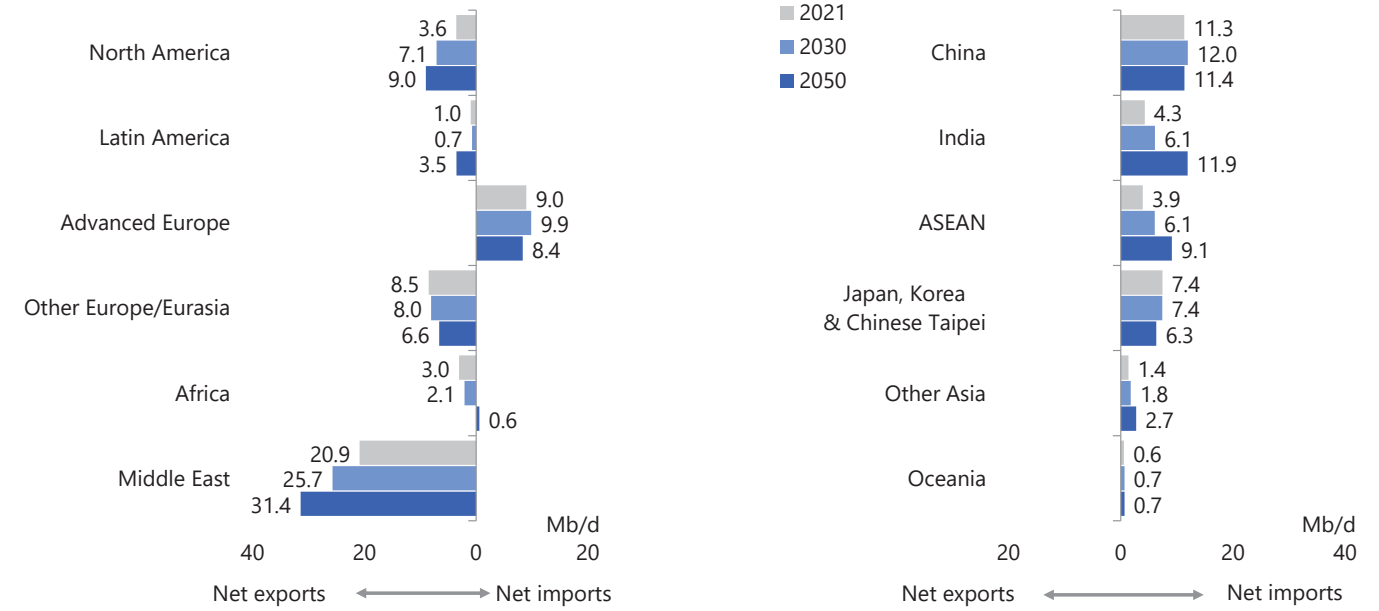
Crude oil production





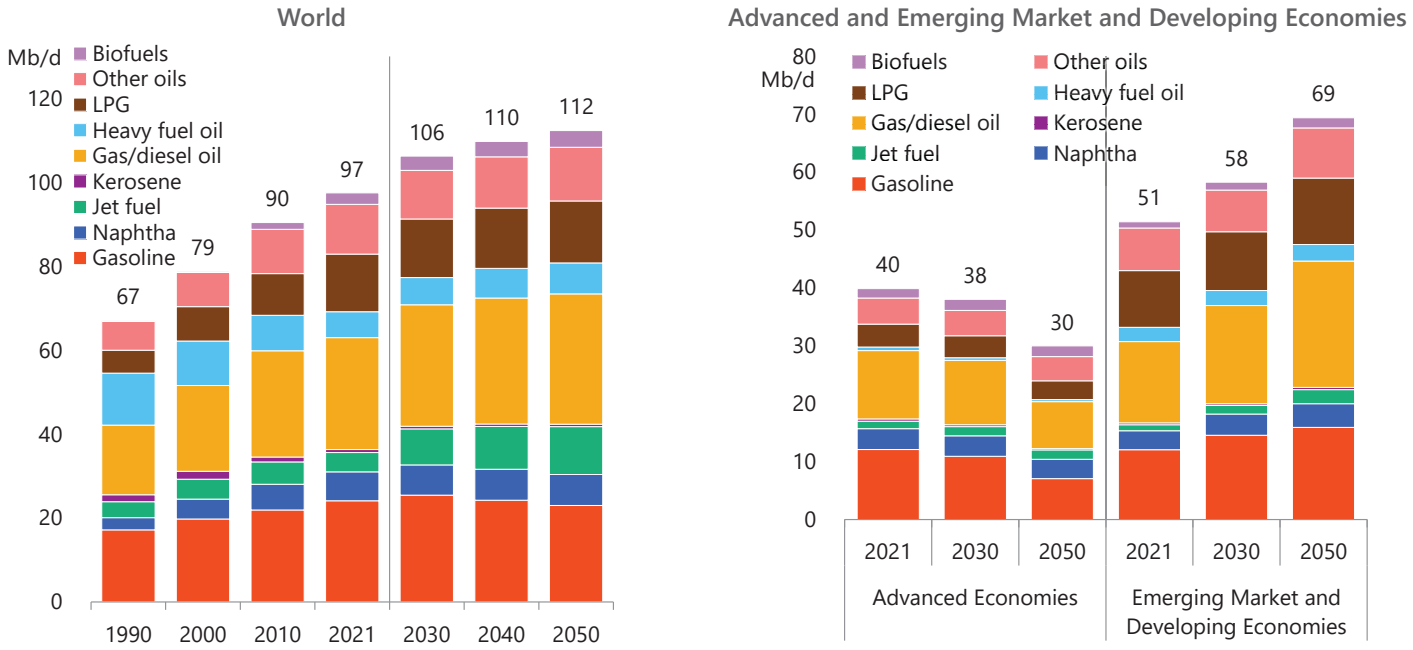
Reference Scenario

Net exports and imports of oil



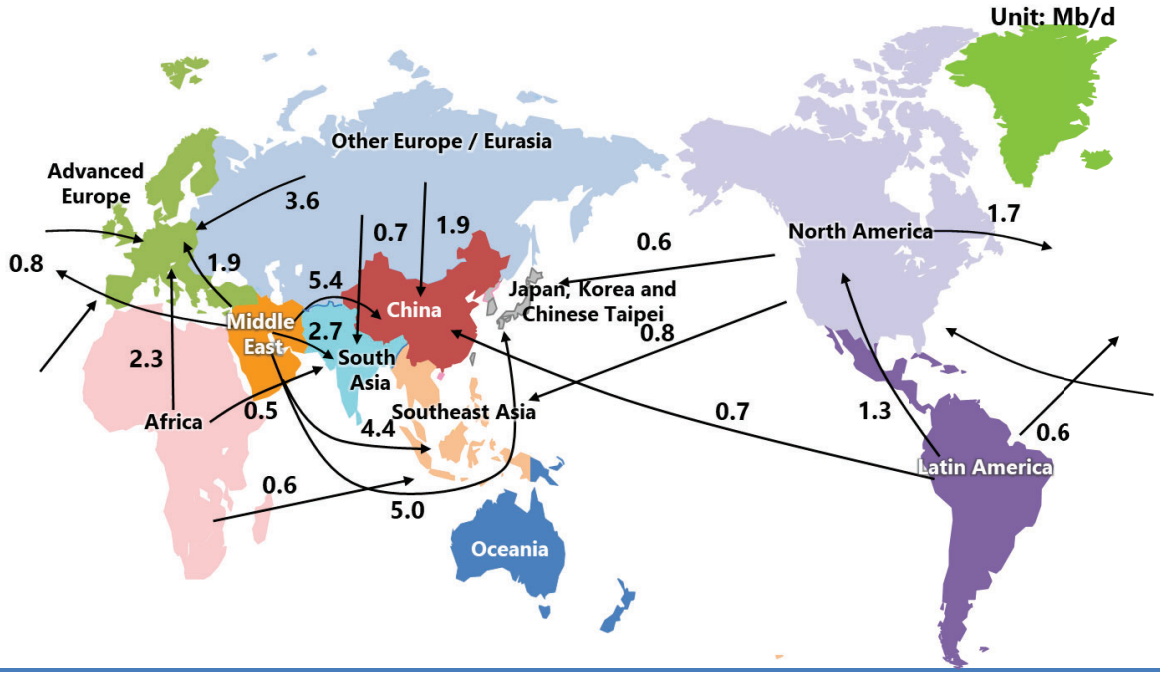
Reference Scenario

Petroleum product demand



Note: Other oils includes crude oil (direct consumption), asphalt, refinery gas, gas-liquefied oil [GTL], etc.

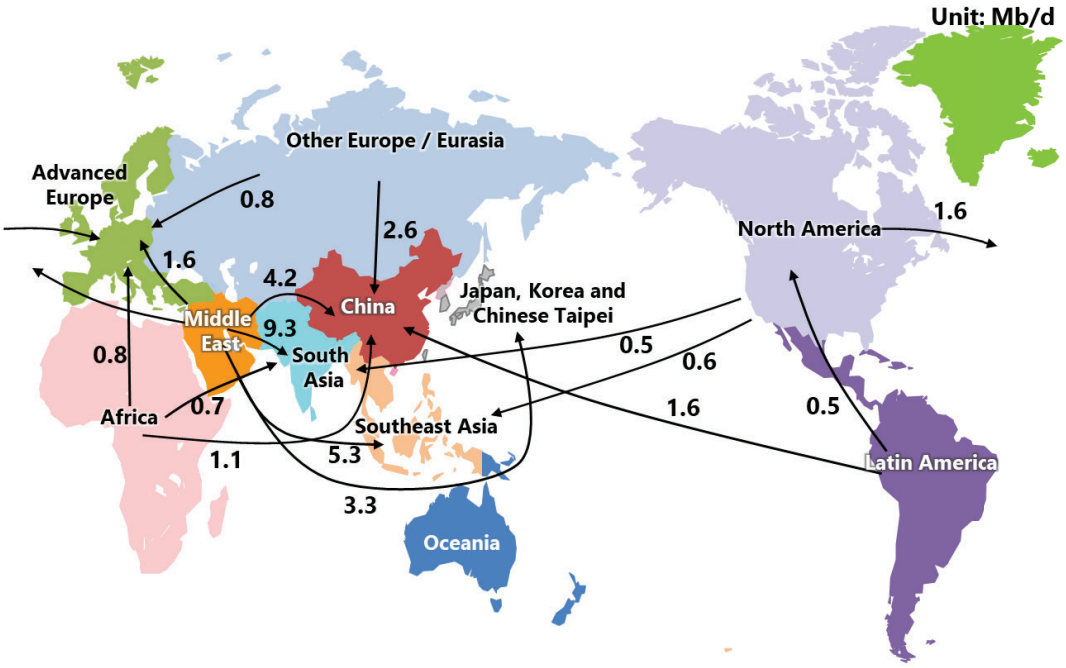
Major trade flows of crude oil (2022)



Note: 0.5 Mb/d or more are shown

Reference Scenario

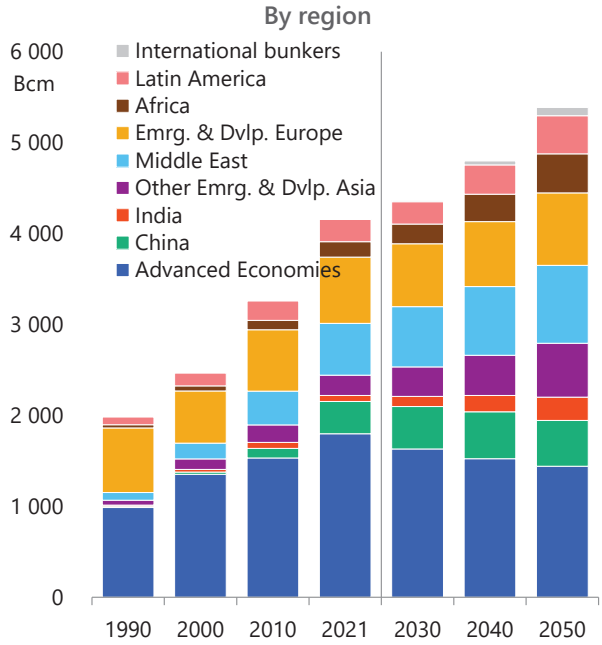
Major trade flows of crude oil (2050)

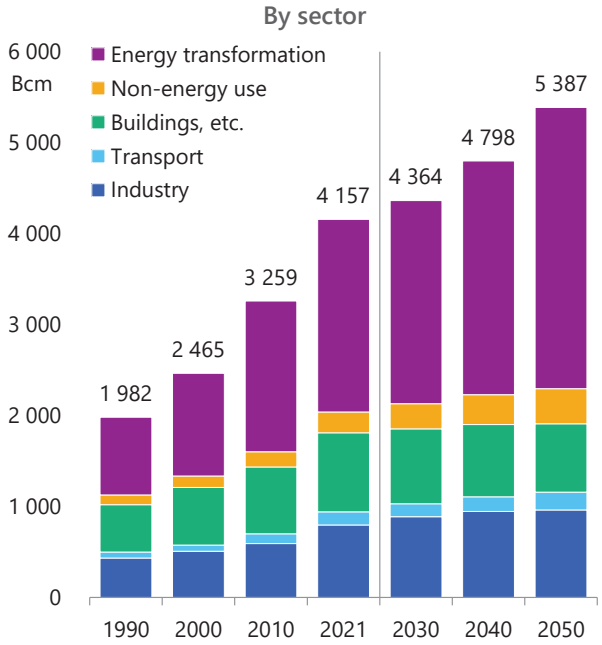


Note: 0.5 Mb/d or more are shown

Reference Scenario

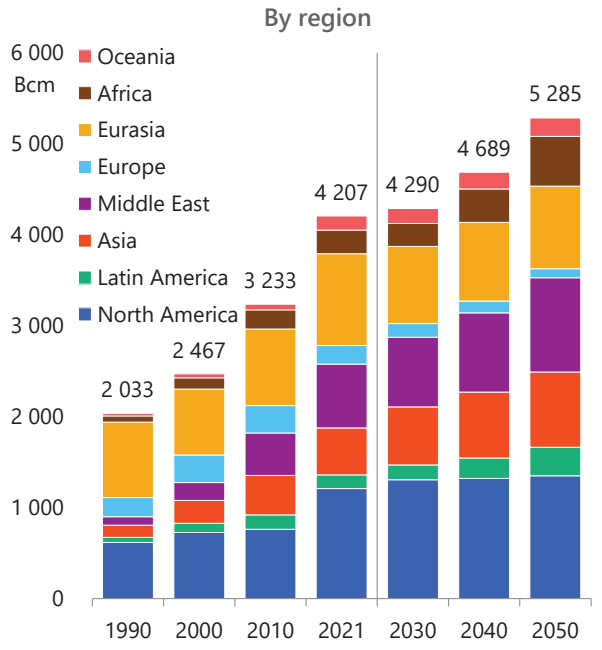
Natural gas consumption

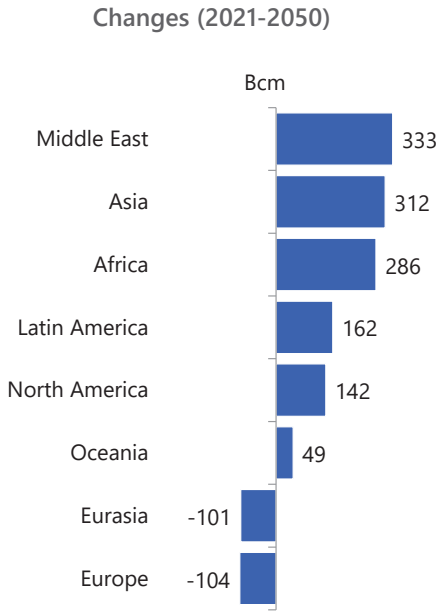




Reference Scenario

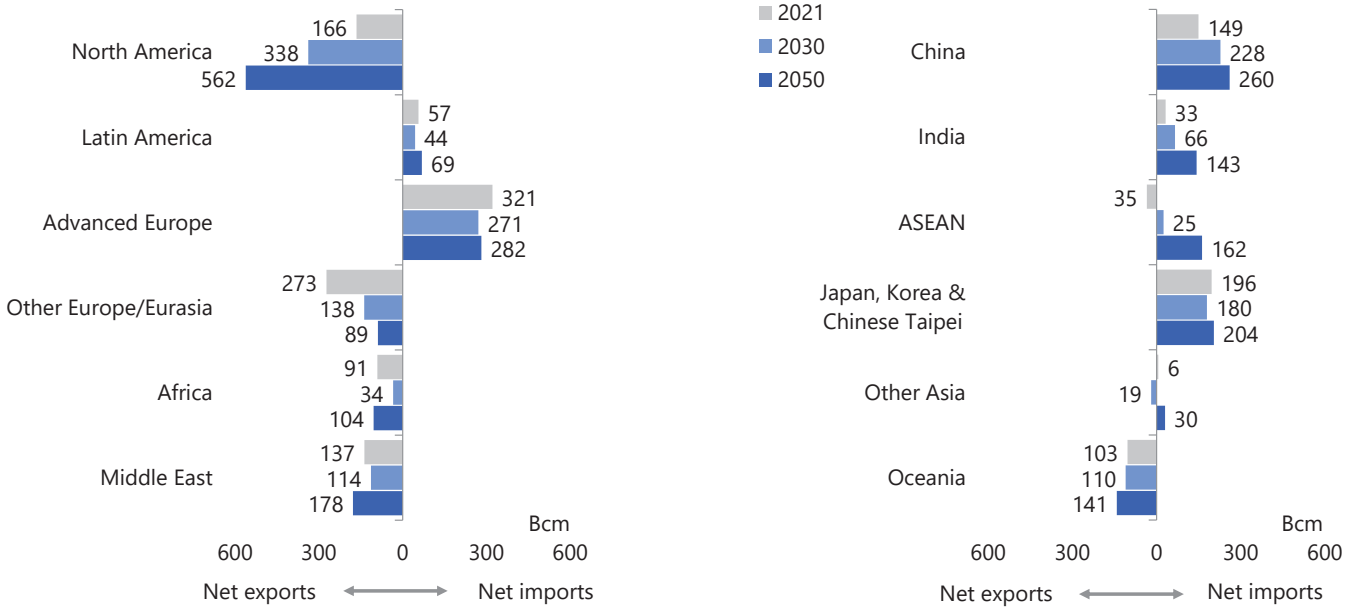
Natural gas production





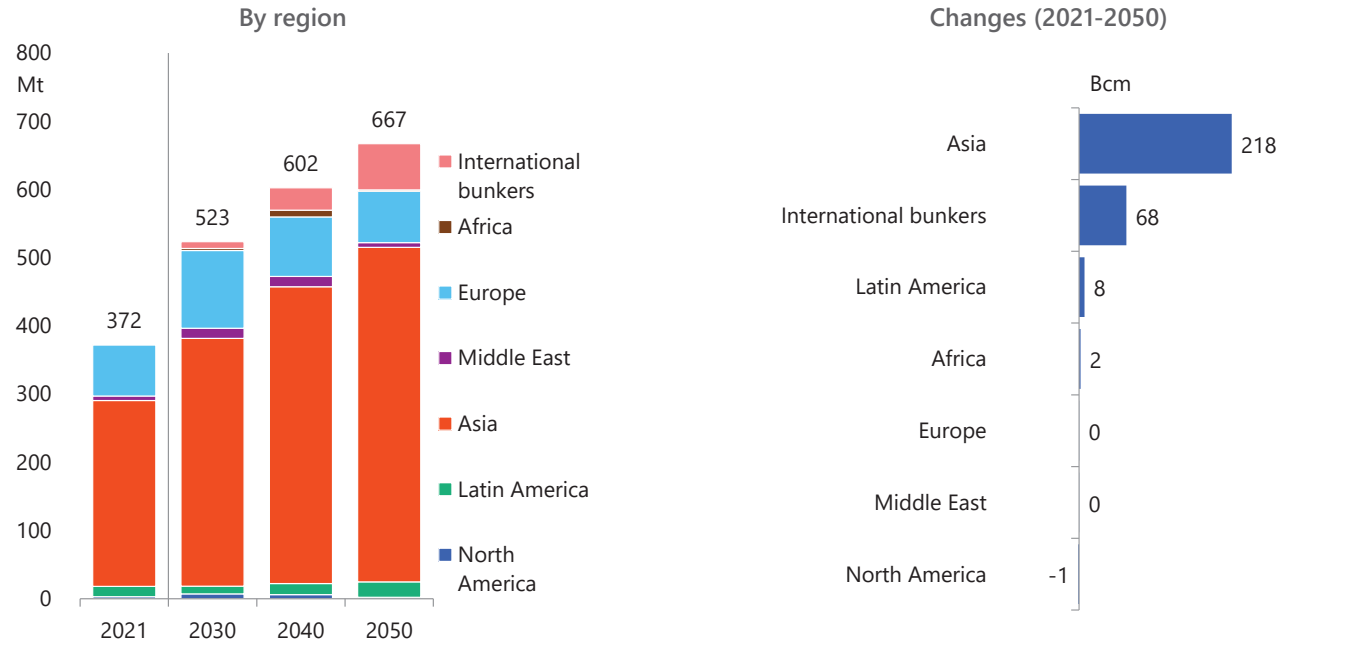
Reference Scenario

Net exports and imports of natural gas

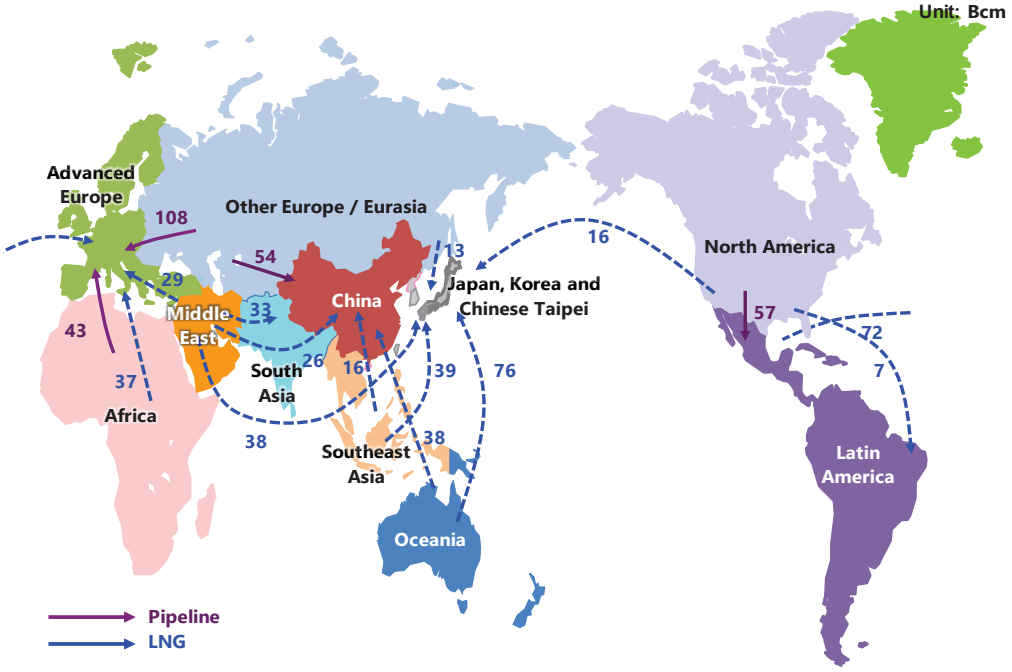


Reference Scenario

LNG demand



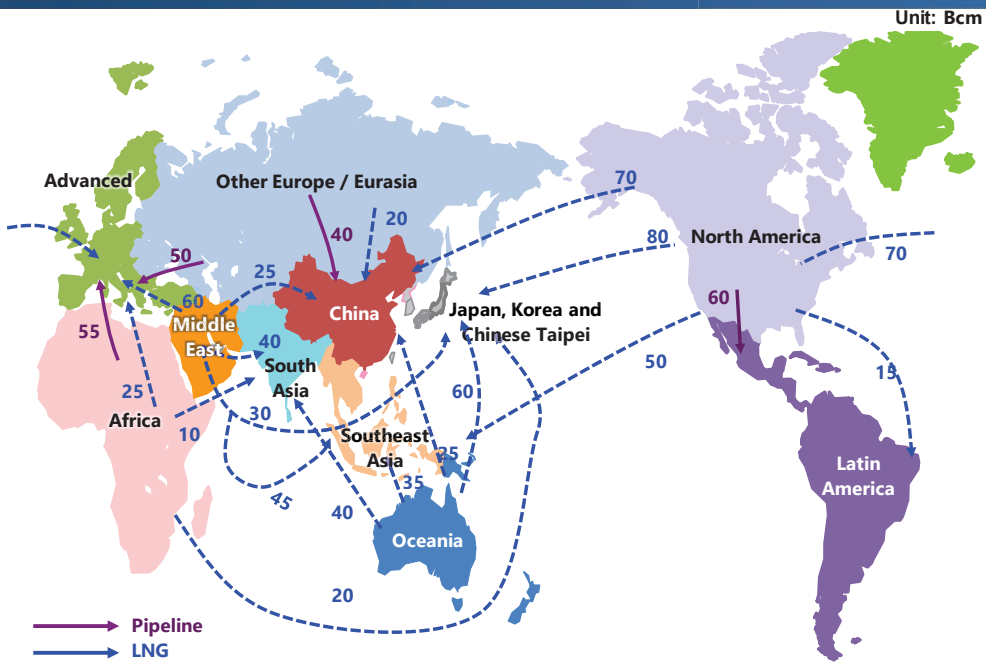
Major trade flows of natural gas (2022)



Note: This figure shows the main interregional trade and does not include the total trade volume. There is a possibility that some pipeline gas may be replaced by LNG.

Reference Scenario

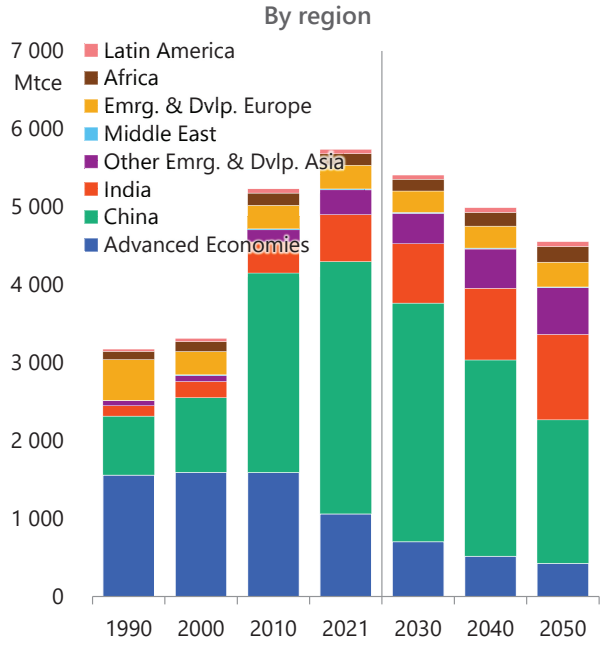
Major trade flows of natural gas (2050)

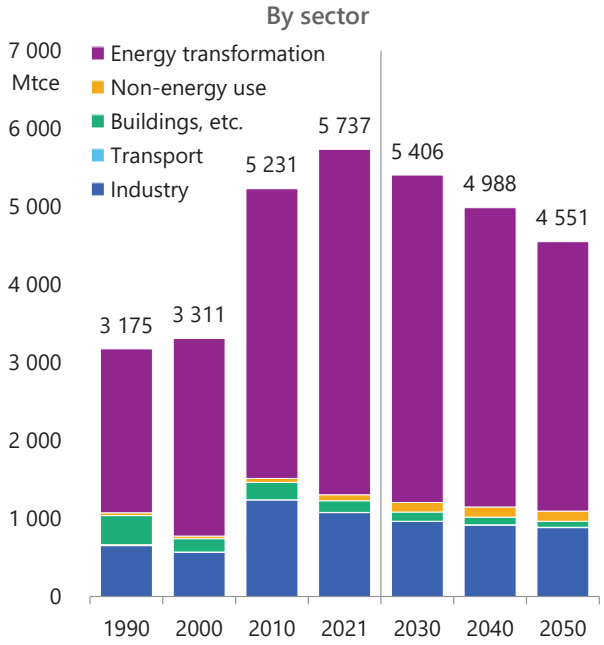


Note: This figure shows the main interregional trade and does not include the total trade volume. There is a possibility that some pipeline gas may be replaced by LNG.

Reference Scenario

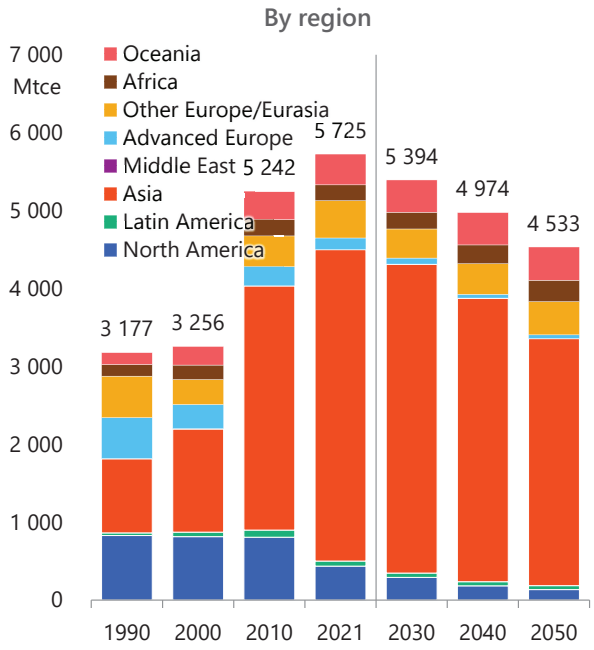
Coal consumption

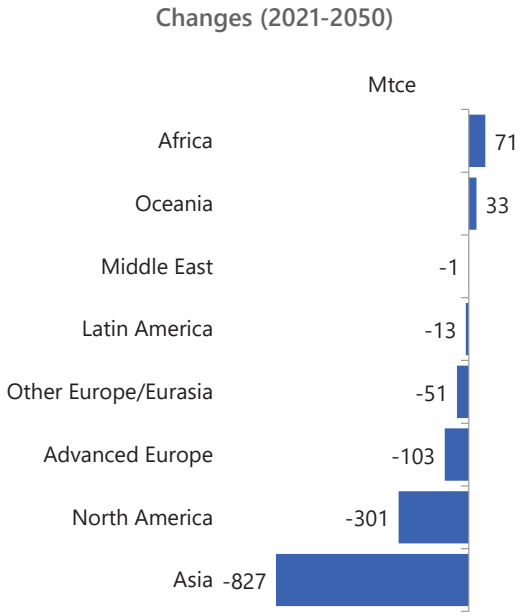




Reference Scenario

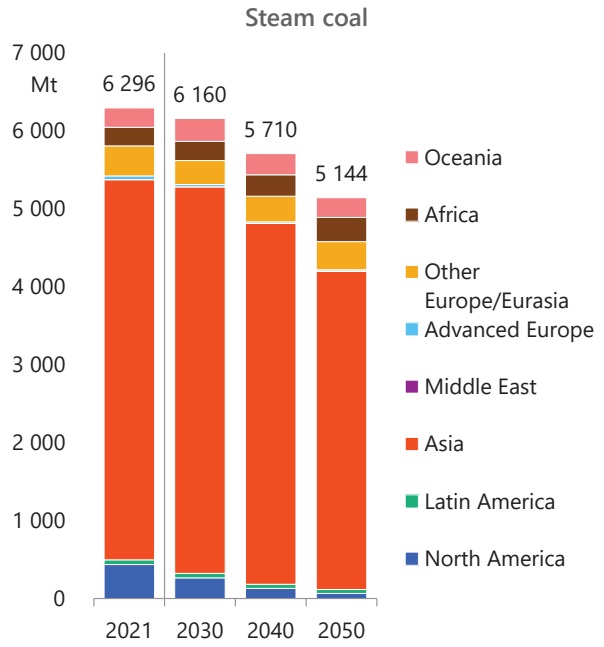
Coal production

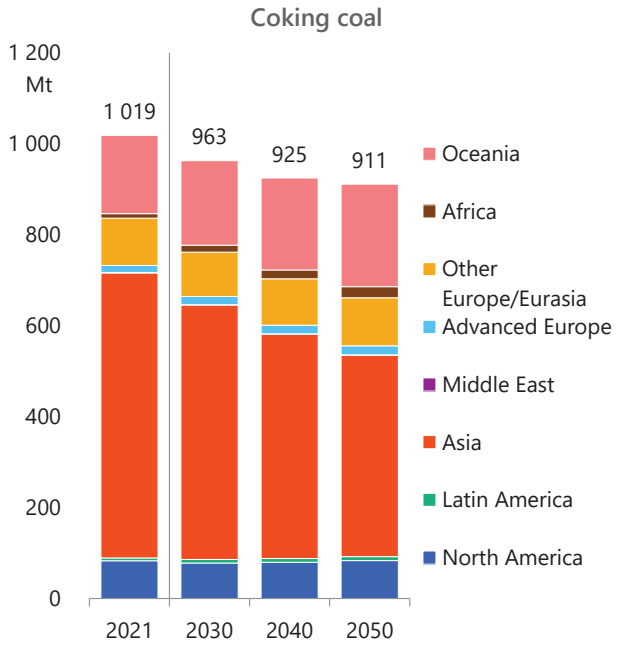




Reference Scenario

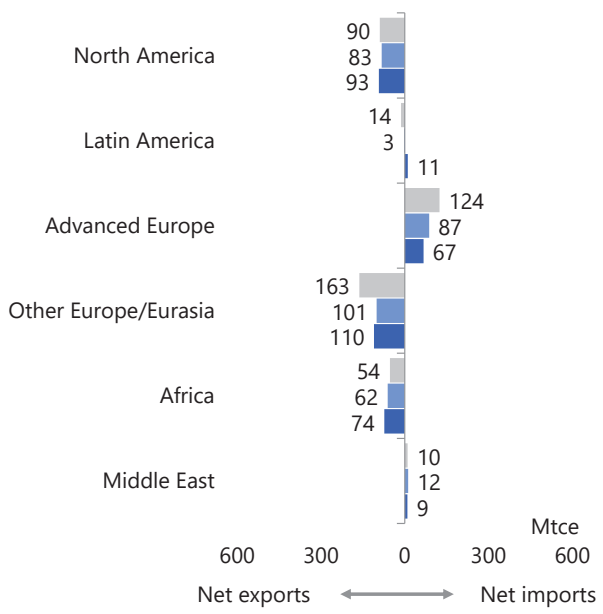
Coal production (steam and coking coal)

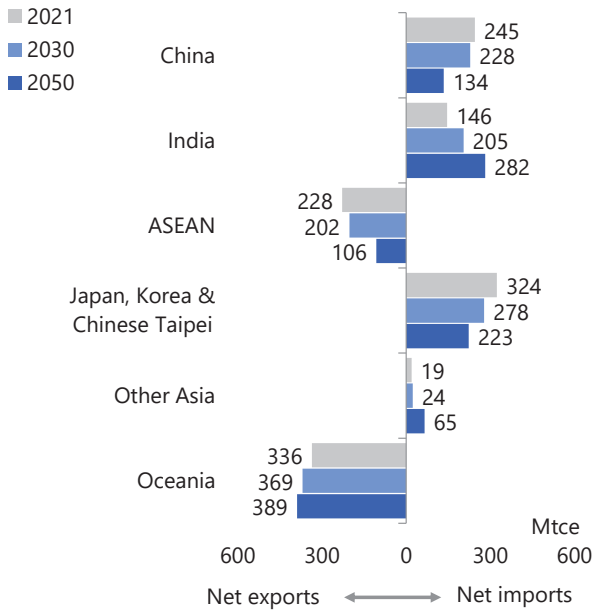




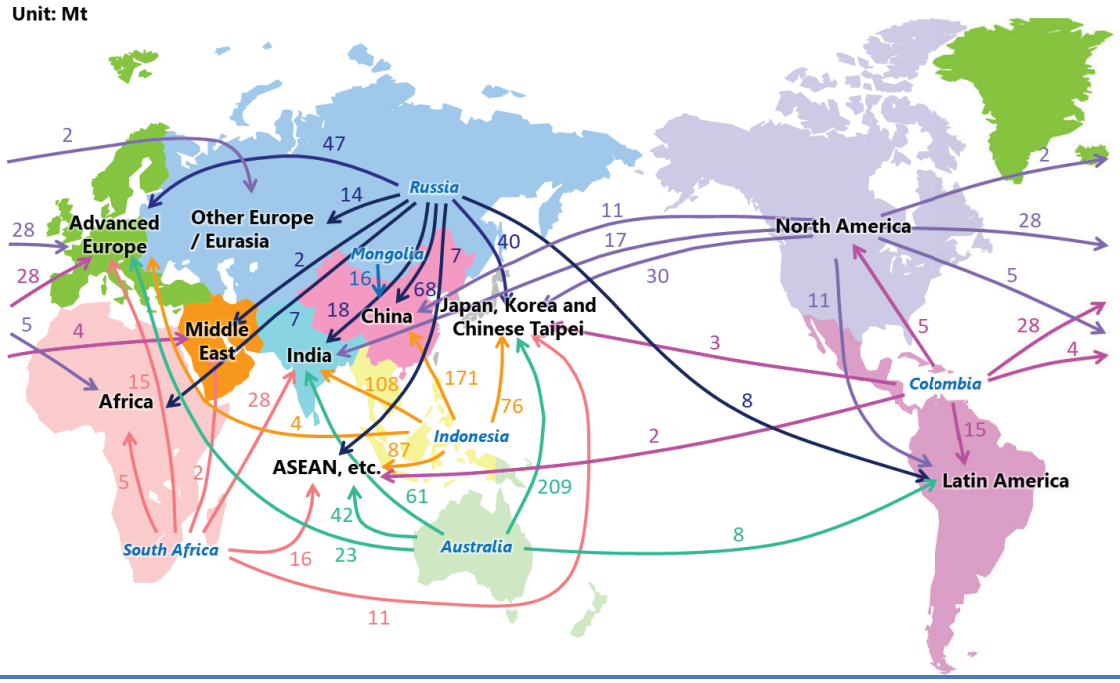
Reference Scenario

Net exports and imports of coal





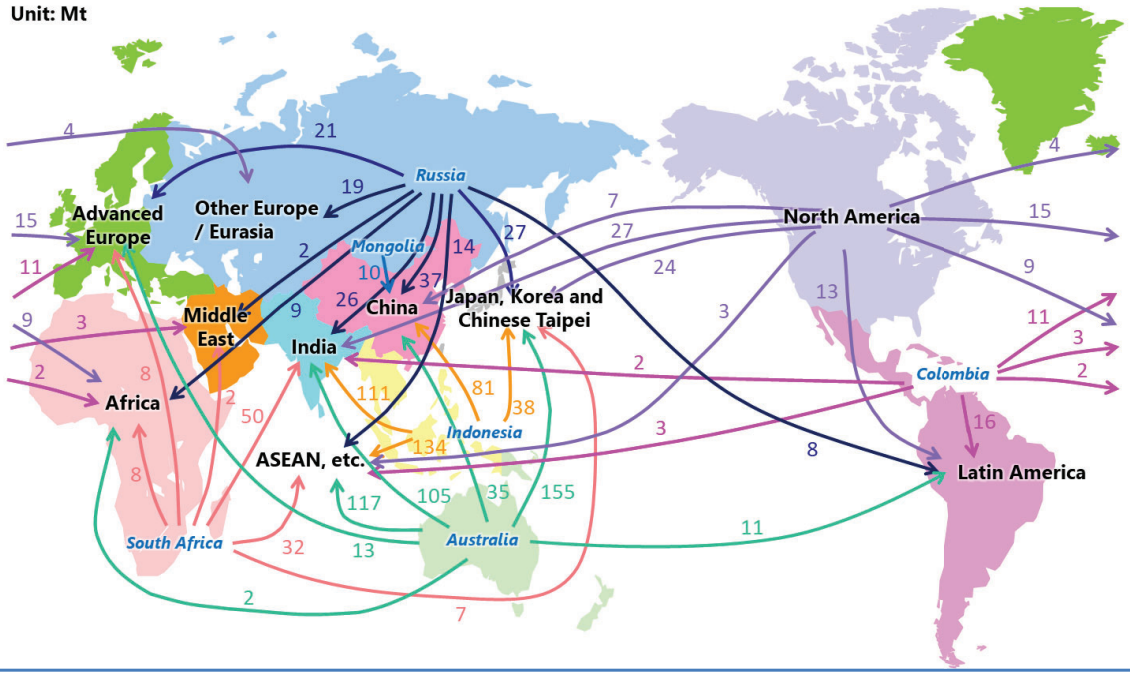
Major trade flows of steam and coking coal (2022)



Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique.
Source: Estimated from IEA "Coal Information 2022", "TEX Report", etc.

Reference Scenario

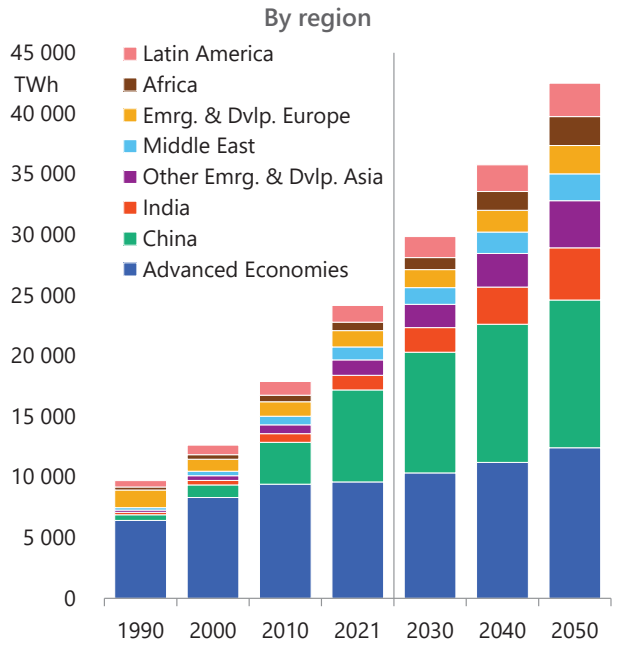
Major trade flows of steam and coking coal (2050)

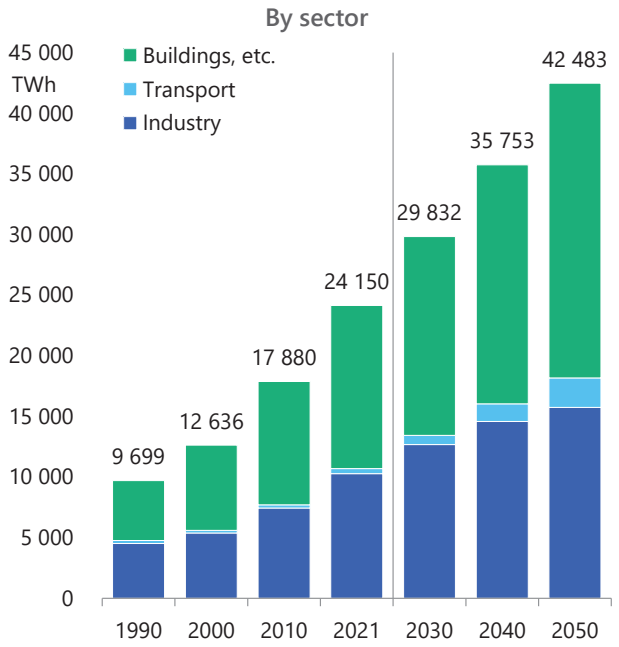


Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique.

Reference Scenario

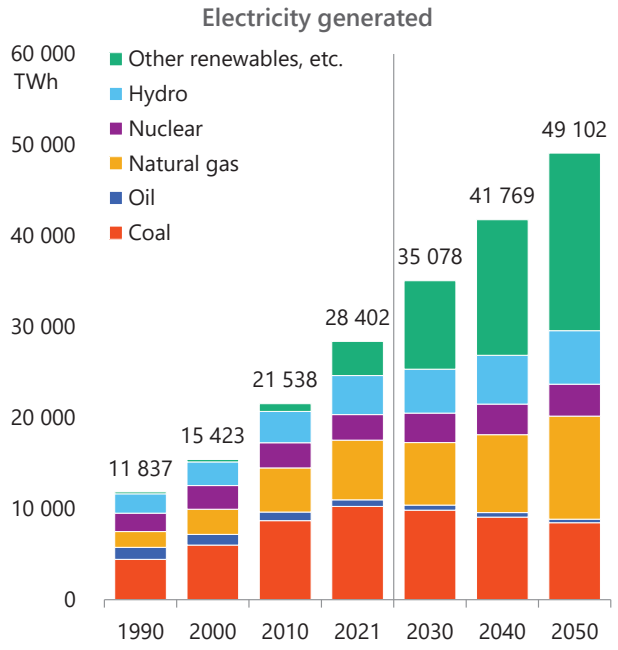
Final consumption of electricity

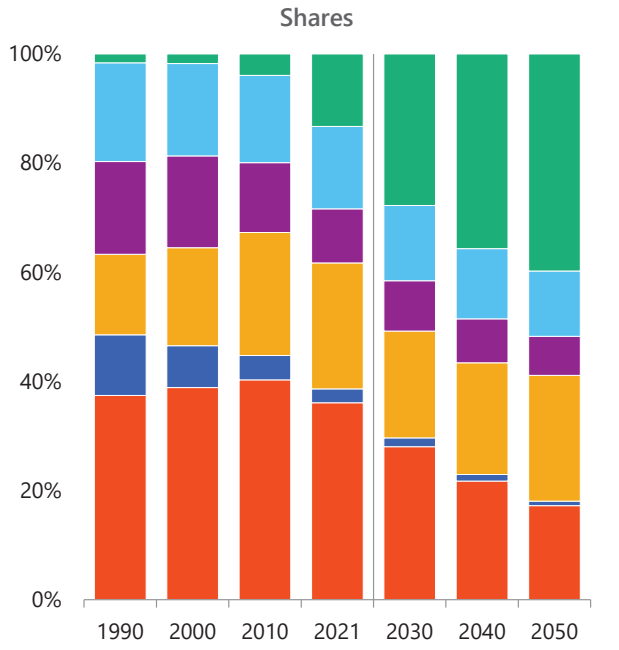




Reference Scenario

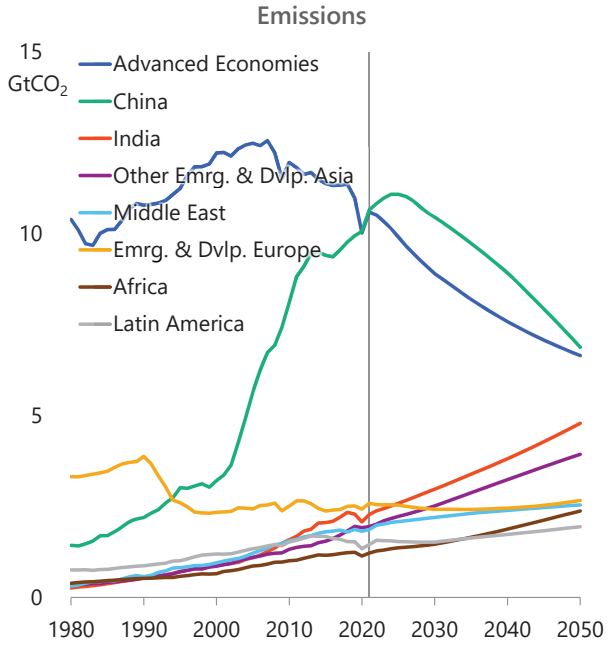
Power generation mix

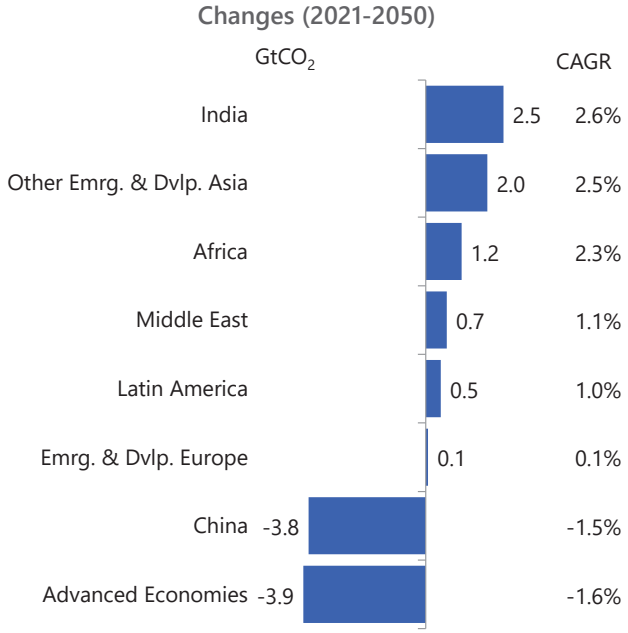




Reference Scenario

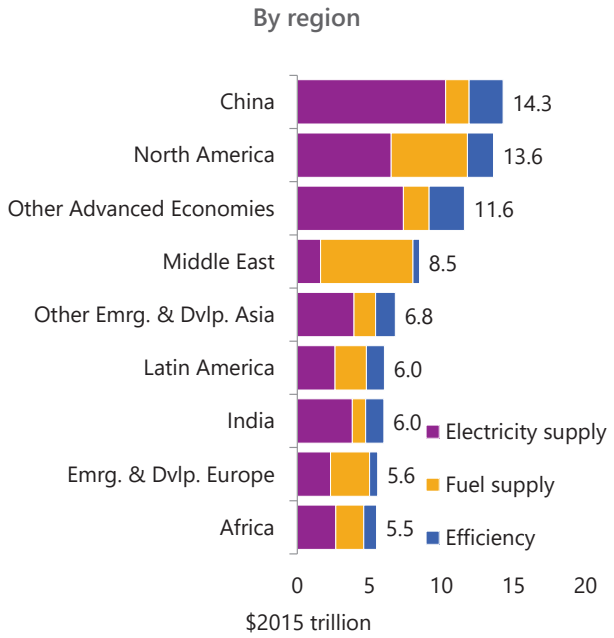
Energy-related CO_2 emissions

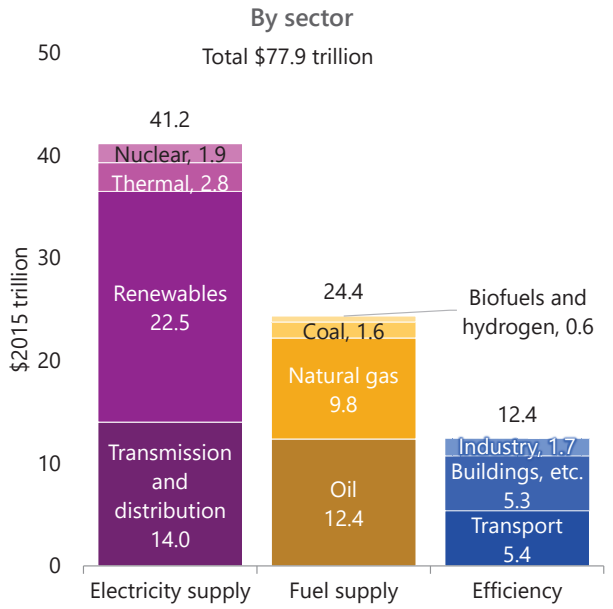




Reference Scenario

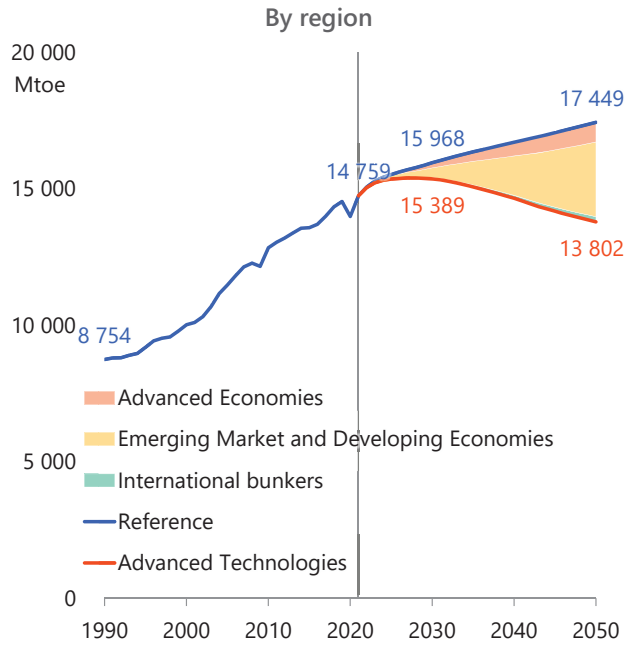
Energy-related investments (2022–2050)

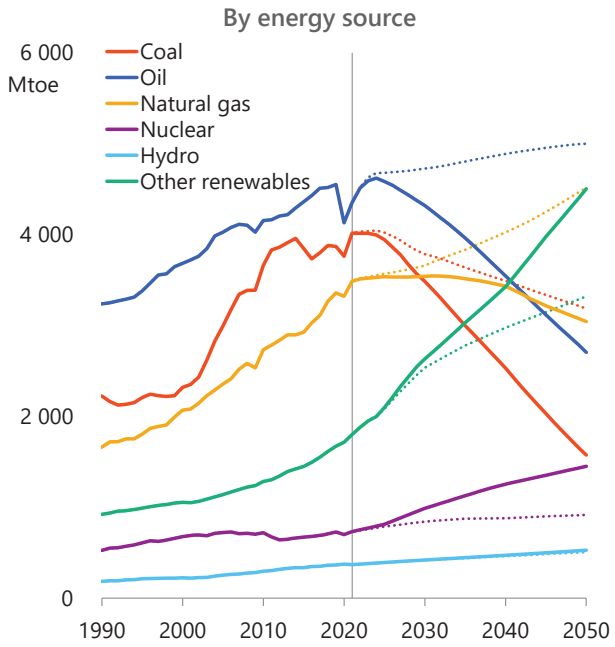




Advanced Technologies Scenario

Primary energy consumption

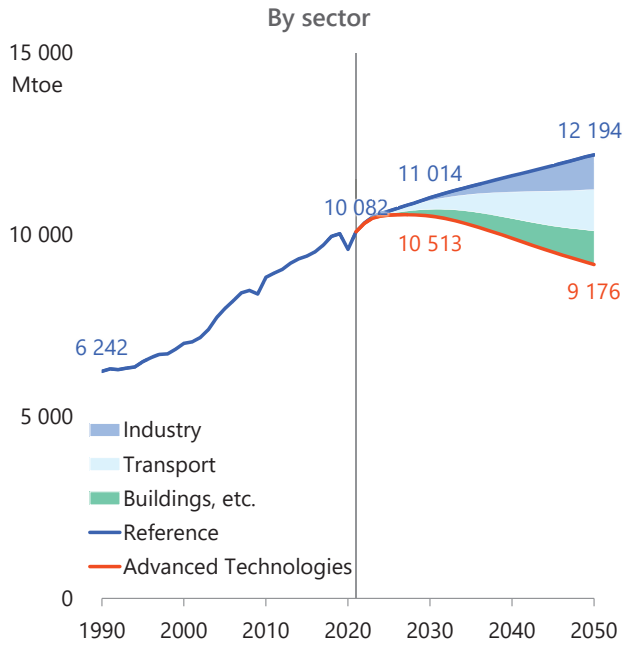


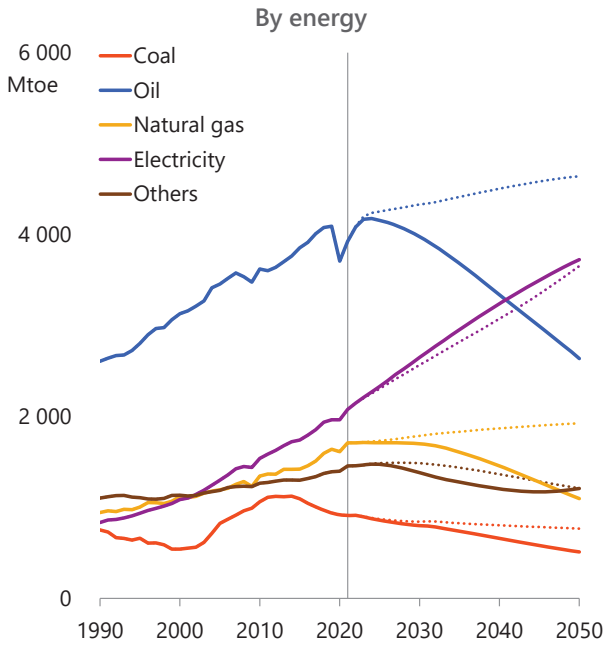


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Advanced Technologies Scenario

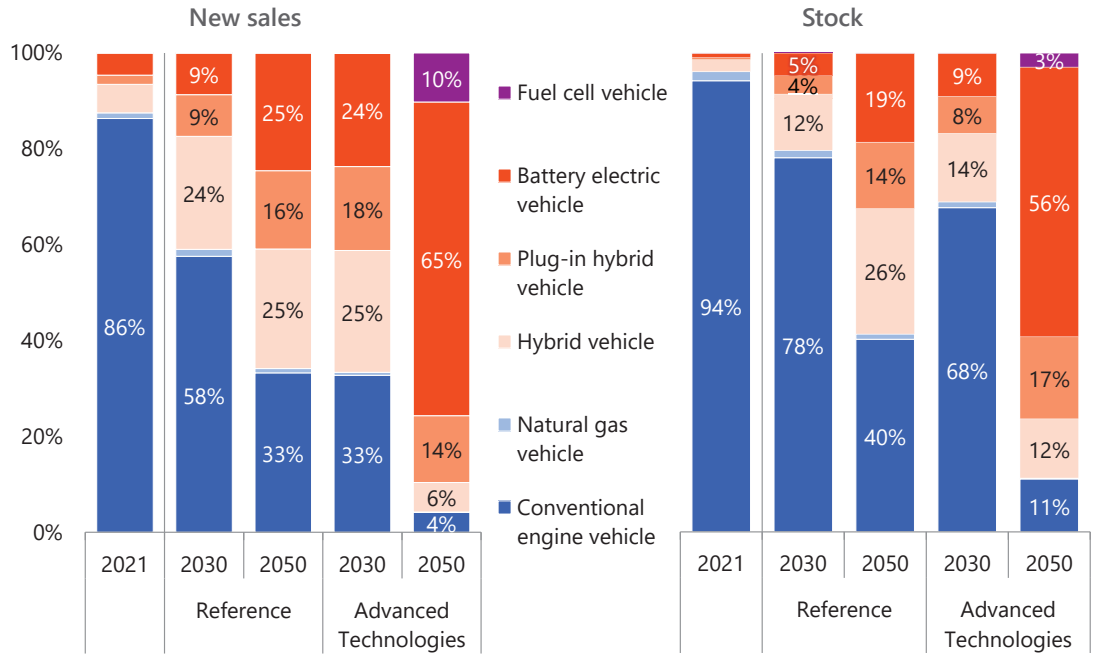
Final energy consumption





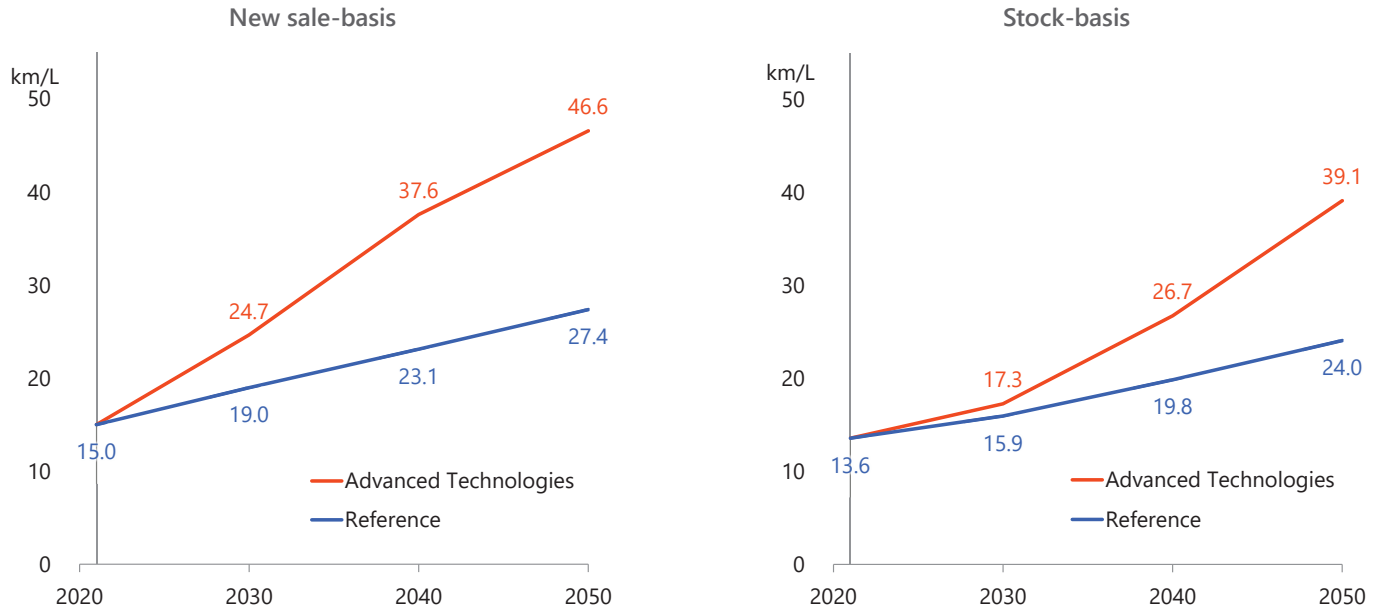
Advanced Technologies Scenario

Share of passenger vehicle



Advanced Technologies Scenario

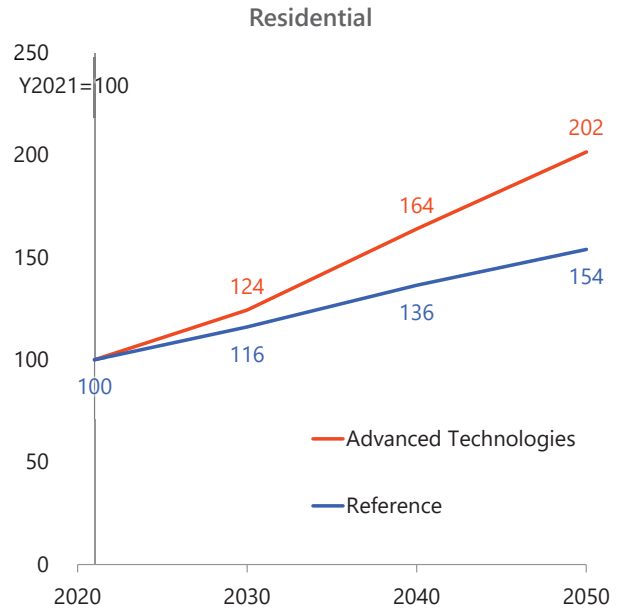
Fuel efficiency of passenger vehicle

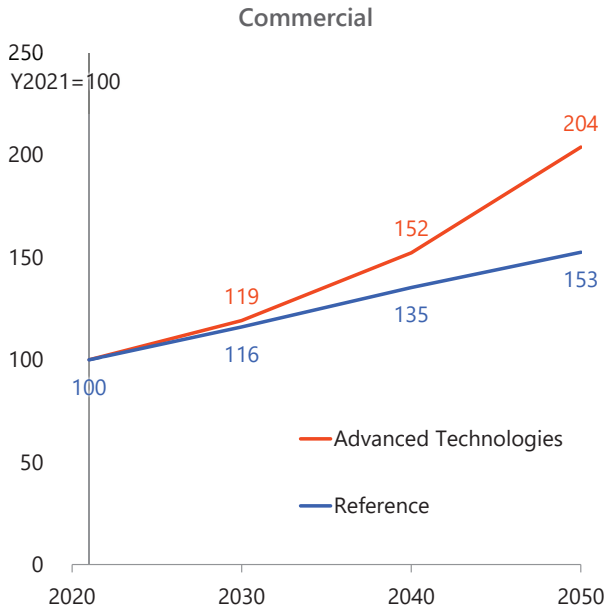


Note: Litres of gasoline equivalent

Advanced Technologies Scenario

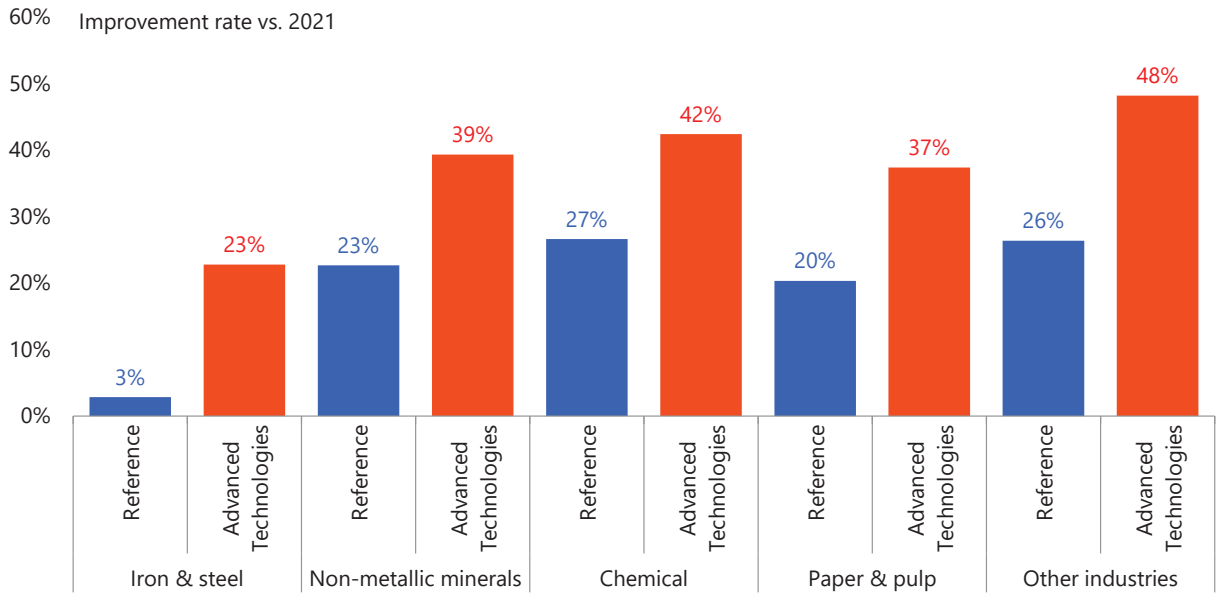
Energy efficiency in buildings sector





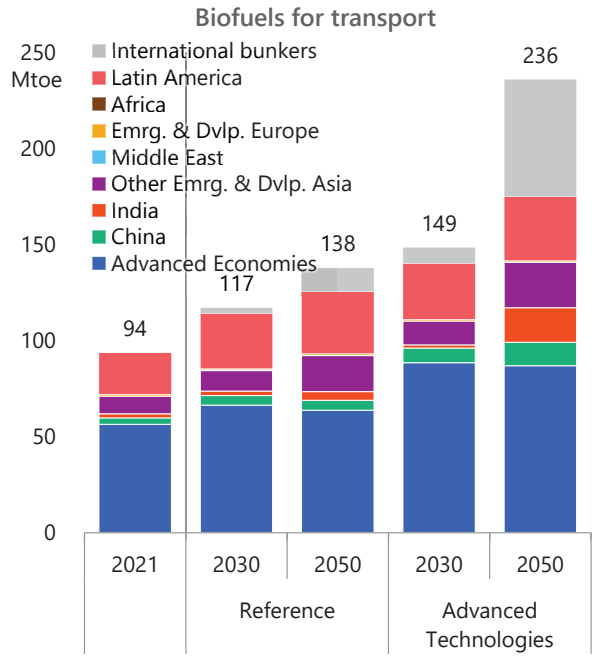
Advanced Technologies Scenario

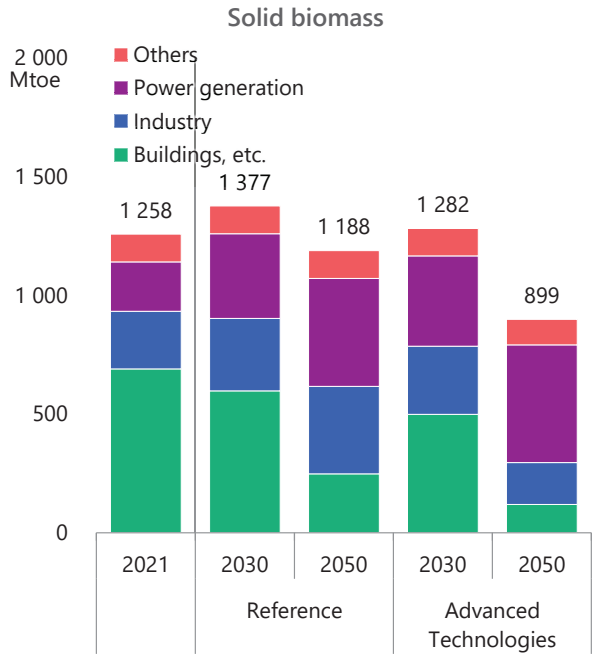
Energy intensity improvement in industry sector



Advanced Technologies Scenario

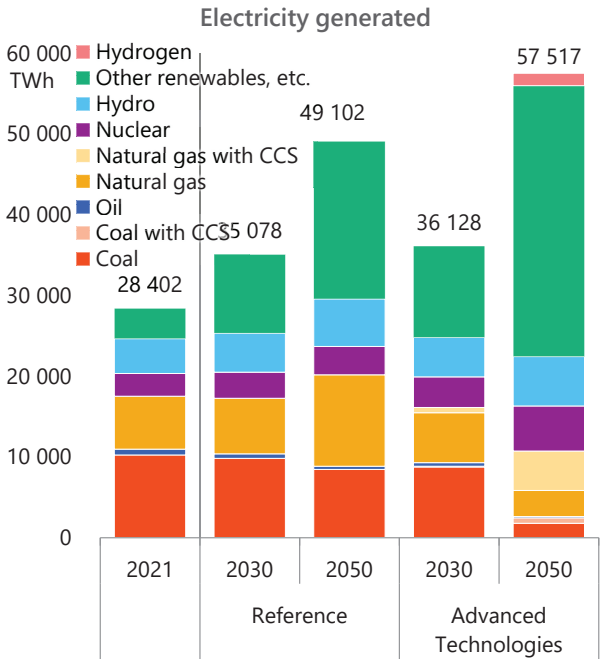
Biomass

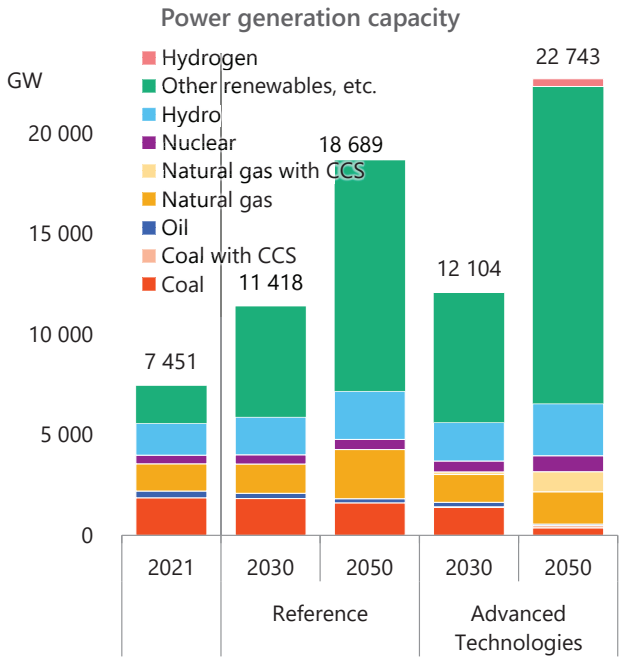




Advanced Technologies Scenario

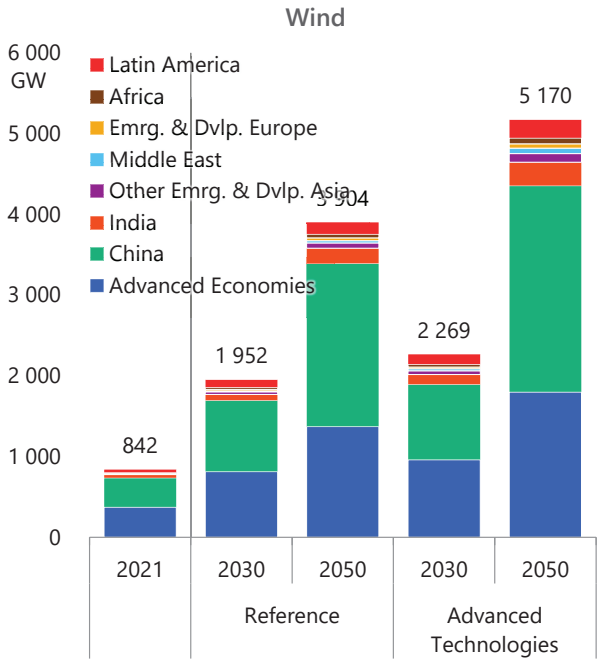
Power generation mix

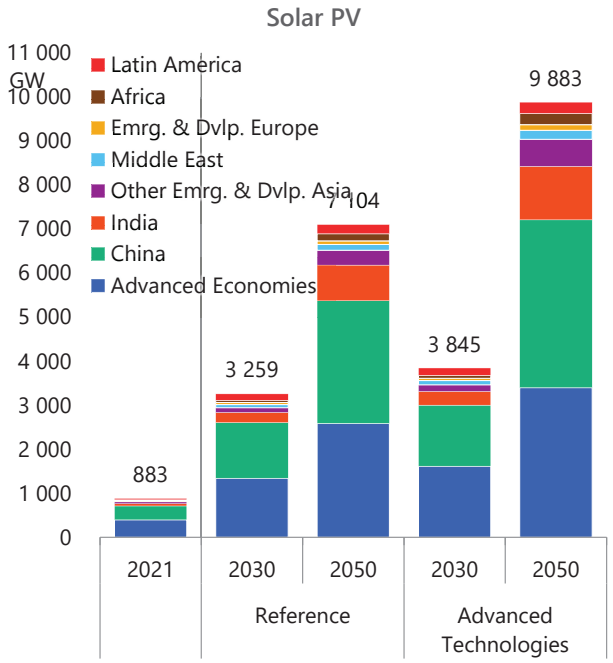




Advanced Technologies Scenario

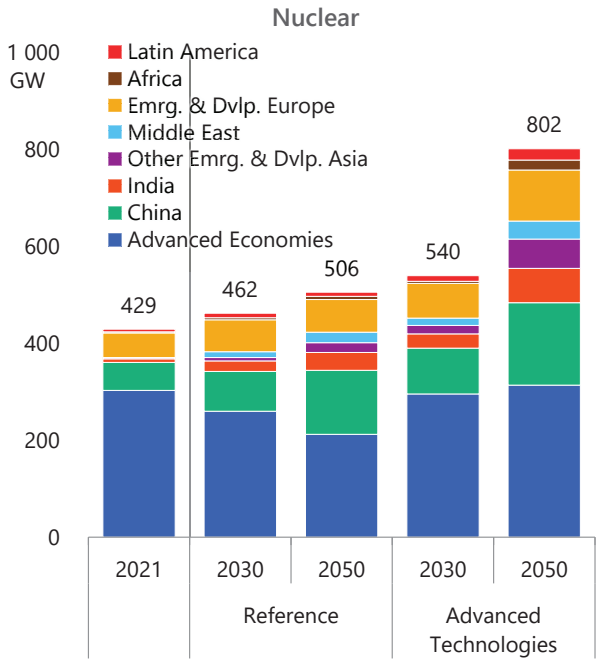
Wind and solar PV power generation capacity

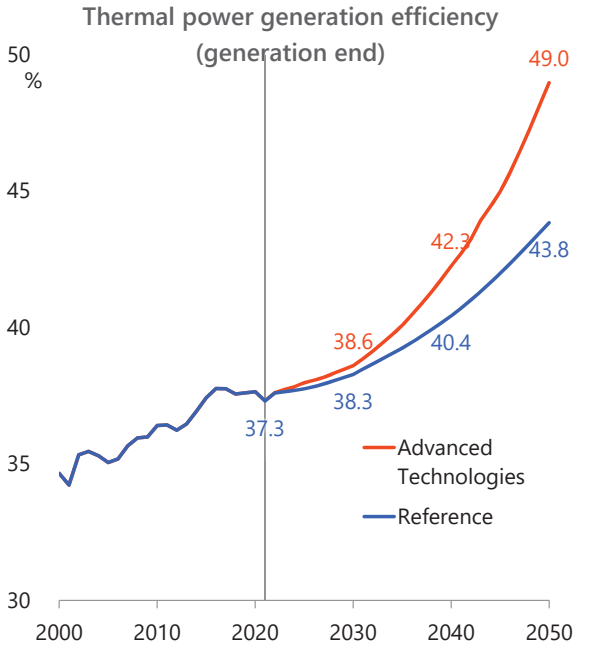




Advanced Technologies Scenario

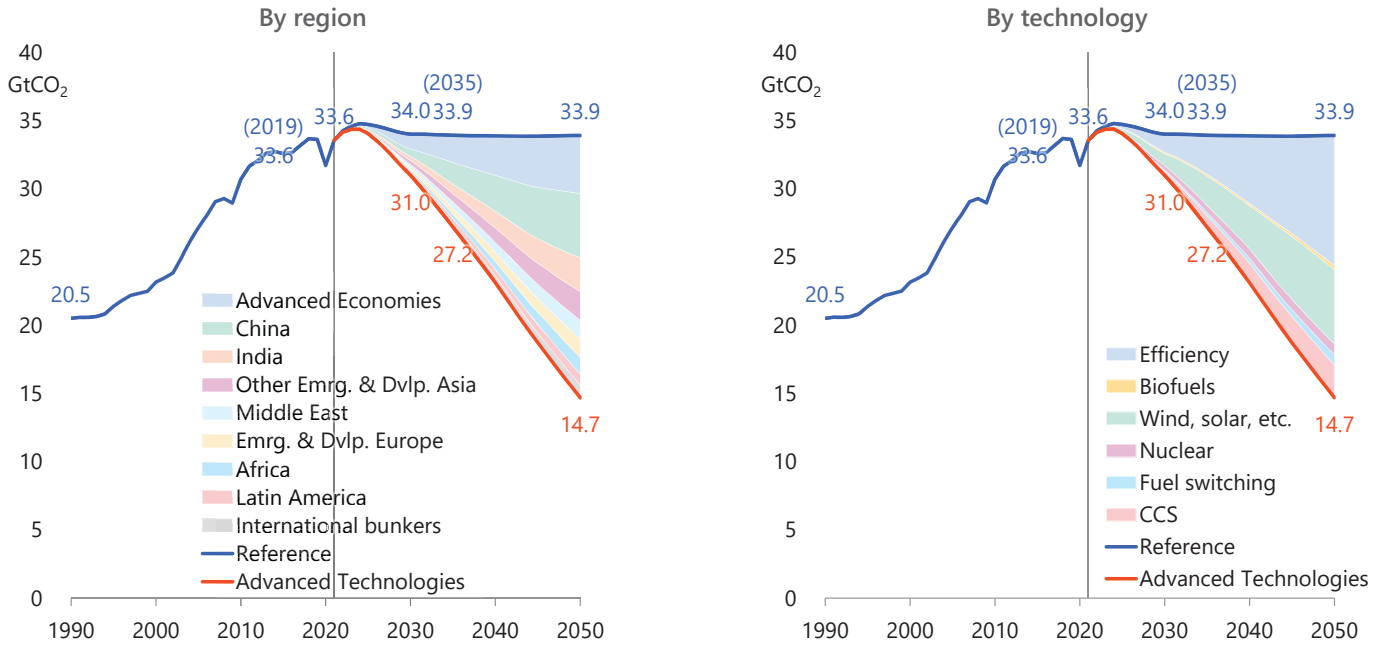
Nuclear power generation capacity and thermal power generation efficiency





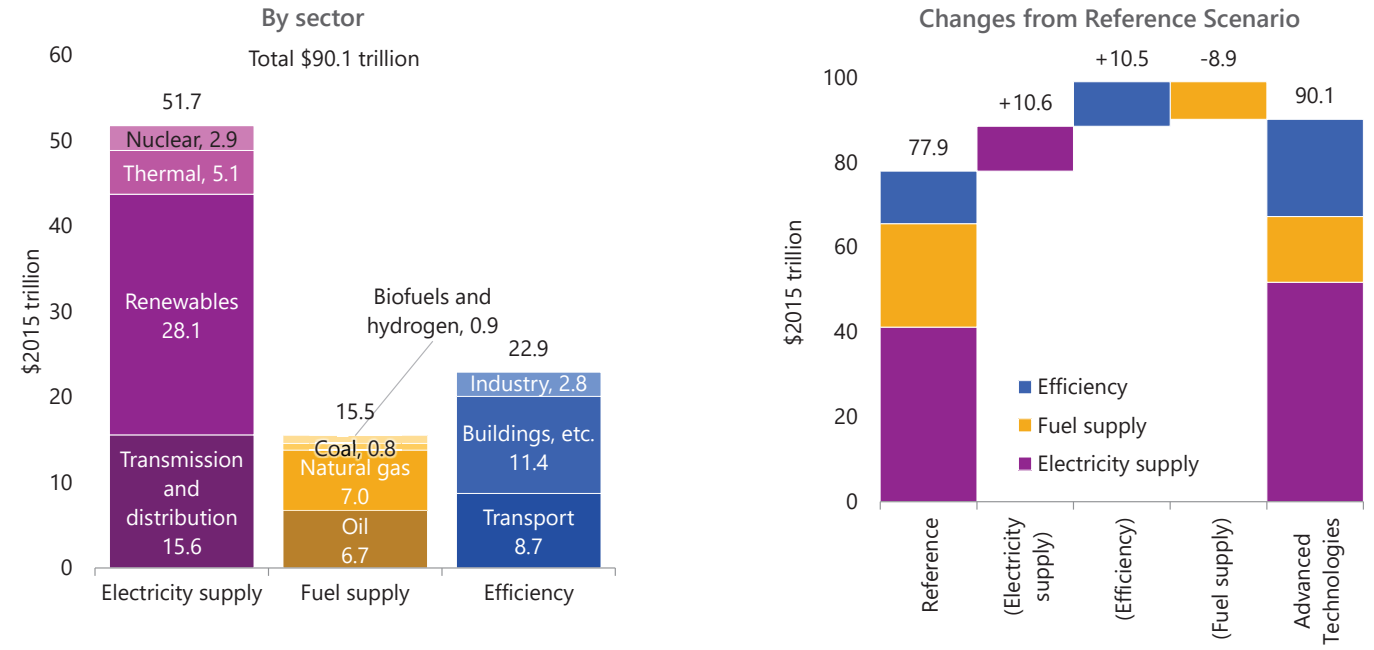
Advanced Technologies Scenario

Energy-related CO_2 emissions

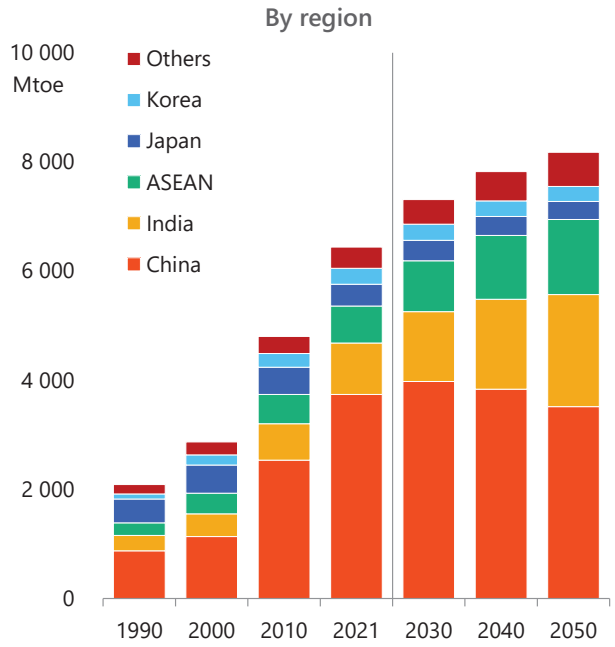


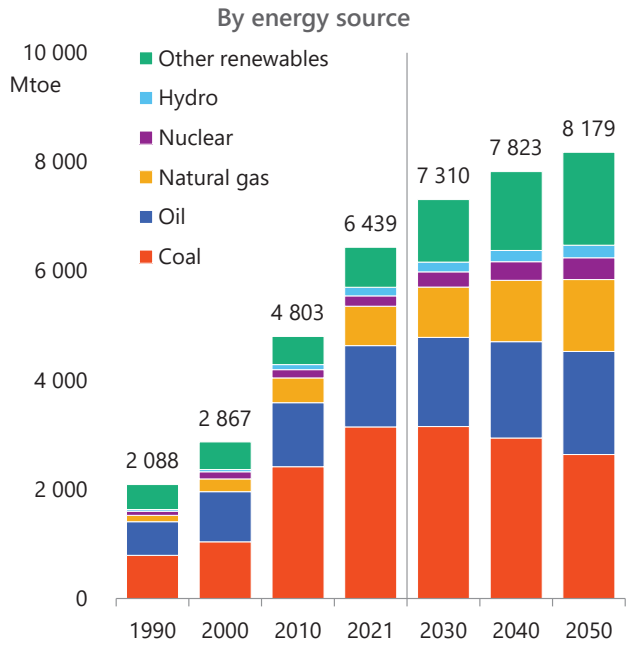
Advanced Technologies Scenario

Energy-related investments (2022–2050)

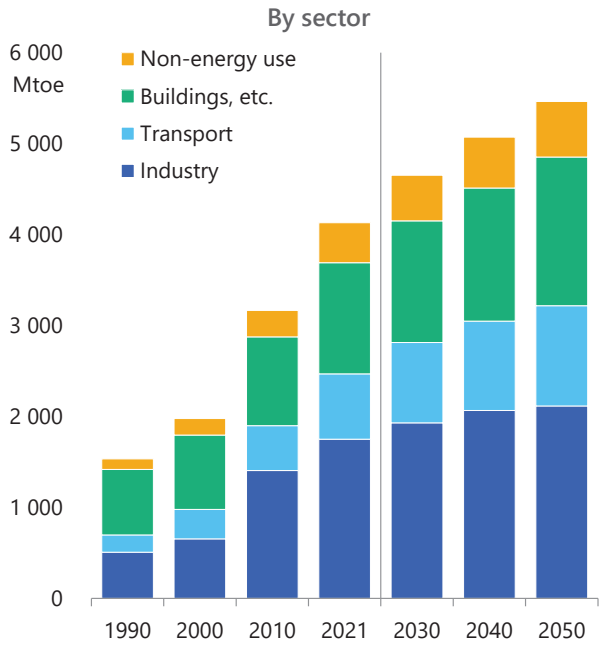


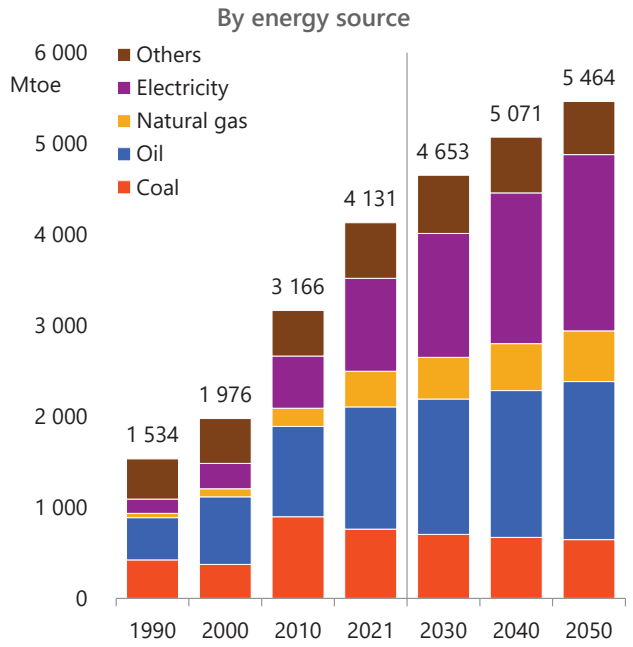
Primary energy consumption





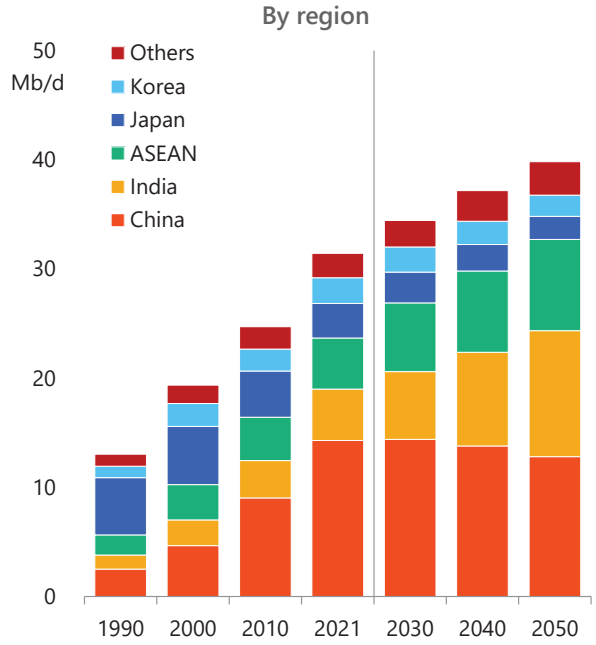
Final energy consumption

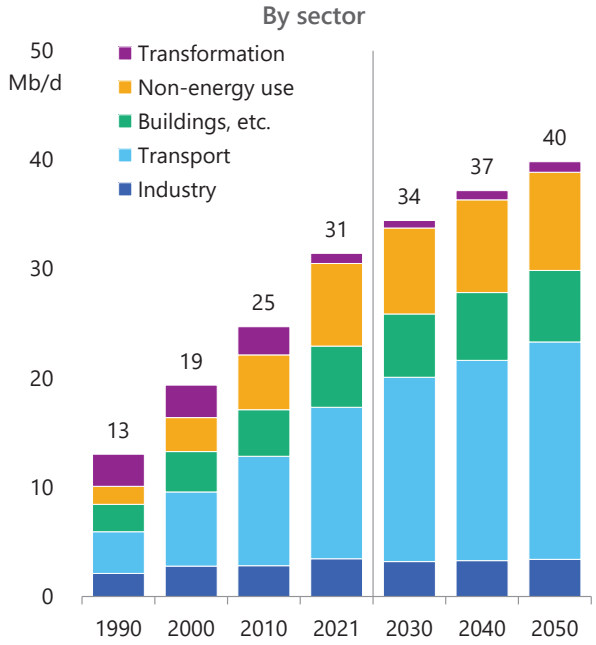




Asia | Reference Scenario

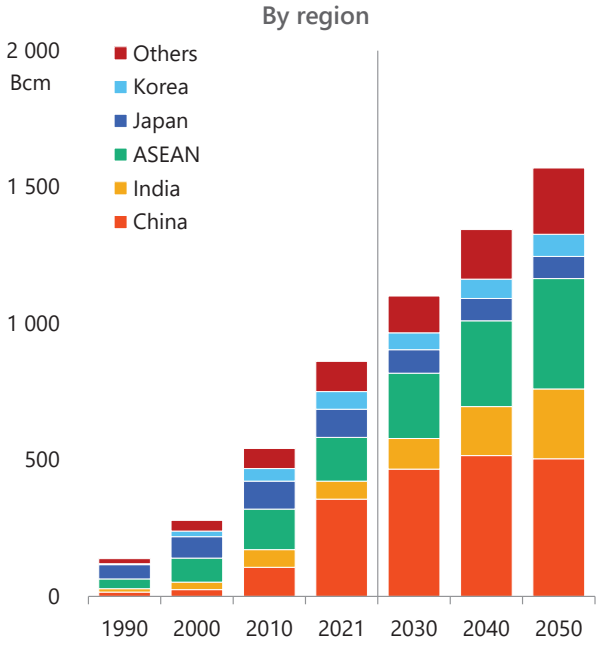
Oil consumption

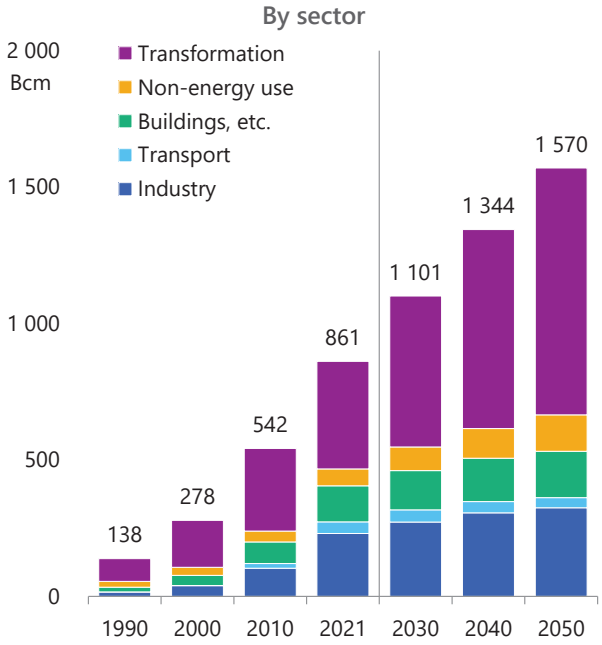




Asia | Reference Scenario

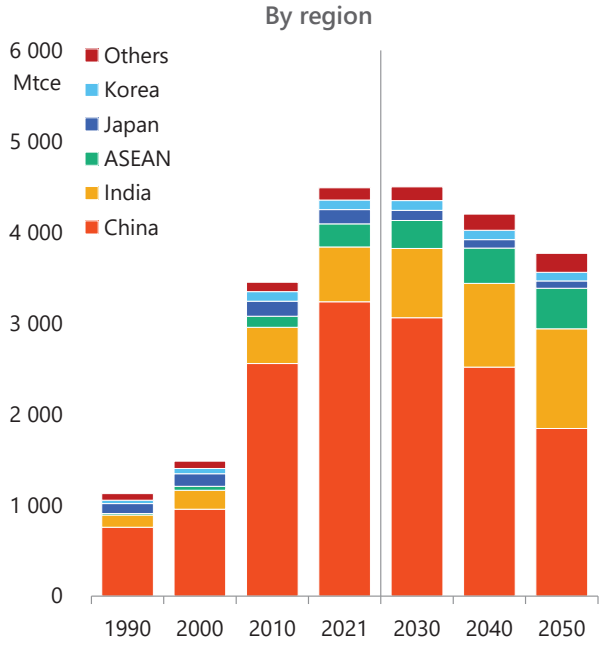
Natural gas consumption

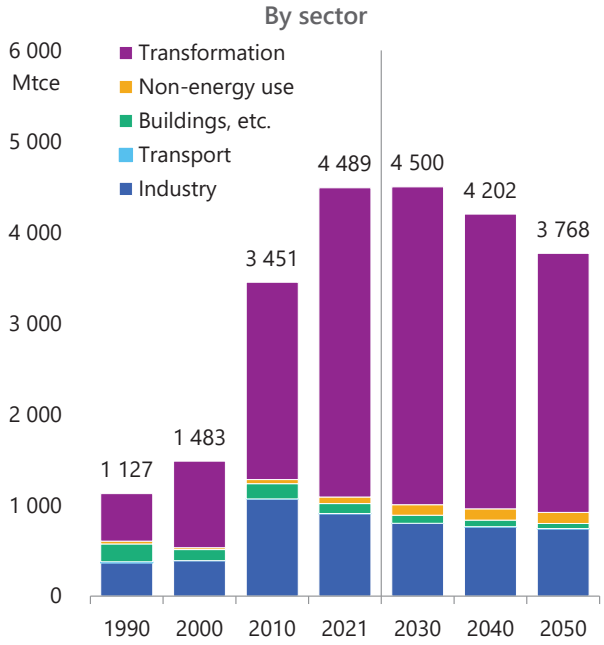




Asia | Reference Scenario

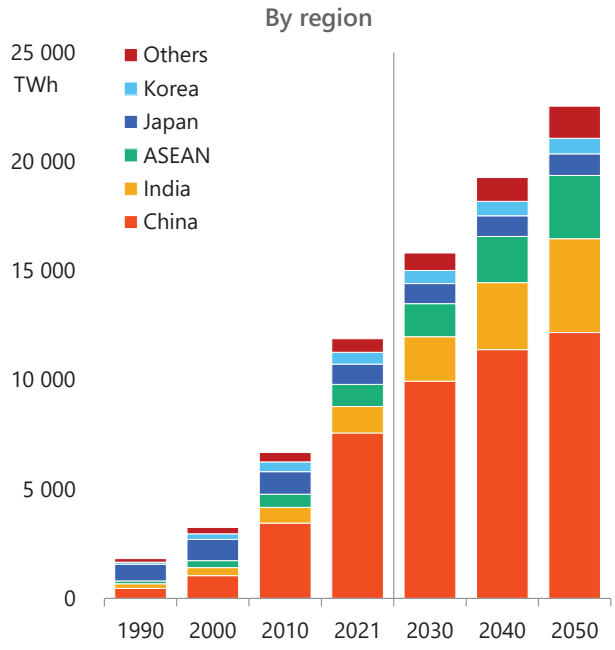
Coal consumption

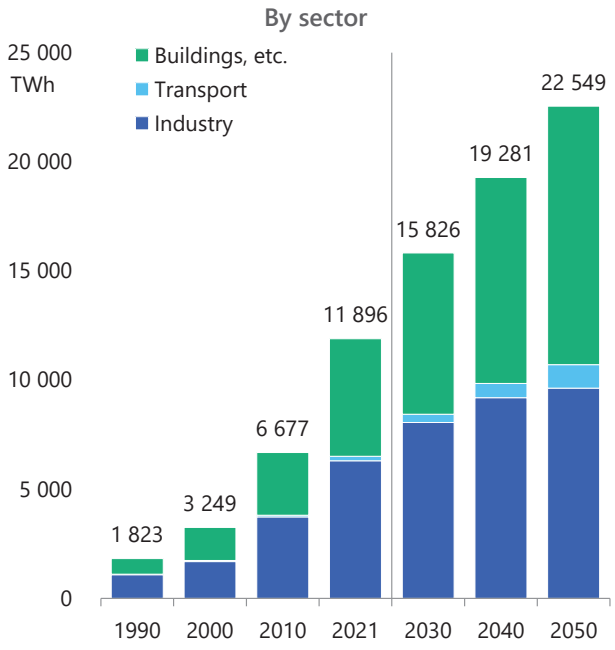




Asia | Reference Scenario

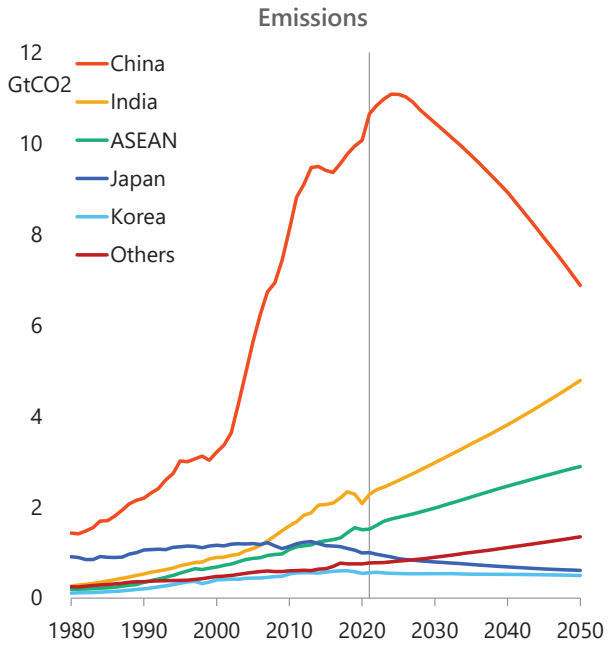
Final consumption of electricity

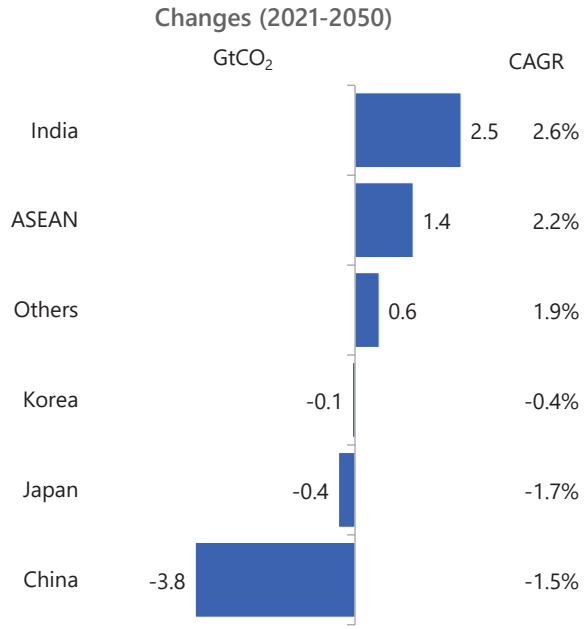




Asia | Reference Scenario

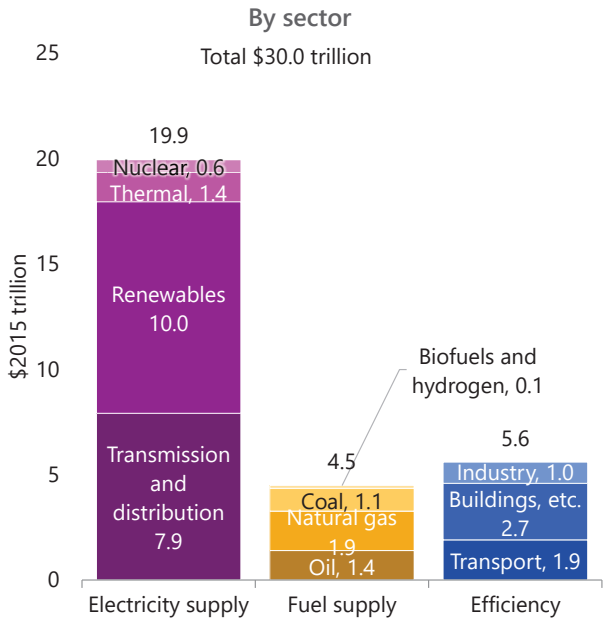
Energy-related CO_2 emissions

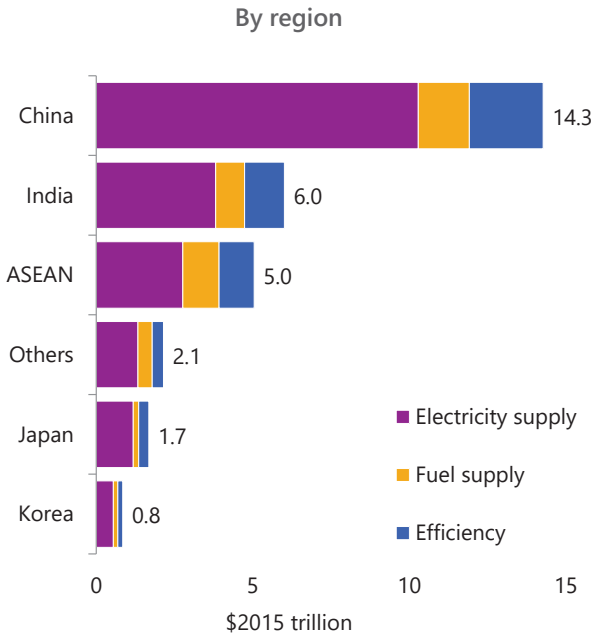




Asia | Reference Scenario

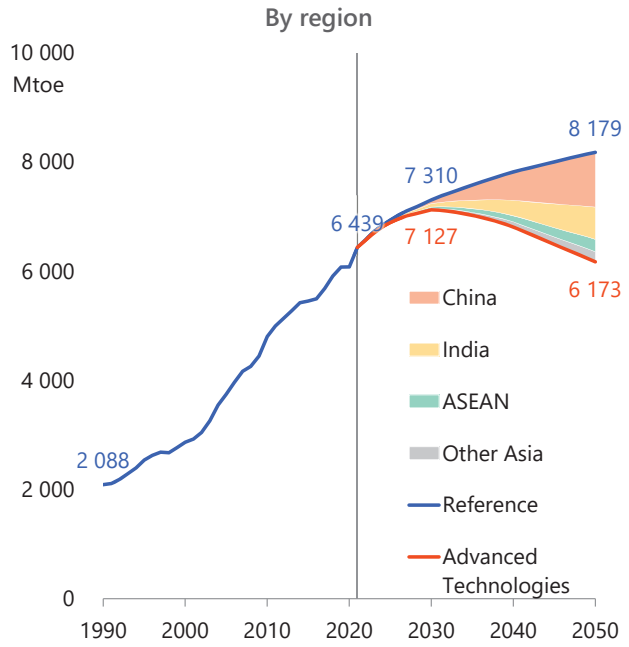
Energy-related investments (2022–2050)

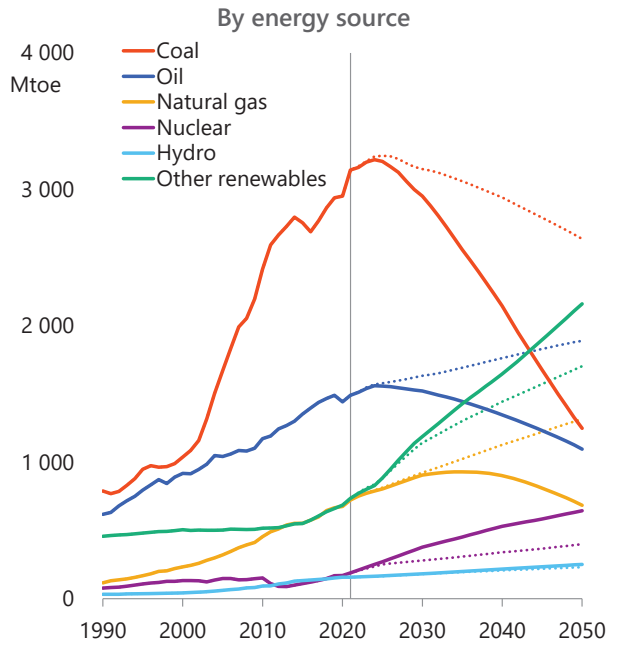




Asia | Advanced Technologies Scenario

Primary energy consumption

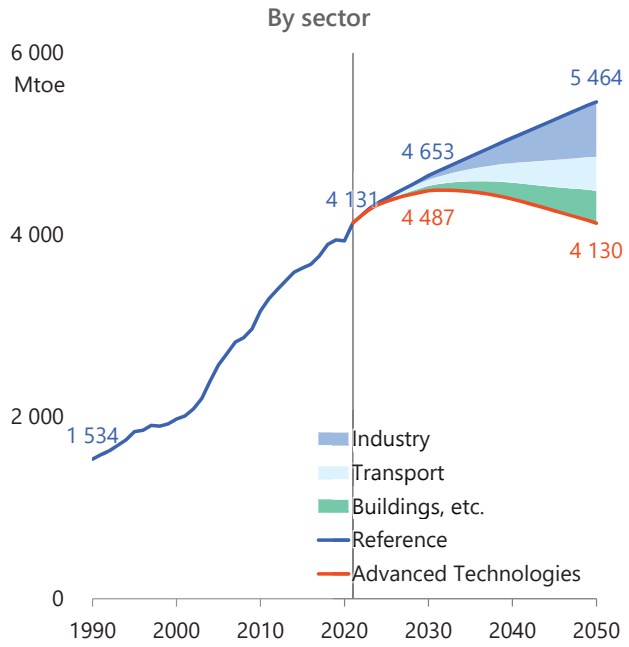


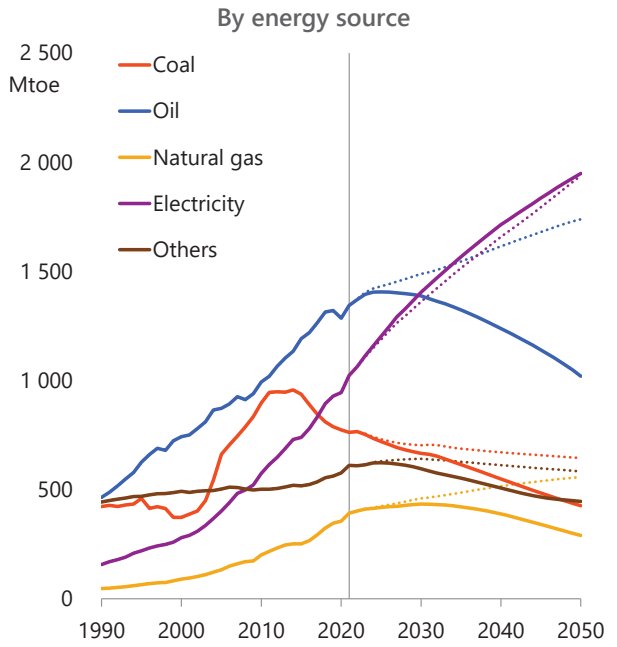


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Asia | Advanced Technologies Scenario

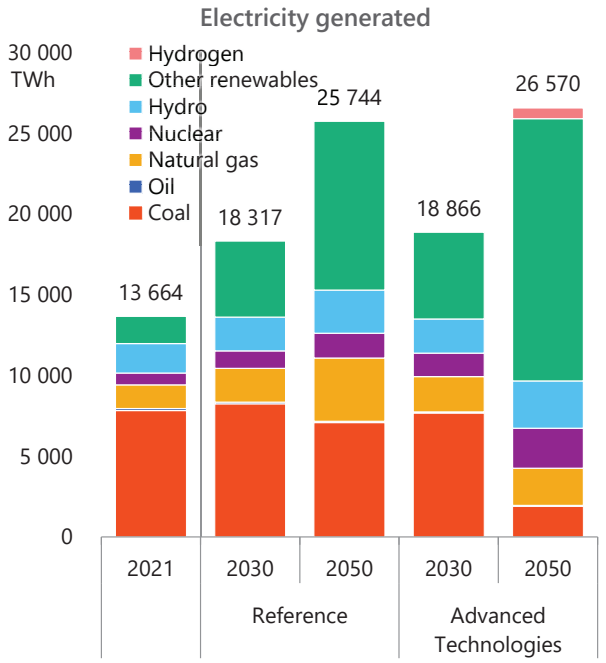
Final energy consumption

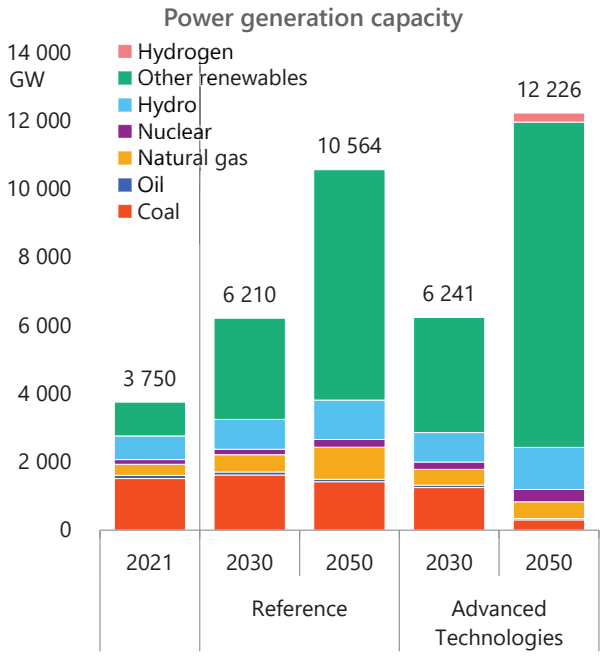




Asia

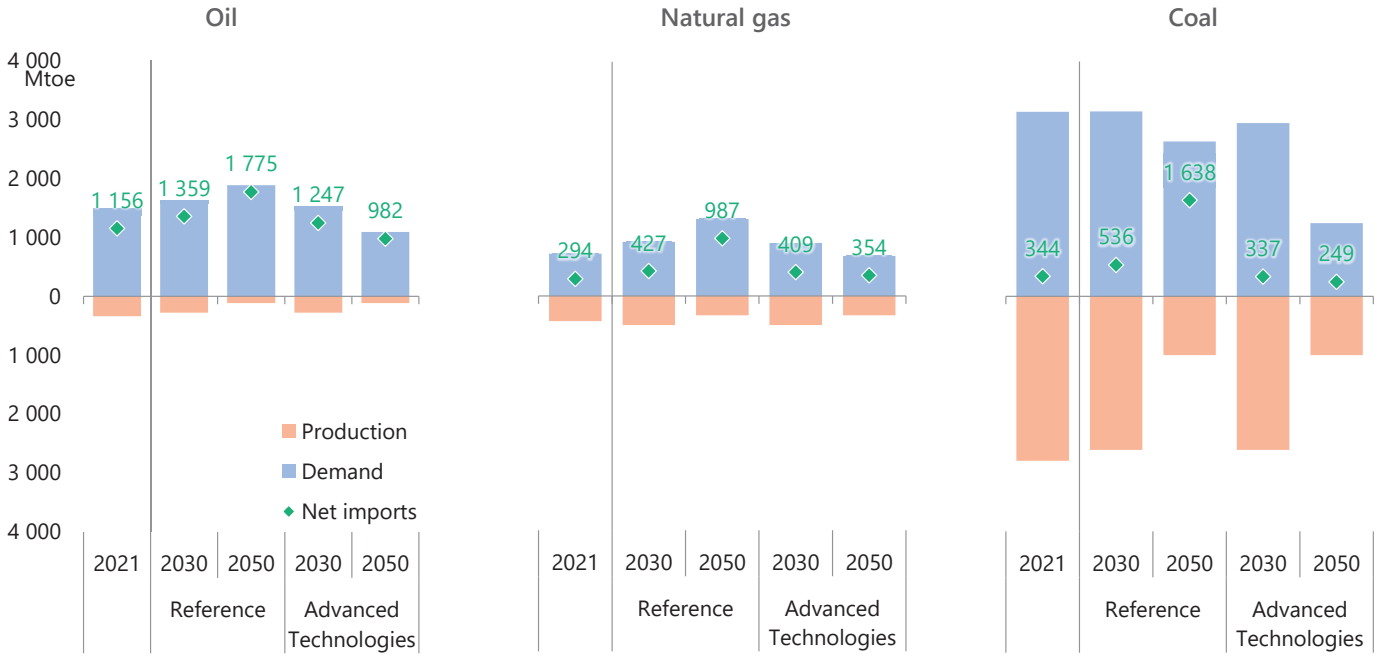
Power generation mix





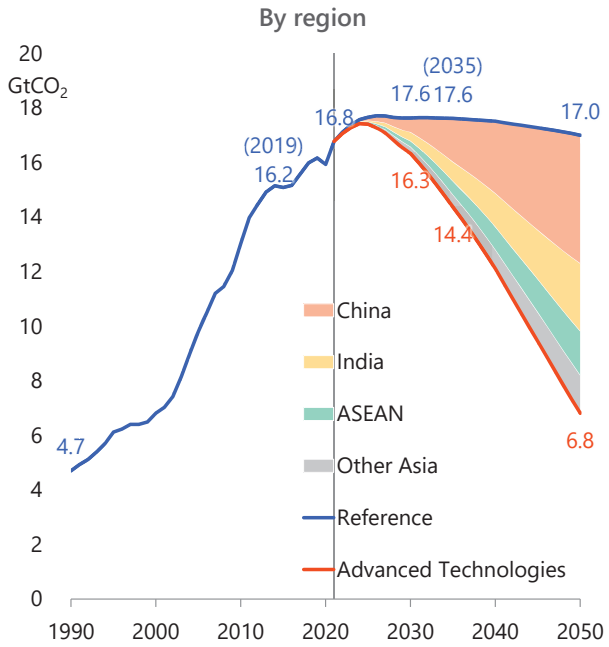
Asia

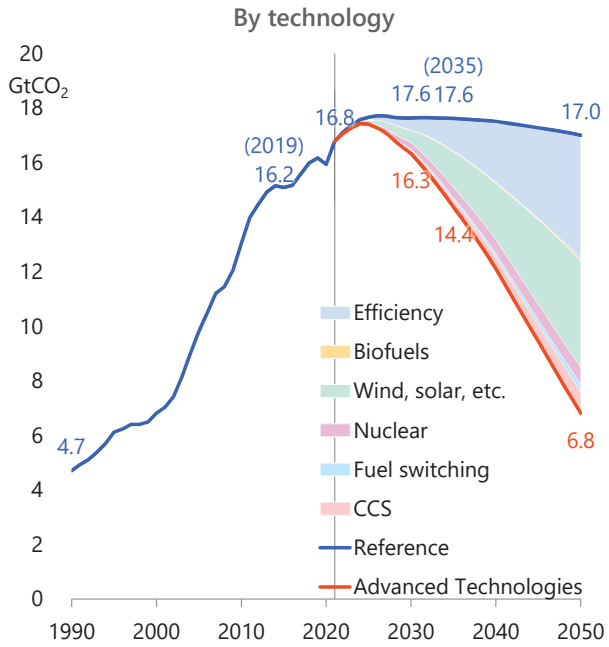
Supply and demand balance of fossil fuels



Asia | Advanced Technologies Scenario

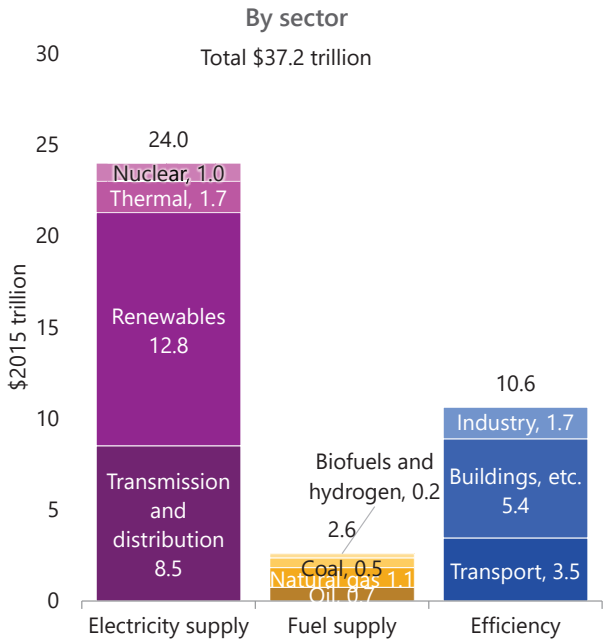
Energy-related CO_2 emissions

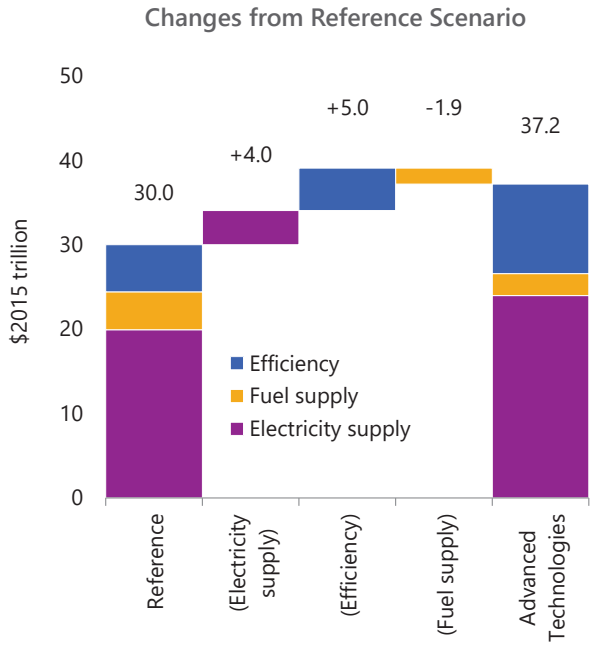




Asia | Advanced Technologies Scenario

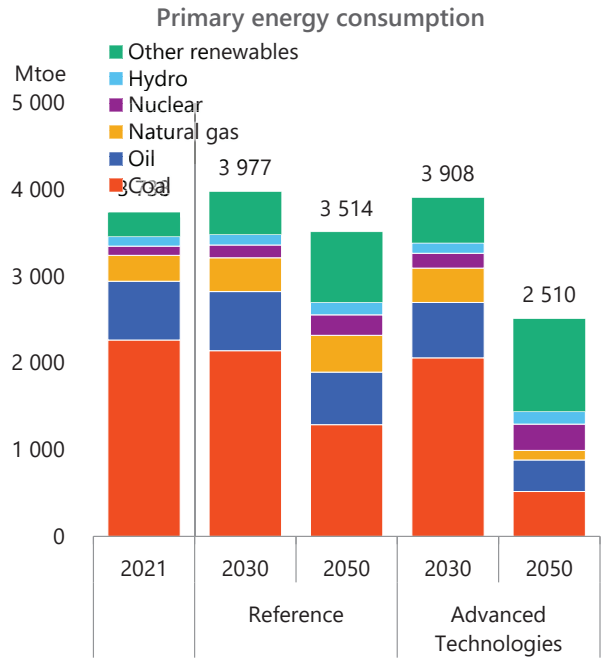
Energy-related investments (2022–2050)

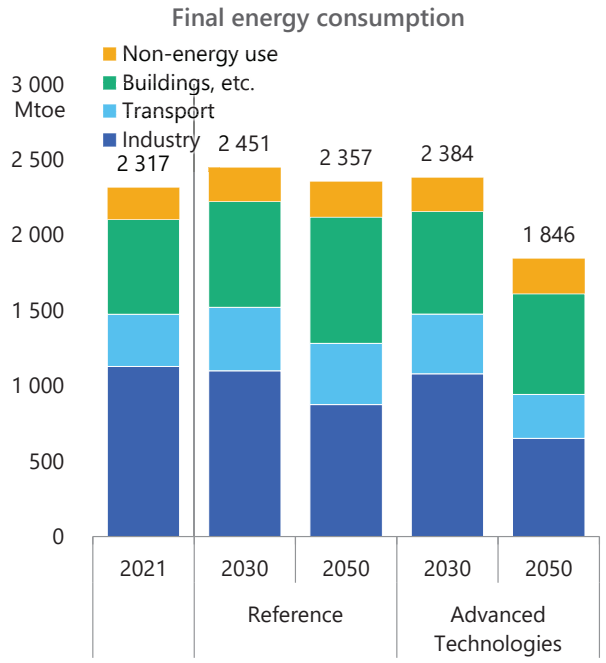




China

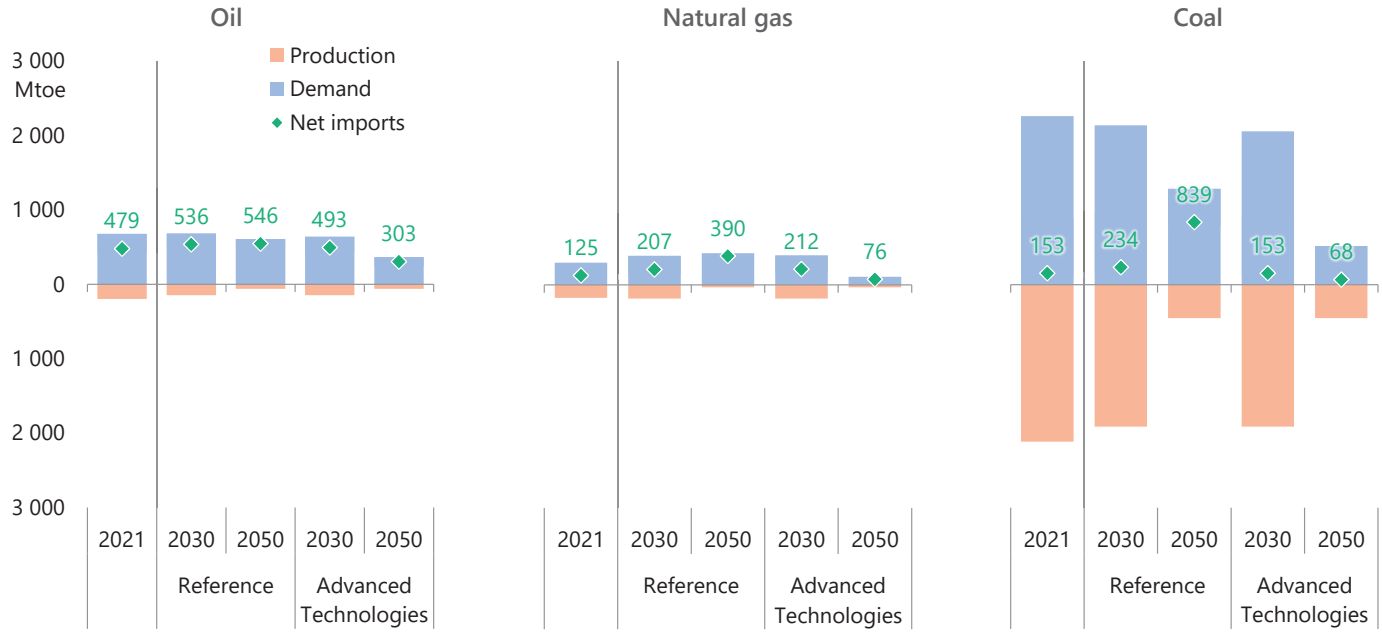
Energy consumption





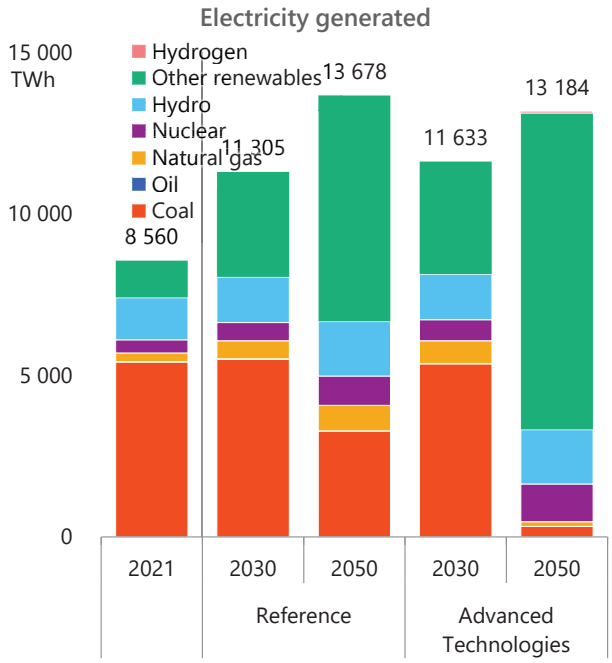
China

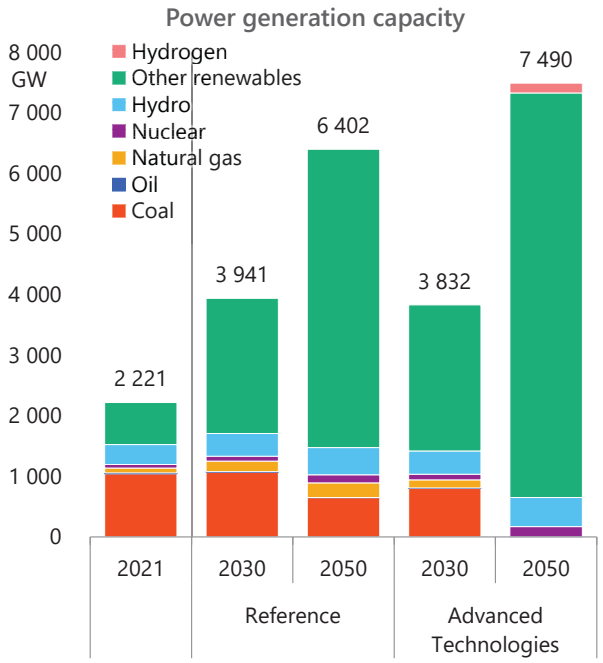
Supply and demand balance of fossil fuels



China

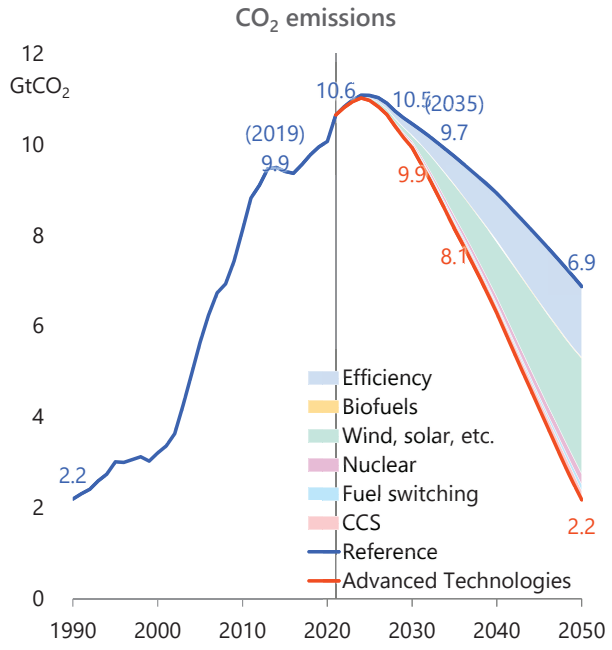
Power generation mix

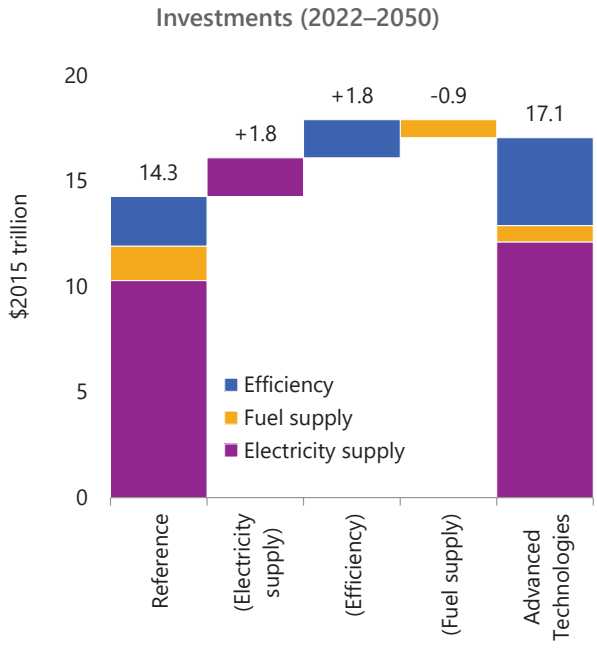




China

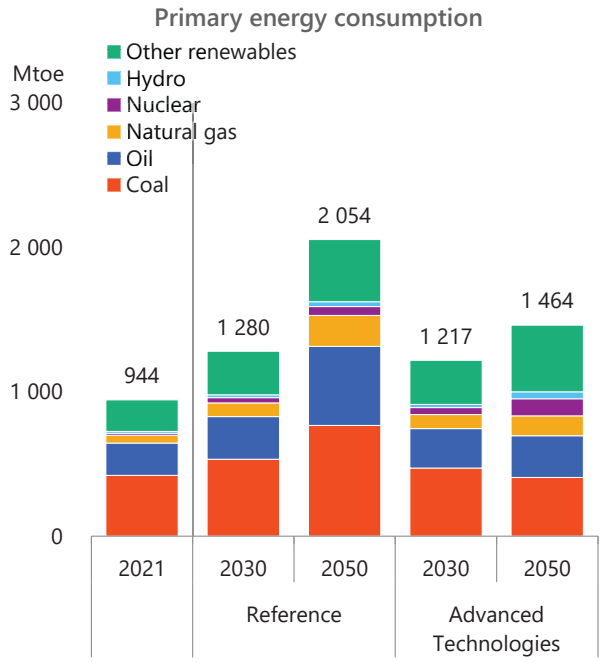
Energy-related CO_2 emissions and investments

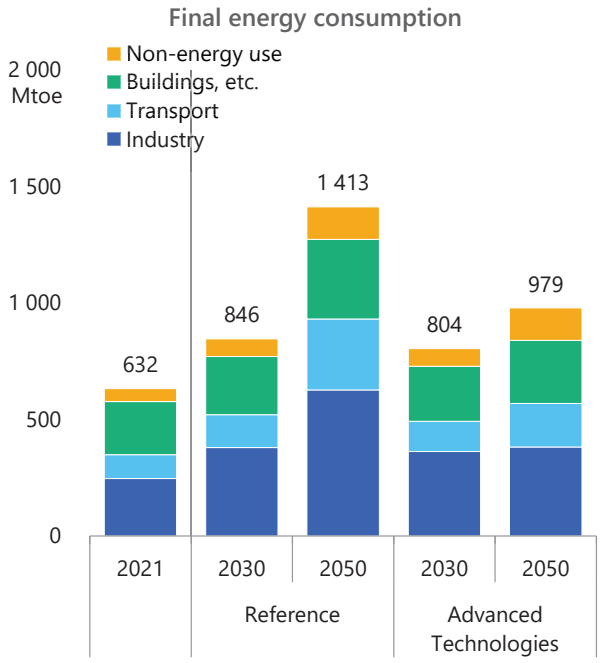




India

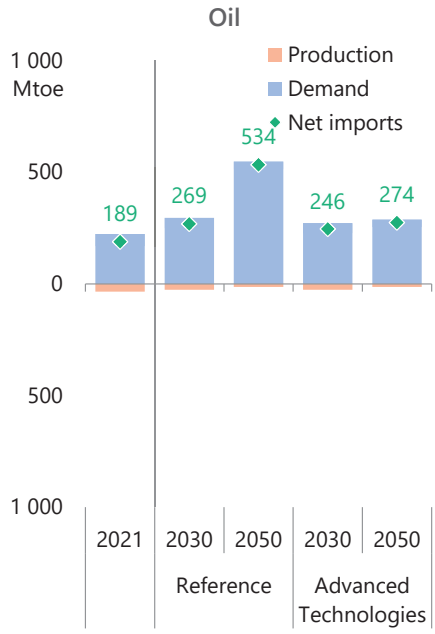
Energy consumption

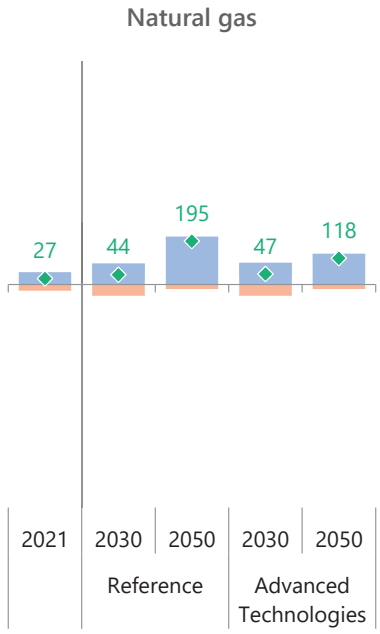


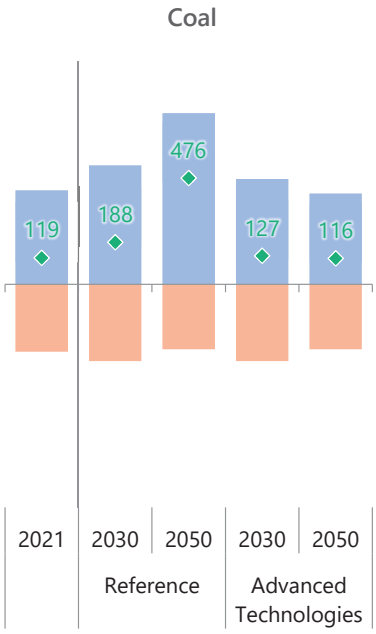


India

Supply and demand balance of fossil fuels

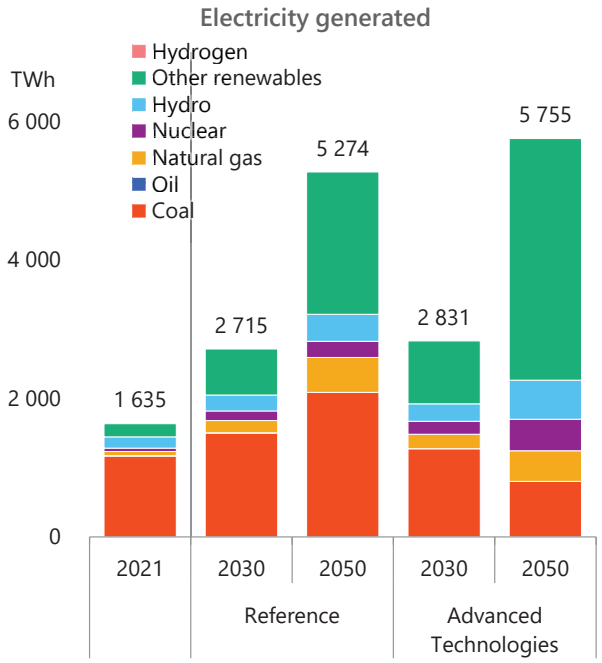


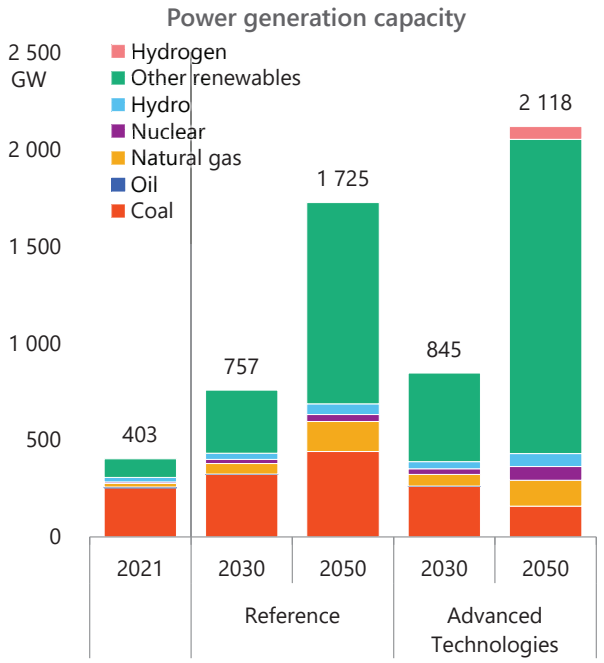




India

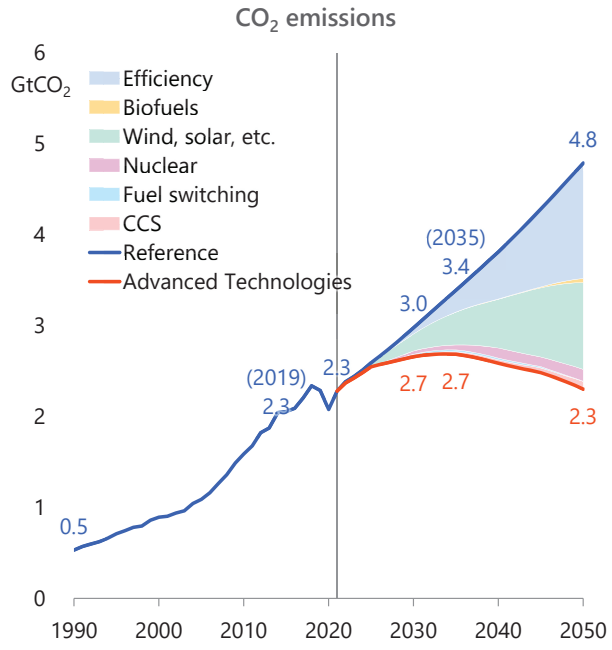
Power generation mix

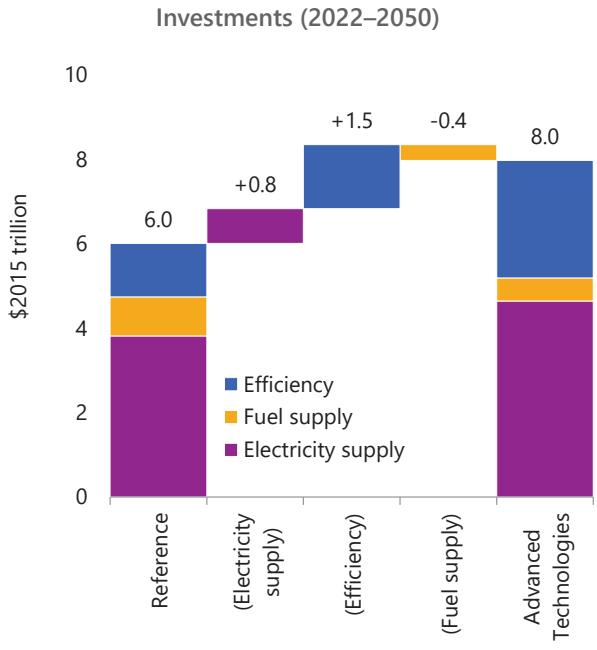




India

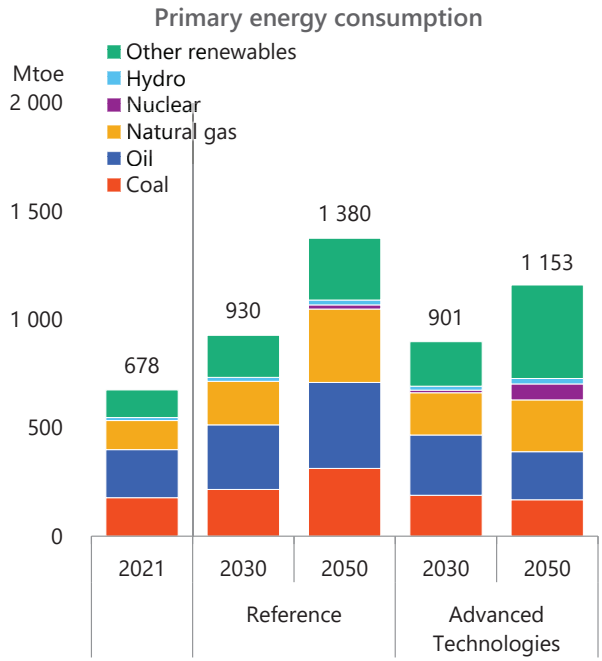
Energy-related CO_2 emissions and investments

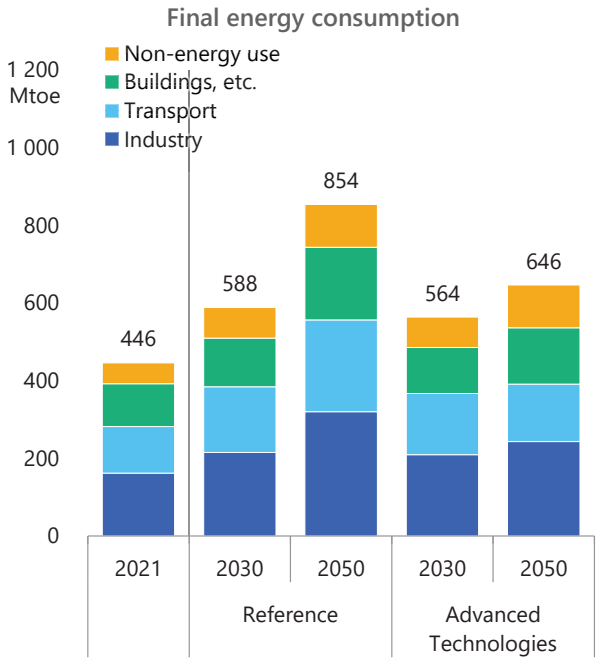




ASEAN

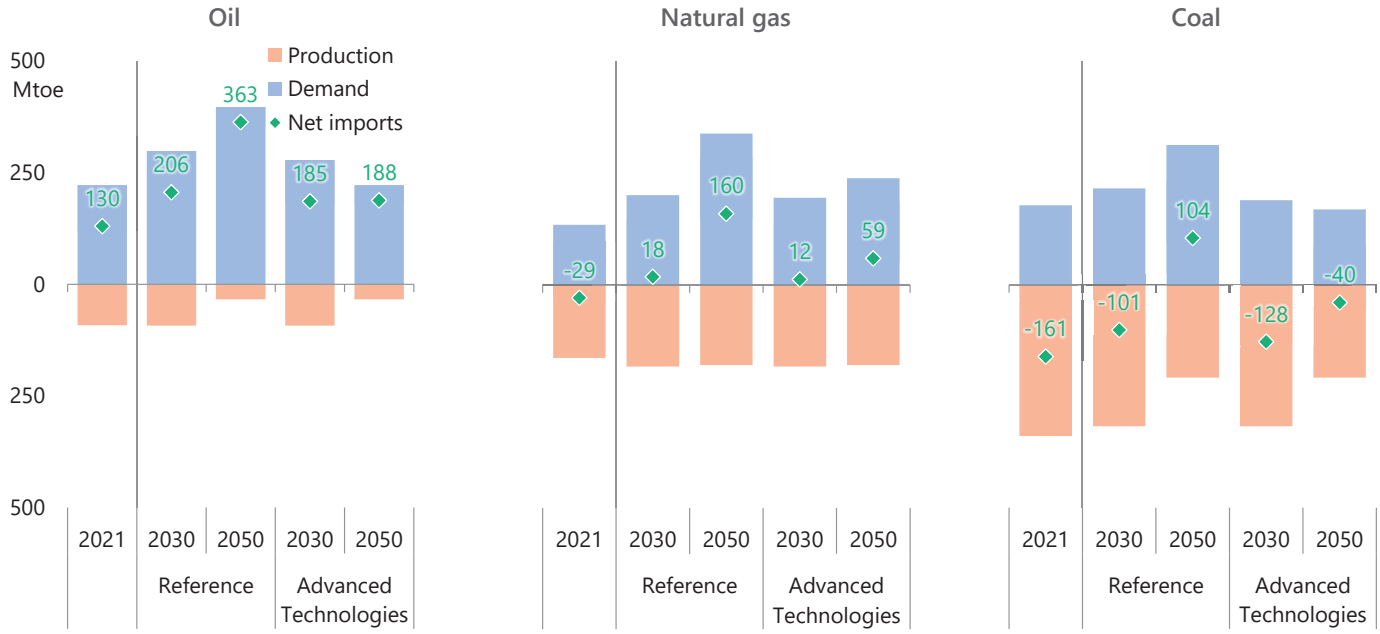
Energy consumption





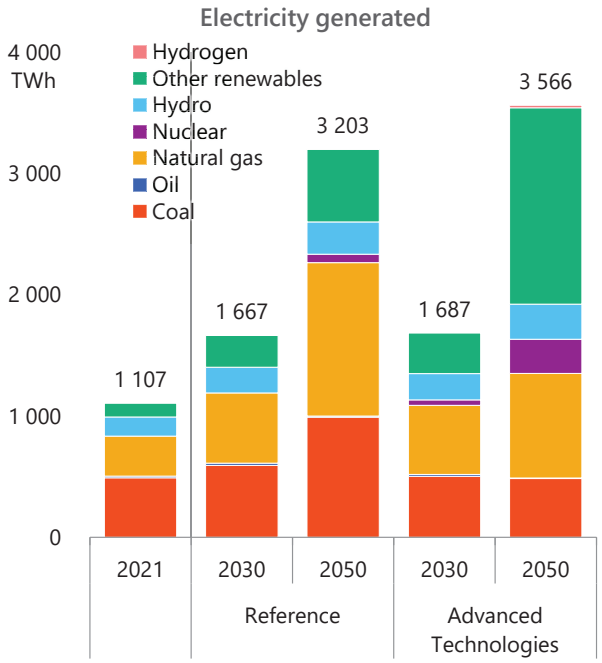
ASEAN

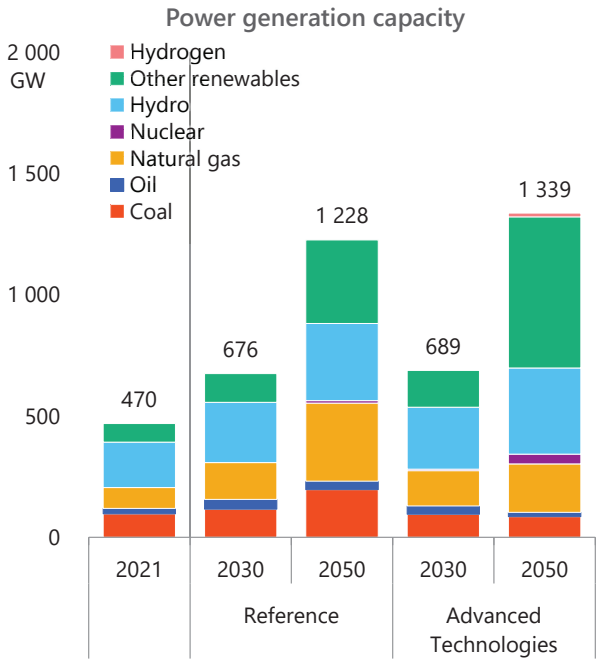
Supply and demand balance of fossil fuels



ASEAN

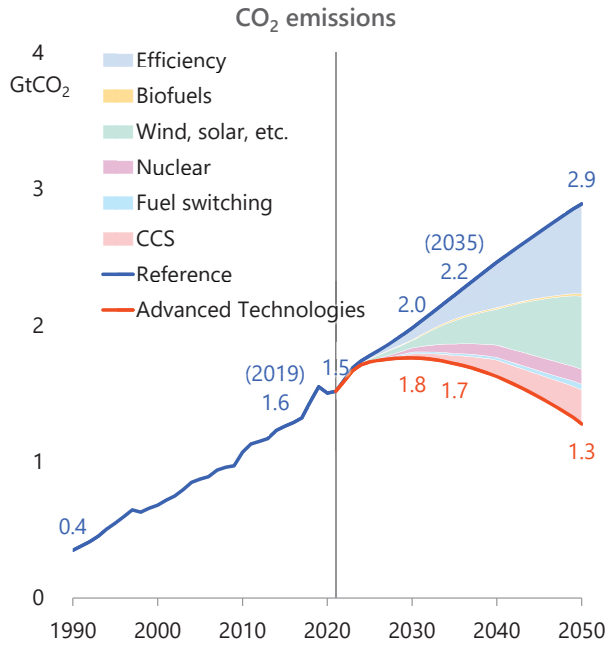
Power generation mix

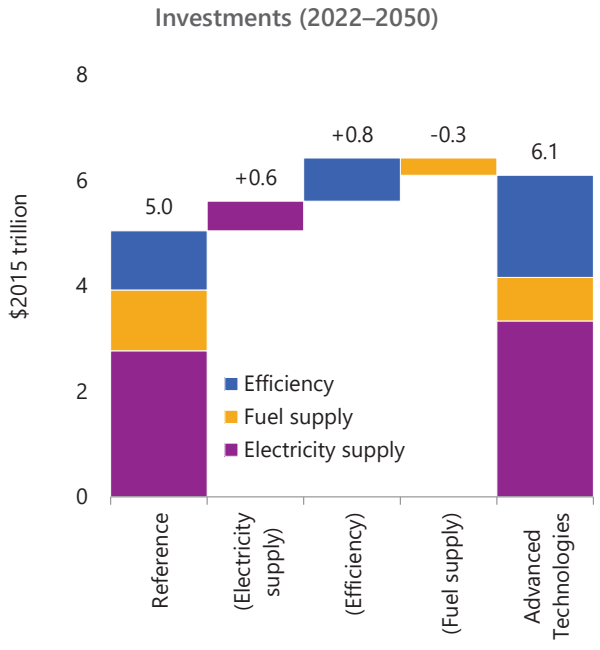




ASEAN

Energy-related CO_2 emissions and investments





The tables for IEEJ Outlook 2024 are currently available at https://eneken.ieej.or.jp/en/whatsnew/445.html.

The full text will be available early 2024 at the same URL.

IEEJ Outlook 2024

October 2023

The Institute of Energy Economics, Japan