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IEEJ Outlook 2025

Global Energy Supply and Demand Outlook to 2050

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Key Points

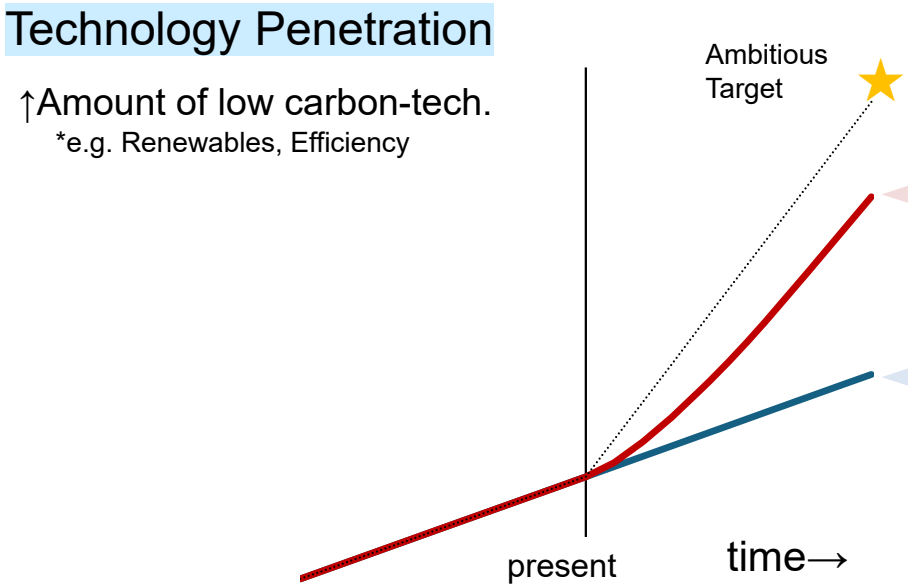
- ✓ Quantitative projection of global energy supply and demand through 2050, using two scenarios:
  (**Reference**: Current Trends & **Adv.Tech.**: Maximum Climate Action)

- ✓ CO_2 reduction requires deployment of all available technologies across sectors.
  (1) energy efficiency, **(2) renewables** (especially solar and wind), and in the longer term, **(3) CCUS** will make particularly significant contributions.

- ✓ Fossil fuel demand faces significant uncertainty. Stable supply remains essential over the coming decades.

Scenario Framework

- Created global energy supply and demand outlook through 2050.
  - Conducted model analysis incorporating latest energy and socioeconomic data. Estimated energy demand by type and CO_2 emissions for 44 regions + international bunkers.
- Established two scenarios with different technology and policy progression assumptions.
  - Both are **forecast-type scenarios** examining "**what if**" scenarios, not **backcast-type scenarios** (which calculate backward from targets to determine "**what should be done**"). Target achievement is not necessarily incorporated.



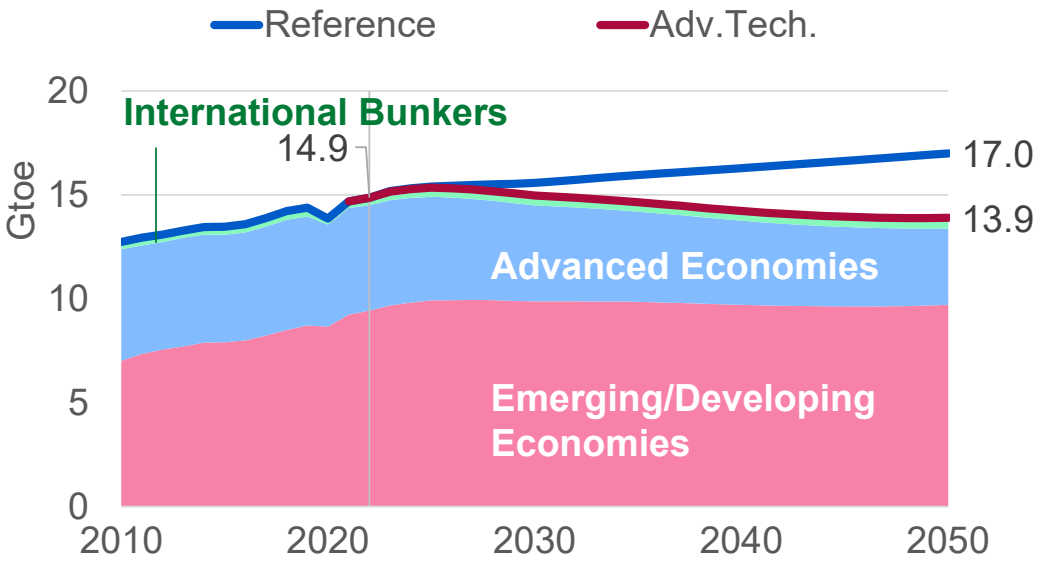
[Advanced Technologies Scenario]
(Adv.Tech.)
Maximum implementation of policies for energy security and climate action, with technologies deployed to maximum extent
(considering feasibility and acceptance)

[Reference Scenario]
Continuation of current trends in energy and environmental policies.
*Does not imply fixed current policies/technologies

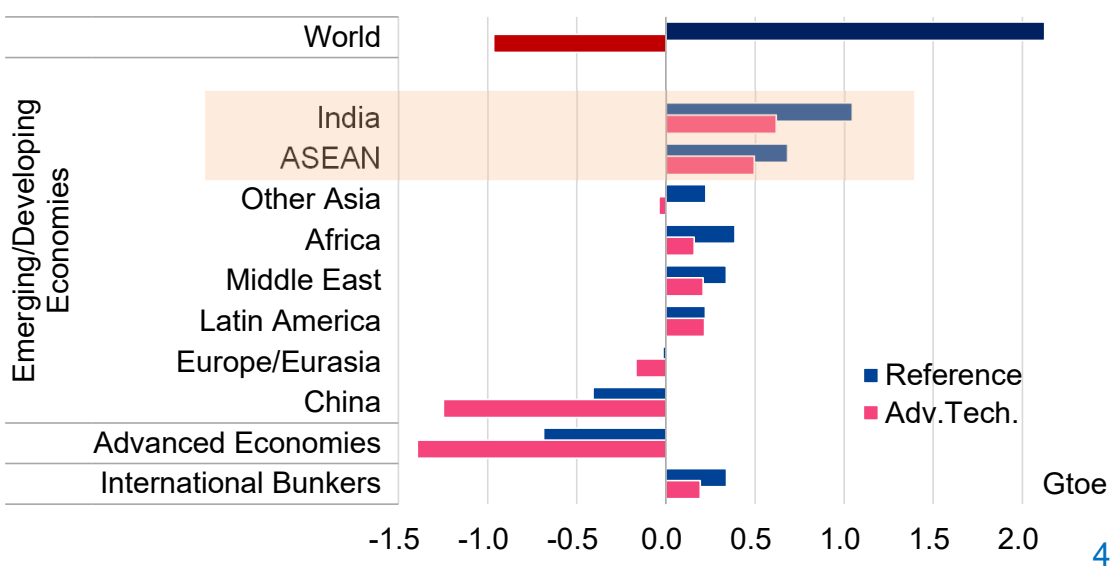
Primary Energy Demand: India and ASEAN at Center of Demand Growth

- **Reference:** Primary energy demand increases 14% from 2022 to 2050.
  - Real GDP doubles during this period. Efficiency improvements and industrial structure transformation suppress demand.
- **Adv.Tech.:** Energy efficiency improvements accelerate, and primary demand peaks before 2030.
- India and ASEAN drive demand growth in both scenarios, pushing up global demand.
  - Global emissions reduction requires engagement of these two regions plus other emerging/developing economies.

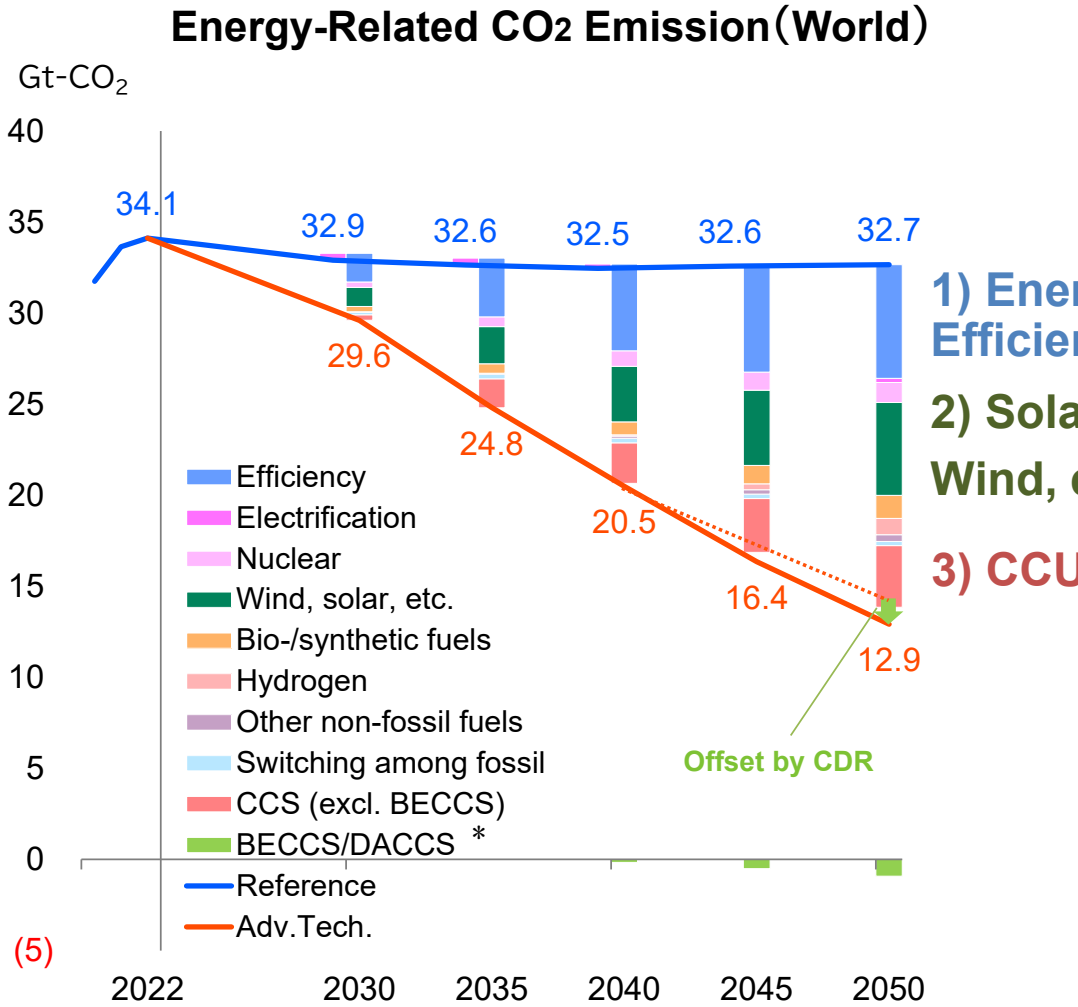
Primary Energy Demand (Global)



Primary Energy Demand Change (2022-2050)



CO_2 Reduction: Energy Efficiency, Renewables and CCUS



*Although not originally applicable to energy-related CO_2, the offsetting effect is included for reference.

1) Energy Efficiency

2) Solar, Wind, etc.

3) CCUS

Reference

- While demand continues to grow, energy transition trend suppresses emissions.

Adv.Tech.

- (1) energy efficiency, (2) solar/wind, and (3) CCUS play key roles in global reduction.
- (1) and (2) contribute significantly from 2030, CCUS expands after 2035.
- Gap remains between “2050 Net Zero” target, particularly challenging for emerging/developing nations and non-power sectors.

1) Energy Efficiency: Different Priority Areas by Region/Economic Level

Sectors with particularly effective efficiency improvements vary by region.

- **Advanced economies show improvement in efficiency across sectors.**

  Transportation can show particularly large improvement due to xEVs with far better efficiency than ICVs.

- **Emerging economies focus on industry.**

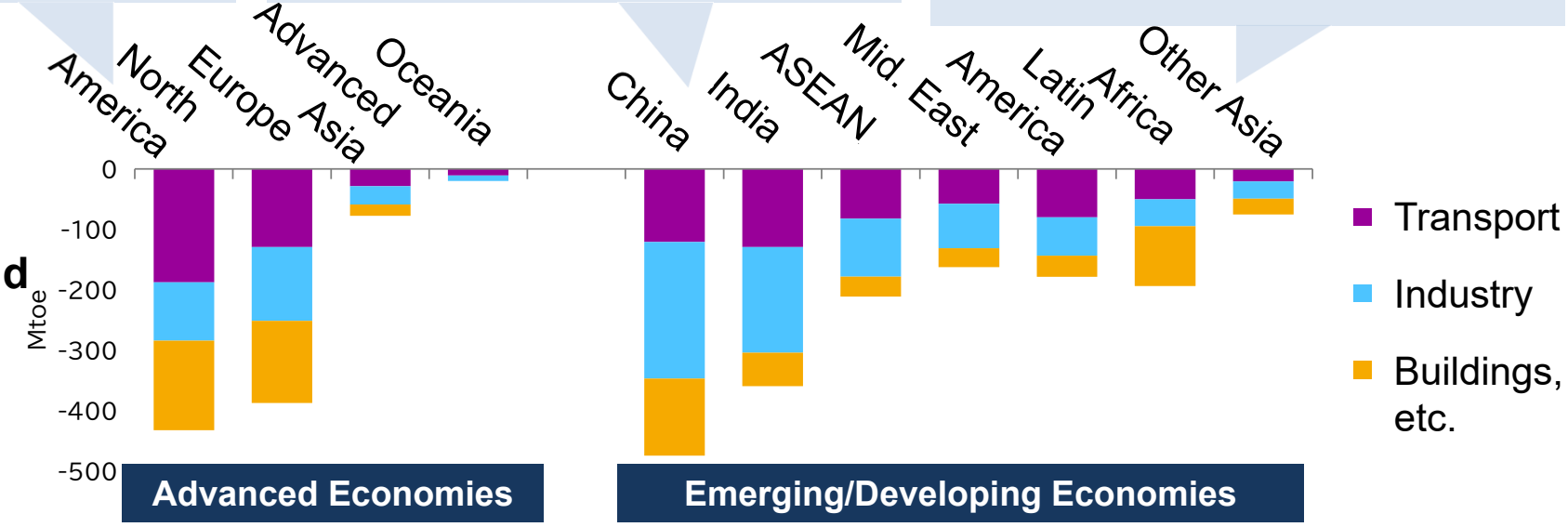
  Major industrial production in China and expected growth in India/ASEAN make efficiency improvements effective.

- **Developing economies (Africa, Other Asia) show major reductions in residential.**

  The household transition from traditional biomass (wood).

Difference in Final Energy Demand
[Adv.Tech.-Reference]

(2050)



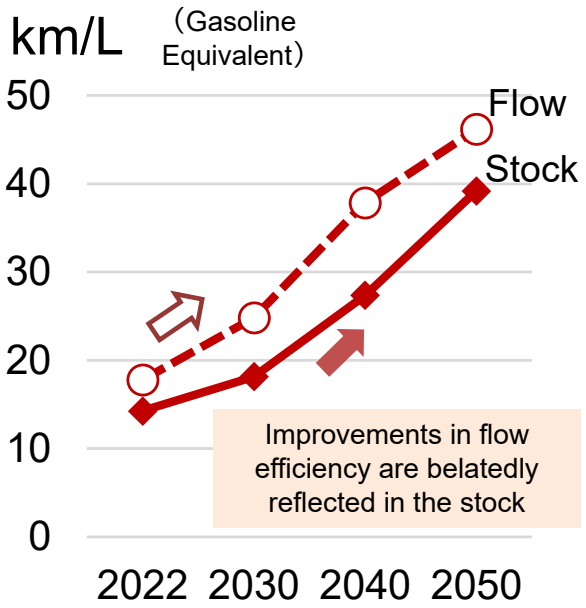
1) Energy Efficiency: Delayed Effect of Improvements

- Energy Efficiency: Delayed Effect of Improvements.
  - Intensity improvements in **Adv.Tech.** become particularly evident after 2030.
- Flow efficiency (new equipment) reflects in stock efficiency (existing equipment) with delay.
  - Particularly pronounced in industrial sector with long equipment lifespans
  - Early action is necessary for significant efficiency improvement by 2050.

Average annual improvement of primary energy demand intensity (World)

		2010-2022	2022-2030	2030-2040	2040-2050
TPES/GDP	Reference	-1.4% (history)	-2.0%	-2.2%	-2.0%
	Advanced		-2.5%	-3.1%	-2.7%

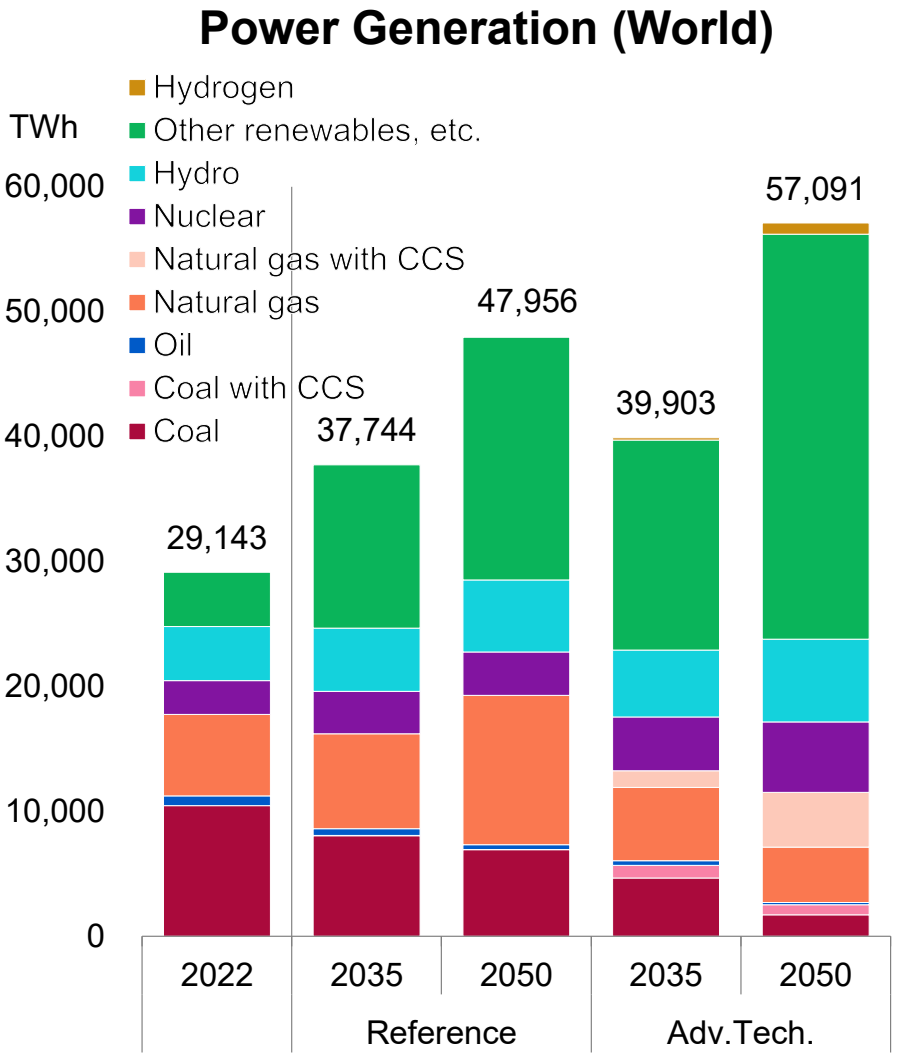
Average fuel economy of passenger vehicles (Adv.Tech., World)



Average years of equipment use (example)

Sector	Facilities	Lifetime (year)
Industry	Blast Furnace	10～25
	Boiler	20～40
Buildings	Air Conditioner	10～20
	House	30～
Transport	Passenger Vehicles	10～15
	Airplanes	20～30
Power	Thermal	25～40
	Solar PV	15～30

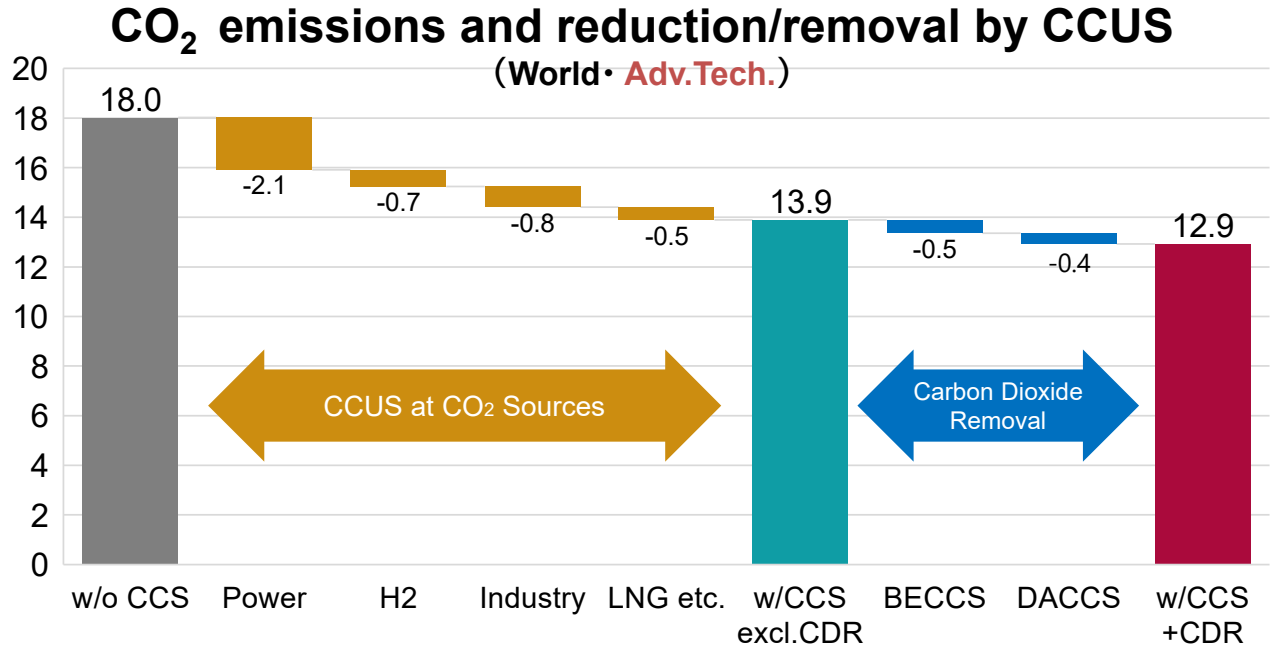
2) Renewables: 60% in Advanced, with Total Generation Increasing Significantly



- **Power generation in 2050 requires 1.6x (Reference) and 2.0x (Adv.Tech.) vs. 2022 levels.**
  - Substantial power demand increase is unavoidable in both scenarios.
  - Particularly in emerging/developing economies; urgent need for generation and transmission expansion.
- **Adv.Tech.: "Renewables (excl. hydro)" increase dramatically to 60% of power.**
  - Mostly solar and wind; implementation at this scale requires fundamental intermittency countermeasures.
- **Nuclear expands particularly in emerging/developing economies.**

3) CCUS: Major Deployment Potential in Industry and Power Generation

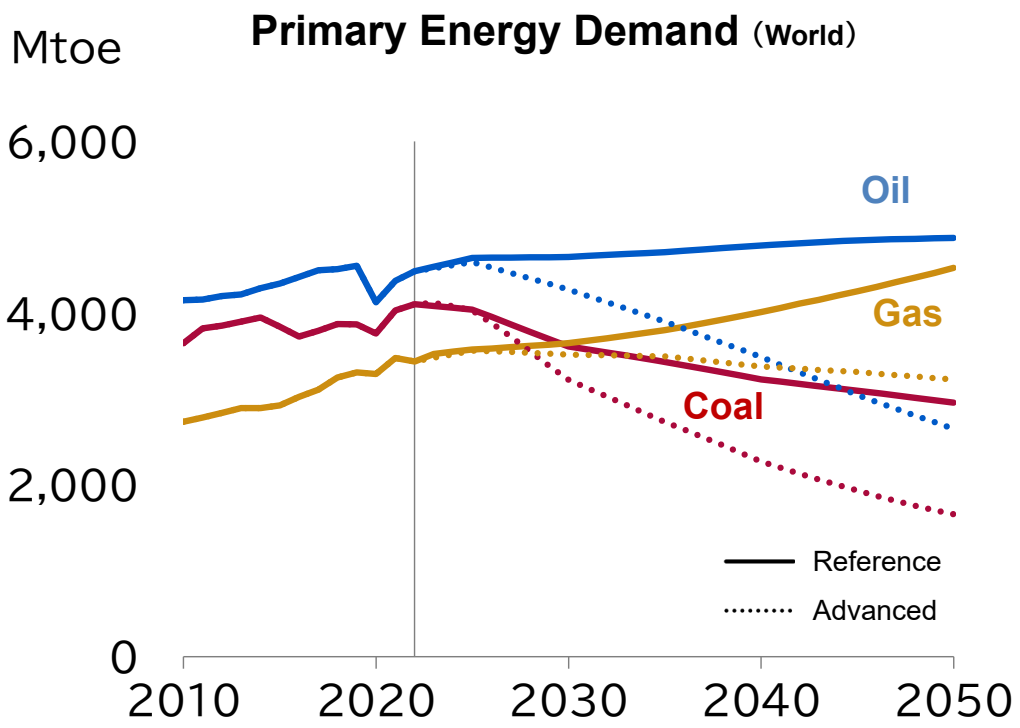
- **Adv.Tech.** projects total CCUS deployment of 5.1 Gt-CO_2 by 2050.
  - Power sector shows largest reduction potential for point-source CCUS.
  - In industrial sector, CCUS becomes a key decarbonization method for sectors with limited electrification potential, like steel and cement.
  - Carbon removal (BECCS, DACCS* in this outlook) expected to be higher cost but valuable for offsetting residual emissions.

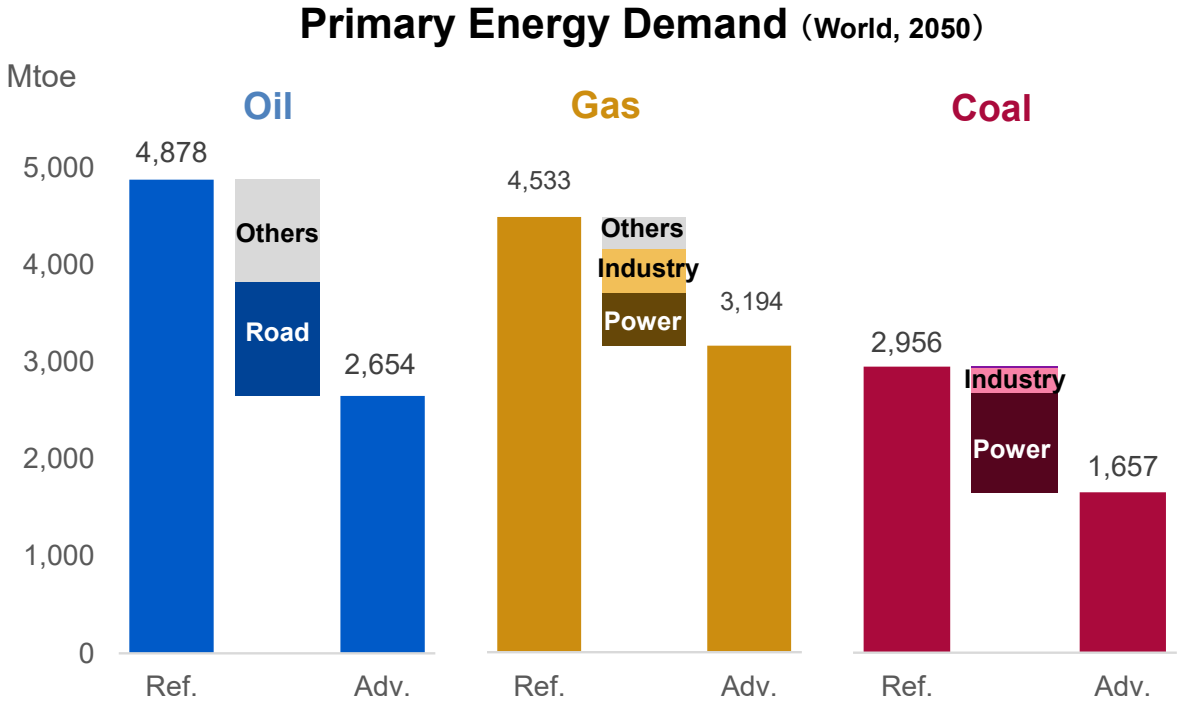


*BECCS: Bioenergy with CCS, DACCS: Direct Air Carbon Capture and Storage
Both qualify as negative emission technologies directly reducing atmospheric CO_2

Fossil Fuel Demand Uncertainty: Wide Gap Between Scenarios

- Large divergence in fossil fuel demand between **Reference** and **Adv.Tech.** scenarios. While pursuing energy transition, stable fossil fuel supply remains necessary.
  - Oil shows the largest demand difference, with road transport accounting for over half. Uncertainty in EV/HEV adoption, and ICE efficiency improvements.
  - Natural gas and coal demand differences primarily driven by power generation and industry.

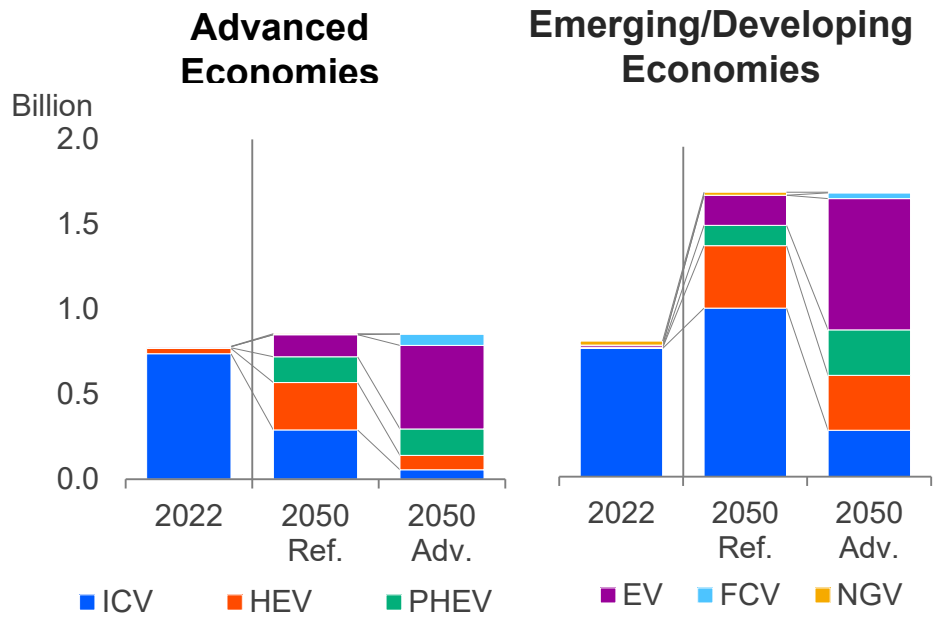




Transition in Powertrain for Vehicles: Behind Large Uncertainty in Global Oil Demand

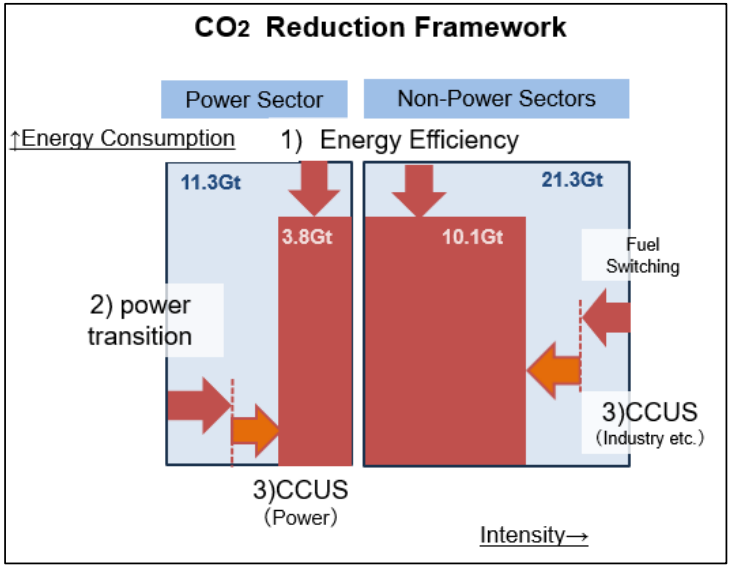
- [Reference] Oil Consumption from ICV/HEV grows significantly in emerging economies.
  - Vehicle ownership in emerging/developing economies will double by 2050 from 2022.
  - Oil demand varies greatly depending on fuel efficiency improvements and powertrain choices.
- [Adv.Tech.] Efficiency improves by EV/PHEV.
  - While EVs see mass adoption, ICEs and hybrids maintain presence especially in emerging/developing economies. Vehicle choice important based on power mix, range requirements, and usage frequency.

Vehicle Ownership（By Powertrain）



Summary

- ✓ CO_2 reduction relies primarily on (1) energy efficiency, (2) renewables, and long-term (3) CCUS. [Adv.Tech.]
  - Energy efficiency enhancement provides 6.2 Gt-CO_2 reduction; early action essential due to implementation lag.
  - Renewables (excl. hydro) covers around 60% of total generation; variable renewable capacity exceeds twice average load.
  - CCUS promising for large emission sources in power and industry; 5.1 Gt-CO_2/year capture (including CDR).

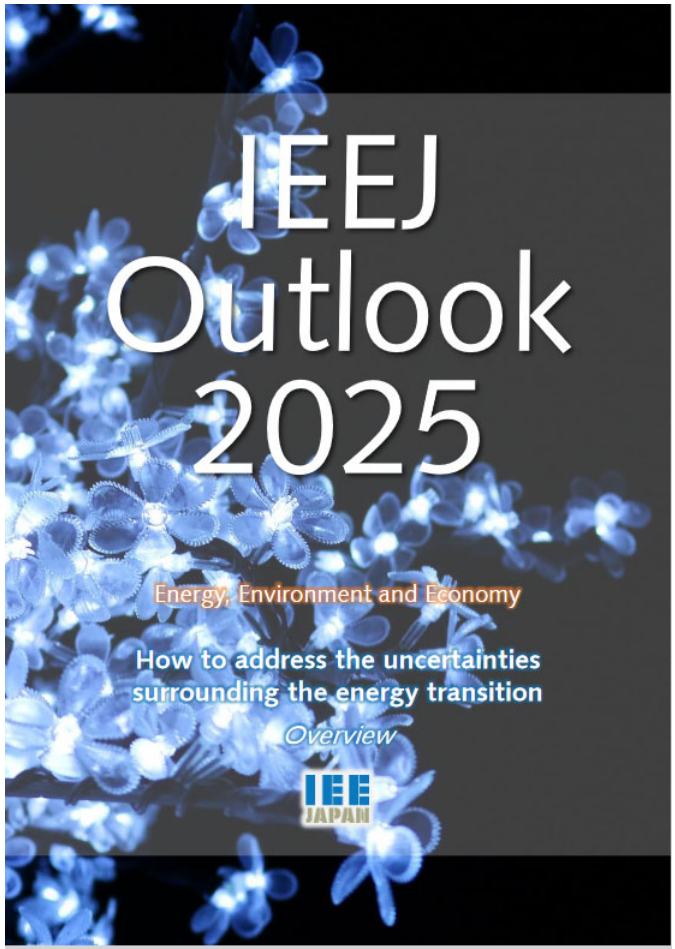


- ✓ **Primary Demand and Power Generation Trends**
  - **India, ASEAN show dramatic primary energy demand increase.** International climate action must include these regions.
  - Global power generation in 2050: 1.6x [Reference], 2.0x [Adv. Tech.] vs. 2022.

- ✓ **Significant Fossil Fuel Demand Uncertainty.**
  - Under current trends, gas and oil demand may continue growing through 2050.
  - Uncertainty drivers: road transport for oil; industry and power generation for gas/coal.
  - Stable fuel supply remains critical through 2050.

Thank you for your attention.

- Summary and Tables are available on IEEJ website.



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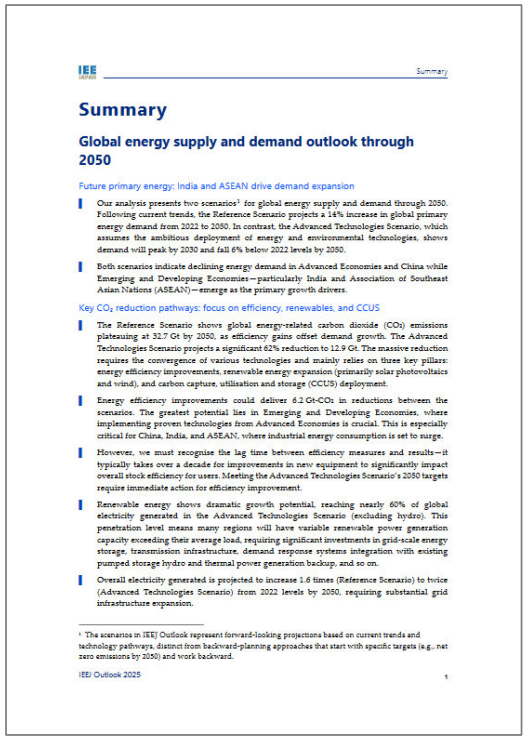

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Summary

Summary

Global energy supply and demand outlook through 2050

Future primary energy: India and ASEAN drive demand expansion

- Our analysis presents two scenarios[1] for global energy supply and demand through 2050. Following current trends, the Reference Scenario projects a 14% increase in global primary energy demand from 2022 to 2050. In contrast, the Advanced Technologies Scenario, which assumes the ambitious deployment of energy and environmental technologies, shows demand will peak by 2030 and fall 6% below 2022 levels by 2050.
- Both scenarios indicate declining energy demand in Advanced Economies and China while Emerging and Developing Economies—particularly India and Association of Southeast Asian Nations (ASEAN)—emerge as the primary growth drivers.

Key CO_2 reduction pathways: focus on efficiency, renewables, and CCUS

- The Reference Scenario shows global energy-related carbon dioxide (CO_2) emissions plateauing at 32.7 Gt by 2050, as efficiency gains offset demand growth. The Advanced Technologies Scenario projects a significant 62% reduction to 12.9 Gt. The massive reduction requires the convergence of various technologies and mainly relies on three key pillars: energy efficiency improvements, renewable energy expansion (primarily solar photovoltaics and wind), and carbon capture, utilisation and storage (CCUS) deployment.
- Energy efficiency improvements could deliver 6.2 Gt-CO_2 in reductions between the scenarios. The greatest potential lies in Emerging and Developing Economies, where implementing proven technologies from Advanced Economies is crucial. This is especially critical for China, India, and ASEAN, where industrial energy consumption is set to surge.
- However, we must recognise the lag time between efficiency measures and results—it typically takes over a decade for improvements in new equipment to significantly impact overall stock efficiency for users. Meeting the Advanced Technologies Scenario's 2050 targets require immediate action for efficiency improvement.
- Renewable energy shows dramatic growth potential, reaching nearly 60% of global electricity generated in the Advanced Technologies Scenario (excluding hydro). This penetration level means many regions will have variable renewable power generation capacity exceeding their average load, requiring significant investments in grid-scale energy storage, transmission infrastructure, demand response systems integration with existing pumped storage hydro and thermal power generation backup, and so on.
- Overall electricity generated is projected to increase 1.6 times (Reference Scenario) to twice (Advanced Technologies Scenario) from 2022 levels by 2050, requiring substantial grid infrastructure expansion.

[1] The scenarios in IEEJ Outlook represent forward-looking projections based on current trends and technology pathways, distinct from backward-planning approaches that start with specific targets (e.g., net zero emissions by 2050) and work backward.

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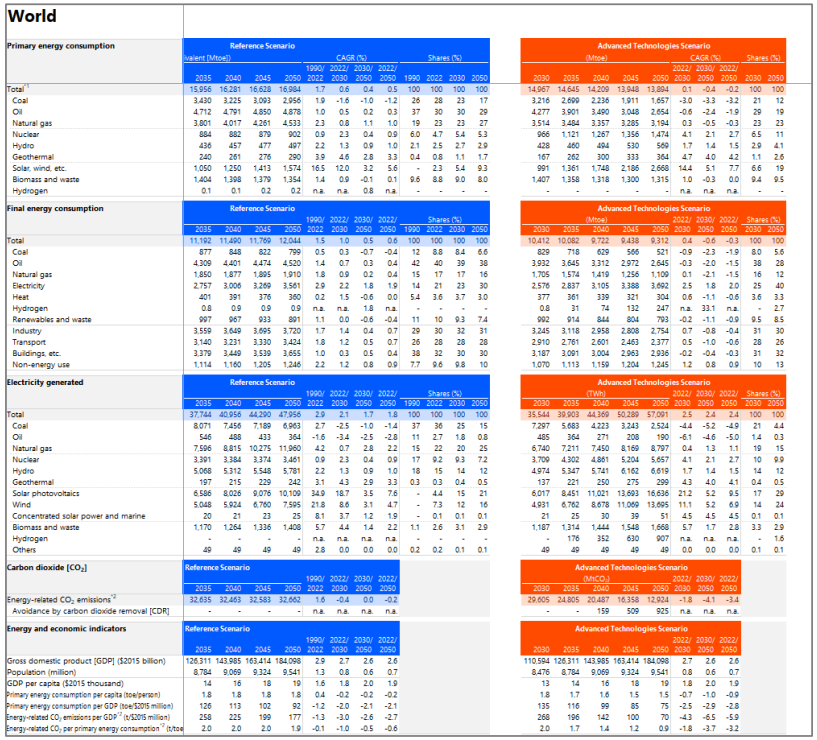

World

Primary energy consumption

	Reference Scenario (Mtoe)				CAGR (%)				Shares (%)				Advanced Technologies Scenario (Mtoe)				CAGR (%)			Shares (%)	
	2035	2040	2045	2050	1990/2022	2022/2030	2030/2050	2022/2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/2030	2030/2050	2022/2050	2030	2050
Total[1]	15,956	16,281	16,628	16,984	1.7	0.6	0.4	0.5	100	100	100	100	14,967	14,645	14,209	13,948	13,894	0.1	-0.4	-0.2	100	100
Coal	3,430	3,225	3,093	2,956	1.9	-1.6	-1.0	-1.2	26	28	23	17	3,216	2,699	2,236	1,911	1,657	-3.0	-3.3	-3.2	21	12
Oil	4,712	4,791	4,850	4,878	1.0	0.5	0.2	0.3	37	30	30	29	4,277	3,901	3,490	3,048	2,654	-0.6	-2.4	-1.9	29	19
Natural gas	3,801	4,017	4,261	4,533	2.3	0.8	1.1	1.0	19	23	23	27	3,514	3,484	3,357	3,285	3,194	0.3	-0.5	-0.3	23	23
Nuclear	884	882	879	902	0.9	2.3	0.4	0.9	6.0	4.7	5.4	5.3	966	1,121	1,267	1,356	1,474	4.1	2.1	2.7	6.5	11
Hydro	436	457	477	497	2.2	1.3	0.9	1.0	2.1	2.5	2.7	2.9	428	460	494	530	569	1.7	1.4	1.5	2.9	4.1
Geothermal	240	261	276	290	3.9	4.6	2.8	3.3	0.4	0.8	1.1	1.7	167	262	300	333	364	4.7	4.0	4.2	1.1	2.6
Solar, wind, etc.	1,050	1,250	1,413	1,574	16.5	12.0	3.2	5.6	-	2.3	5.4	9.3	991	1,361	1,748	2,186	2,668	14.4	5.1	7.7	6.6	19
Biomass and waste	1,404	1,398	1,379	1,354	1.4	0.9	-0.1	0.1	9.6	8.8	9.0	8.0	1,407	1,358	1,318	1,300	1,315	1.0	-0.3	0.0	9.4	9.5
Hydrogen	0.1	0.1	0.2	0.2	n.a.	n.a.	0.8	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

Final energy consumption

	Reference Scenario (Mtoe)				1990/2022	2022/2030	2030/2050	2022/2050	Shares (%)				Advanced Technologies Scenario (Mtoe)				2022/2030	2030/2050	2022/2050	Shares (%)	
	2035	2040	2045	2050					1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
Total	11,192	11,490	11,769	12,044	1.5	1.0	0.5	0.6	100	100	100	100	10,412	10,082	9,722	9,438	9,312	0.4	-0.6	-0.3	100	100
Coal	877	848	822	799	0.5	0.3	-0.7	-0.4	12	8.8	8.4	6.6	829	718	629	566	521	-0.9	-2.3	-1.9	8.0	5.6
Oil	4,309	4,401	4,474	4,520	1.4	0.7	0.3	0.4	42	40	39	38	3,932	3,645	3,312	2,972	2,645	-0.3	-2.0	-1.5	38	28
Natural gas	1,850	1,877	1,895	1,910	1.8	0.9	0.2	0.4	15	17	17	16	1,705	1,574	1,419	1,256	1,109	0.1	-2.1	-1.5	16	12
Electricity	2,757	3,006	3,269	3,561	2.9	2.2	1.8	1.9	14	21	23	30	2,576	2,837	3,105	3,388	3,692	2.5	1.8	2.0	25	40
Heat	401	391	376	360	0.2	1.5	-0.6	0.0	5.4	3.6	3.7	3.0	377	361	339	321	304	0.6	-1.1	-0.6	3.6	3.3
Hydrogen	0.8	0.9	0.9	0.9	n.a.	n.a.	1.8	n.a.	-	-	-	-	0.8	31	74	132	247	n.a.	33.1	n.a.	-	2.7
Renewables and waste	997	967	933	891	1.1	0.0	-0.6	-0.4	11	10	9.3	7.4	992	914	844	804	793	-0.2	-1.1	-0.9	9.5	8.5
Industry	3,559	3,649	3,695	3,720	1.7	1.4	0.4	0.7	29	30	32	31	3,245	3,118	2,958	2,808	2,754	0.7	-0.8	-0.4	31	30
Transport	3,140	3,231	3,330	3,424	1.8	1.2	0.5	0.7	26	28	28	28	2,910	2,761	2,601	2,463	2,377	0.5	-1.0	-0.6	28	26
Buildings, etc.	3,379	3,449	3,539	3,655	1.0	0.3	0.5	0.4	38	32	30	30	3,187	3,091	3,004	2,963	2,936	-0.2	-0.4	-0.3	31	32
Non-energy use	1,114	1,160	1,205	1,246	2.2	1.2	0.8	0.9	7.7	9.6	9.8	10	1,070	1,113	1,159	1,204	1,245	1.2	0.8	0.9	10	13

Electricity generated

	Reference Scenario (TWh)				1990/2022	2022/2030	2030/2050	2022/2050	Shares (%)				Advanced Technologies Scenario (TWh)				2022/2030	2030/2050	2022/2050	Shares (%)	
	2035	2040	2045	2050					1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
Total	37,744	40,956	44,290	47,956	2.9	2.1	1.7	1.8	100	100	100	100	35,544	39,903	44,369	50,289	57,091	2.5	2.4	2.4	100	100
Coal	8,071	7,456	7,189	6,963	2.7	-2.5	-1.0	-1.4	37	36	25	15	7,297	5,683	4,223	3,243	2,524	-4.4	-5.2	-4.9	21	4.4
Oil	546	488	433	364	-1.6	-3.4	-2.5	-2.8	11	2.7	1.8	0.8	485	364	271	208	190	-6.1	-4.6	-5.0	1.4	0.3
Natural gas	7,596	8,815	10,275	11,960	4.2	0.7	2.8	2.2	15	22	20	25	6,740	7,211	7,450	8,169	8,797	0.4	1.3	1.1	19	15
Nuclear	3,391	3,384	3,374	3,461	0.9	2.3	0.4	0.9	17	9.2	9.3	7.2	3,709	4,302	4,861	5,204	5,657	4.1	2.1	2.7	10	9.9
Hydro	5,068	5,312	5,548	5,781	2.2	1.3	0.9	1.0	18	15	14	12	4,974	5,347	5,741	6,162	6,619	1.7	1.4	1.5	14	12
Geothermal	197	215	229	242	3.1	4.3	2.9	3.3	0.3	0.3	0.4	0.5	137	221	250	275	299	4.3	4.0	4.1	0.4	0.5
Solar photovoltaics	6,586	8,026	9,076	10,109	34.9	18.7	3.5	7.6	-	4.4	15	21	6,017	8,451	11,021	13,693	16,636	21.2	5.2	9.5	17	29
Wind	5,048	5,924	6,760	7,595	21.8	8.6	3.1	4.7	-	7.3	12	16	4,931	6,762	8,678	11,069	13,695	11.1	5.2	6.9	14	24
Concentrated solar power and marine	20	21	23	25	8.1	3.7	1.2	1.9	-	0.1	0.1	0.1	21	25	30	39	51	4.5	4.5	4.5	0.1	0.1
Biomass and waste	1,170	1,264	1,336	1,408	5.7	4.4	1.4	2.2	1.1	2.6	3.1	2.9	1,167	1,314	1,444	1,568	1,667	5.7	1.7	2.8	3.3	2.9
Hydrogen	-	-	-	-	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	176	352	630	907	n.a.	n.a.	n.a.	-	1.6
Others	49	49	49	49	2.8	0.0	0.0	0.0	0.2	0.2	0.1	0.1	49	49	49	49	49	0.0	0.0	0.0	0.1	0.1

Carbon dioxide [CO_2]

	Reference Scenario				1990/2022	2022/2030	2030/2050	2022/2050	Advanced Technologies Scenario ($MtCO_2$)				2022/2030	2030/2050	2022/2050
	2035	2040	2045	2050					2030	2035	2040	2045	2050			
Energy-related CO_2 emissions[2]	32,635	32,463	32,583	32,662	1.6	-0.4	0.0	-0.2	29,605	24,805	20,487	16,358	12,924	-1.8	-4.1	-3.4
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	n.a.	n.a.	n.a.	n.a.	-	-	159	509	925	n.a.	n.a.	n.a.

Energy and economic indicators

	Reference Scenario				1990/2022	2022/2030	2030/2050	2022/2050	Advanced Technologies Scenario				2022/2030	2030/2050	2022/2050
	2035	2040	2045	2050					2030	2035	2040	2045	2050			
Gross domestic product [GDP] ($2015 billion)	126,311	143,985	163,414	184,098	2.9	2.7	2.6	2.6	110,594	126,311	143,985	163,414	184,098	2.7	2.6	2.6
Population (million)	8,784	9,069	9,324	9,541	1.3	0.8	0.6	0.7	8,476	8,784	9,069	9,324	9,541	0.8	0.6	0.7
GDP per capita ($2015 thousand)	14	16	18	19	1.6	1.8	2.0	1.9	13	14	16	18	19	1.8	2.0	1.9
Primary energy consumption per capita (toe/person)	1.8	1.8	1.8	1.8	0.4	-0.2	-0.2	-0.2	1.8	1.7	1.6	1.5	1.5	-0.7	-1.0	-0.9
Primary energy consumption per GDP (toe/$2015 million)	126	113	102	92	-1.2	-2.0	-2.1	-2.1	135	116	99	85	75	-2.5	-2.9	-2.8
Energy-related CO_2 emissions per GDP[3] (t/$2015 million)	258	225	199	177	-1.3	-3.0	-2.6	-2.7	268	196	142	100	70	-4.3	-6.5	-5.9
Energy-related CO_2 per primary energy consumption[3] (t/toe)	2.0	2.0	2.0	1.9	-0.1	-1.0	-0.5	-0.6	2.0	1.7	1.4	1.2	0.9	-1.8	-3.7	-3.2