Energy

Figures current as of October 2026

The global energy system: oil, gas, and coal; electricity, nuclear, renewables, and storage; demand, policy, and geopolitics. With the data, worked examples, and the 2026 Hormuz crisis throughout.

MODULE 1 — Foundations: Units, Sources, and the Mix

Goal: Set the vocabulary and the numbers the rest of the course uses.

Energy against power, the units in a conversion table, world energy and electricity by source, the mix by country, the accounting conventions that change the answers, and energy return on investment.

MODULE 2 — A Brief History: Transitions That Were Additions

Goal: Show how each source arrived and what it displaced, which was usually nothing.

Wood to coal to oil to gas to electricity in a timeline table; the shocks of 1973, 1979, 2008, 2022, and 2026; and why new sources have stacked on old ones.

MODULE 3 — Oil: The Resource and the Industry

Goal: Cover where oil comes from, who produces it, and how the industry is built.

Reserves, production, and consumption by country; the shale revolution; upstream, midstream, and downstream; the national companies, the majors, and the independents; crude grades and refining.

MODULE 4 — Oil Markets: OPEC+, Prices, and the 2026 Shock

Goal: Explain how the price forms and what the 2026 war did to it.

The price record, OPEC+ and the UAE's exit, the 2014-16 price war, a netback worked, and the Hormuz crisis from the February 28 strikes to October, with the flows, prices, and stocks.

MODULE 5 — Natural Gas: Pipelines and Regional Markets

Goal: Cover the fuel that runs on pipes and its three regional prices.

Production and consumption by country; Henry Hub, TTF, and JKM; Europe's break with Russia and the law that ends it; and gas as bridge, backstop, and methane problem.

MODULE 6 — LNG: The Global Gas Market

Goal: Explain the ships and terminals that made gas a world commodity.

Exporters and importers, the American tolling model, a Gulf Coast train's economics worked, contracts and the spot market, and the loss of Qatar's exports in 2026.

MODULE 7 — Coal: The Fuel That Will Not Die

Goal: Cover the largest single source of electricity and of emissions.

Production and consumption by country, why coal persists in Asia, its economics and its American politics, and the 2026 record that the gas shortage produced.

MODULE 8 — The Grid: How Electricity Moves

Goal: Explain the machine that must balance its product every second.

Generation, transmission, and distribution; frequency and voltage; the mix by country; connection queues and equipment shortages; Texas in 2021 and Iberia in 2025; and who owns the wires.

MODULE 9 — Electricity Markets and Prices

Goal: Explain how the price of a megawatt-hour forms and who pays it.

The merit order worked, the wholesale markets, retail prices by country, PJM's capacity auctions, negative prices, and the 2022 European crisis.

MODULE 10 — Nuclear: The Fleet and the Revival

Goal: Cover the largest source of clean firm power and its second life.

The fleet by country, the accidents that stopped the building, the cost of new reactors from Vogtle to Hinkley, the 2024-26 revival, and the argument over whether the West can build again.

MODULE 11 — Nuclear: Small Modular Reactors, the Fuel Cycle, and Fusion

Goal: Cover the next reactors and the fuel behind them.

Small modular reactors and their licenses, the fuel cycle from mine to repository, Russia's place in enrichment, the uranium price, and fusion's status.

MODULE 12 — Solar

Goal: Explain the cheapest electricity in history and its limits.

The cost curve, additions by country, the Chinese supply chain and its consolidation, a solar farm's economics worked in Texas and Xinjiang, and the limits of a source that sets every evening.

MODULE 13 — Wind

Goal: Cover onshore wind's maturity and offshore wind's troubles.

Capacity and additions by country, turbine economics, the offshore crisis and the American halt, and the turbine makers.

MODULE 14 — Hydro, Geothermal, and Bioenergy

Goal: Cover the older renewables and the newest one.

Hydropower's scale and its exposure to drought, geothermal from volcanic fields to enhanced wells, biofuels' claim on crops, and the argument over burning wood for power.

MODULE 15 — Storage

Goal: Explain the technology that lets variable power be used when it is needed.

The 2025 battery record, the duration ladder, the economics and the long-duration gap, and how a grid battery earns its money.

MODULE 16 — Hydrogen and the Molecules

Goal: Assess hydrogen, ammonia, e-fuels, and carbon capture against their numbers.

The colors and costs, the shrinking project pipeline, where hydrogen makes sense, ammonia and e-fuels, and carbon capture's record.

MODULE 17 — Demand: Who Uses Energy and How

Goal: Cover the consumption side by sector, country, and use.

Demand by sector and per person; efficiency and electrification; EVs, heat pumps, and air conditioning; and the industries that resist electricity.

MODULE 18 — Data Centers and the AI Load

Goal: Give the decade's largest new source of electricity demand its own module.

The forecasts and the argument over their size, the connection and turbine bottlenecks, the hyperscalers' power deals, and the cost to other customers worked.

MODULE 19 — Energy Access and the Developing World

Goal: Cover the people who use too little energy.

Access by region, clean cooking, Africa's grid gap and the distributed answer, Pakistan's rooftop revolution, and the finance problem after the aid cuts.

MODULE 20 — Policy: The US Reversal, Europe, and China

Goal: Map the rules that decide what gets built.

The July 2025 US law and the executive orders, the argument over them, Europe's carbon market and border tax, Germany's Energiewende as a case, and China's plans and pledge.

MODULE 21 — The Geopolitics of Energy

Goal: Examine energy as power between states.

The chokepoints in 2026; Russia, the Gulf, China, and the United States as energy powers; sanctions and their evasion; and the minerals behind the transition.

MODULE 22 — Emissions, Climate, and the Transition's Economics

Goal: Assess where emissions stand and what the transition costs.

Emissions by country, the cost of electricity by source, the capital arithmetic, and the argument over whether the world is in a transition or only adding.

MODULE 23 — Where Things Stand, and What to Watch

Goal: Assemble the argument and name what moves next.

The course's argument on a page, the contradictions its evidence leaves open, the turning points and the assumptions they broke, a dated watch list, and a last word.

A note on the figures. Energy statistics come in rival conventions, so the course names its source and its basis each time. World energy totals are the Energy Institute's unless the text says otherwise. That count credits wind, solar, and hydro with the electricity they produce, and fossil fuels and nuclear with the heat they release, so clean sources look smaller in energy than they do in electricity. Oil prices are Brent futures settlements on the Intercontinental Exchange (ICE) unless the text calls them spot prices; in 2026 the physical (spot) price ran as much as $35 a barrel above the futures. Where the course reaches a contested question, it makes each side's case as its advocates make it, then gives the evidence and its own reading. It is education, not investment advice.

Key Numbers, as of October 2026

The production, capacity, prices, and flows the course relies on

Measure	Figure	Period	Source and release
World energy supply	600 exajoules (EJ), up 1.7%; fossil fuels 86%	2025	Energy Institute (EI), *Statistical Review of World Energy 2026* (June 30, 2026)
World electricity generated	About 32,000 terawatt-hours (TWh), up about 3%; coal 33%, renewables 34%, low-carbon sources 43%	2025	Ember, *Global Electricity Review 2026* (April 21, 2026); International Energy Agency (IEA), *Global Energy Review 2026* (April 20, 2026)
World oil demand	104.4 million barrels a day (mb/d) in 2025; 102.4 mb/d forecast for 2026	2025-26	US Energy Information Administration (EIA), *Short-Term Energy Outlook* (STEO), October 6, 2026; the IEA's September 2026 *Oil Market Report* has a 2.5 mb/d fall in 2026
Brent crude	$104.28 a barrel (ICE futures settlement); 2025 average $69 (spot)	October 8, 2026	ICE; EIA spot price series
West Texas Intermediate (WTI)	$91.49 a barrel (futures); 2025 average $65	October 8, 2026	New York Mercantile Exchange (NYMEX); EIA
Oil supply cut by the war	About 4.8 mb/d still shut in, down from a peak near 11 mb/d in May	September 2026	EIA STEO, October 2026
US crude production	13.66 mb/d (a record); 13.87 mb/d forecast for 2026	2025	EIA STEO, October 2026
US Strategic Petroleum Reserve	283 million barrels, the lowest since 1982	October 2, 2026	EIA weekly data
Natural gas prices	Henry Hub about $3 per million British thermal units (MMBtu); the Dutch Title Transfer Facility (TTF) about €80 per megawatt-hour (MWh), or about $26/MMBtu; the Japan Korea Marker (JKM) for Asian liquefied natural gas (LNG) about $26/MMBtu	October 6-9, 2026	EIA; ICE; S&P Global Platts via market data
EU gas storage	About 73% full, against a five-year average of about 87%	Early October 2026	Gas Infrastructure Europe (AGSI)
LNG trade	About 428 million tonnes (Mt), or 56.3 billion cubic feet a day (Bcf/d), a record	2025	International Group of LNG Importers (GIIGNL) data via the EIA (July 14, 2026)
Coal	8.84 billion tonnes (9.7 billion short tons) used, a record; 8.94 billion forecast for 2026; Newcastle thermal coal $149 a tonne	2025-26; price October 8, 2026	IEA, *Coal Mid-Year Update 2026* (September 10, 2026); ICE
Solar added	About 600-700 gigawatts (GW): over 600 (IEA), 664 (SolarPower Europe)	2025	IEA, *Global Energy Review 2026*; SolarPower Europe, *Global Market Outlook 2026-2030* (June 2026)
Wind added	165 GW; 1,299 GW installed in all	2025	Global Wind Energy Council (GWEC), *Global Wind Report 2026* (April 20, 2026)
Battery storage added	112 GW of power and 307 gigawatt-hours (GWh) of energy	2025	BloombergNEF (BNEF), *Energy Storage Market Outlook 1H 2026* (May 11, 2026)

Measure	Figure	Period	Source and release
Nuclear	2,702 TWh generated, a record; 413 reactors and 377 GW operating; 72 under construction	2025 (fleet at end-2025)	World Nuclear Association (WNA), *World Nuclear Outlook Report 2026*; International Atomic Energy Agency (IAEA)
Uranium	$89.63 a pound (spot)	September 30, 2026	Cameco, from UxC and TradeTech
Electric cars sold	Over 20 million, 25% of new cars	2025	IEA, *Global EV Outlook 2026* (May 20, 2026)
Data centers' electricity	485 TWh, up 17%	2025	IEA, *Key Questions on Energy and AI* (April 16, 2026)
Energy investment	$3.4 trillion: $2.2 trillion clean, $1.2 trillion fossil	2026 (planned)	IEA, *World Energy Investment 2026* (May 28, 2026)
Energy-related CO2	38.4 billion tonnes (gigatonnes, Gt), a record, up 0.4%	2025	IEA, *Global Energy Review 2026*
CO2 in the air	About 427 parts per million (ppm) on average; a May peak of 432 ppm	2025; May 2026	US National Oceanic and Atmospheric Administration (NOAA) and Scripps Institution of Oceanography, Mauna Loa
People without electricity	655 million, 86% of them in Sub-Saharan Africa	2024	IEA, International Renewable Energy Agency (IRENA), UN, World Bank, and World Health Organization (WHO), *Tracking SDG 7: The Energy Progress Report 2026* (June 2026)

Prices move daily; the dates in the third column are the dates of the figures, not of this course. Where two sources differ, both are named in the module that uses the figure.

Module 1 — Foundations

Units, Sources, and the Mix

Recommended Reading / Reference

Book: Vaclav Smil, *Energy and Civilization: A History*

Reference: The Energy Institute's *Statistical Review of World Energy 2026* (75th edition, June 2026); the IEA's *Global Energy Review 2026* (April 2026); Ember's *Global Electricity Review 2026* (April 2026); the EIA's *Short-Term Energy Outlook* (monthly)

1a. Energy and Power

Energy is the capacity to do work, and power is the rate at which energy is used. A kilowatt (kW) is a unit of power, while a kilowatt-hour (kWh) is a unit of energy: one kilowatt sustained for one hour, about what a small space heater uses in an hour.

The distinction matters because the industry's confusions live in it. A power plant rated at 1 gigawatt (GW), a million kilowatts, would produce 8,760 gigawatt-hours (GWh) in a year only if it ran flat out every hour, and a 1 GW solar farm produces about a quarter of that, because the sun sets and clouds pass. Actual output divided by the most a plant could produce is its capacity factor, the fraction that reconciles headlines about capacity, measured in GW, with the electricity that actually arrives, measured in GWh.

Unit	What it measures	Equals	Everyday scale
Kilowatt-hour (kWh)	Energy (electricity)	3.6 megajoules; 3,412 British thermal units (BTU)	A US home uses about 30 kWh a day; an electric car about 0.3 kWh a mile
Megawatt-hour (MWh)	Energy (wholesale electricity)	1,000 kWh	US wholesale power averages about $50/MWh in 2026 (EIA)
Terawatt-hour (TWh)	Energy (a nation's electricity)	1 billion kWh	The US generated about 4,500 TWh in 2025; the world about 32,000
Barrel (bbl)	Volume of oil	42 US gallons; 159 liters; about 5.8 million BTU, or 1.7 MWh	The world used about 104 million barrels a day (mb/d) of oil and other liquids in 2025
Million BTU (MMBtu)	Energy (natural gas)	About 1,000 cubic feet of gas; 0.293 MWh	In early October 2026 US gas sold near $3/MMBtu; European and Asian gas near $26
Billion cubic meters (bcm); billion cubic feet a day (Bcf/d)	Volume and flow of gas	1 bcm = 35.3 billion cubic feet; 1 Bcf/d sustained for a year ≈ 7.6 million tonnes of LNG	US exports of liquefied natural gas (LNG) average about 17.6 Bcf/d in 2026 (EIA forecast)
Exajoule (EJ); tonne of oil equivalent (toe)	Energy from all sources	1 EJ = 10^{18} joules = 23.9 million toe = 278 TWh	The world used about 600 EJ in 2025 (Energy Institute)
Gigawatt (GW)	Power (capacity)	1,000 megawatts (MW); a large reactor or gas plant is about 1 GW	Renewables were about half of the world's generating capacity at the end of 2025 (IRENA)
Capacity factor	Actual output ÷ maximum possible output	A percentage	Nuclear about 85-90%; combined-cycle gas about 50-60%; wind about 35%; solar 20-25%
Tonne of carbon dioxide (CO_2)	Emissions	1.1 US short tons	A coal plant emits about 1 tonne per MWh and a gas plant about 0.4; burning a barrel of oil emits about 0.43

1b. World Energy and Electricity by Source

Source	Share of world energy supply, 2025	Share of world electricity, 2025	2025-26	Note
Oil	33.5% (201 EJ)	About 3%	104 mb/d in 2025; a fall of about 2 mb/d forecast for 2026 on the Hormuz crisis	Transport and petrochemicals
Coal	27.7% (166 EJ)	33%	A record 8.84 billion tonnes in 2025, and a higher record forecast for 2026	Still the largest single source of electricity and of CO2
Natural gas	25.1% (151 EJ; 4,186 bcm)	22%	Up 1.6% in 2025	Power, heat, industry, and fertilizer
Nuclear	5.2% (31 EJ)	9%	Record output in 2025	Counted by the heat its reactors produce
Hydropower	2.7% (16 EJ)	14%	Flat; exposed to drought	The largest renewable source of electricity
Wind	1.6% (10 EJ)	8.5%	165 GW added in 2025	China added about 70% of it
Solar	1.7% (10 EJ)	8.7%	600-700 GW added in 2025	Passed wind in 2025; almost level with nuclear
Other renewables (modern bioenergy, geothermal)	2.6% (16 EJ)	About 3%	Slow growth	Excludes wood and dung burned for cooking
Total	600 EJ	About 32,000 TWh	Energy up 1.7%; electricity up about 3%	Fossil fuels: 86% of energy, 57% of electricity

Energy Institute, *Statistical Review of World Energy 2026*, on its physical-content basis; electricity shares from Ember, *Global Electricity Review 2026*. The EI's total leaves out traditional biomass; the IEA, which includes it, counts 655 EJ for 2025, about 80% of it fossil.

The world used about 600 exajoules of energy in 2025 on the Energy Institute's count, and fossil fuels supplied 86% of it. On any accounting their share has fallen by only a few percentage points since 1990, because total demand grew almost as fast as the clean sources that were added at a record pace.

The accounting matters. The Energy Institute counts a kilowatt-hour from a wind turbine as the energy it delivers, but it counts coal, gas, and nuclear by the heat they release, about two-thirds of which a power plant loses. On that basis wind and solar together are only about 3% of world energy, so electricity is the better gauge: wind and solar produced about 17% of the world's electricity in 2025, and low-carbon sources as a group about 43%.

Electricity was about 21% of final energy use in 2025 on the IEA's count, and it is the fastest-growing part, with demand up about 3% in 2025 against 1.3% for energy as a whole. Coal was still the largest single source of electricity, at 33%, but renewables taken together edged past it on Ember's count, at 34%, and the IEA calls the two level. Oil for transport and gas and coal for heat and industry are where the fuels burned directly, the 'molecules,' still dominate.

1c. The Mix by Country

Country	Share of world energy	Largest energy source	Electricity mix, 2025 (largest sources)	Note
China	About 27% (162 EJ)	Coal	Coal 55%, hydro 13%, solar 11%, wind 11%	Adds more of everything than anyone; imports 73% of its oil
United States	About 16%	Oil	Gas 40%, nuclear 17%, coal 16%, wind 10%, solar 9%	The largest producer of oil and gas
India	About 6.5% (39 EJ)	Coal	Coal 71%, solar 9%, hydro 9%, wind 5%	Imports 86% of its oil
Russia	About 5%	Gas	Gas 45%, coal 18%, nuclear 18%, hydro 17%	The largest gas reserves; exports redirected to Asia
Japan	About 3%	Oil	Gas 33%, coal 32%, solar 10%, nuclear 9%	Imports nearly all its fuel; restarting reactors
Germany	About 2%	Oil	Wind 27%, coal 21%, solar 18%, gas 17%; no nuclear since 2023	The Energiewende (Module 20)
Brazil	About 2%	Oil	Hydro 52%, wind 16%, solar 12%	The cleanest large grid; cane ethanol
Saudi Arabia	About 2%	Oil	Gas and oil, roughly 60:40	The largest oil exporter before 2026
France	About 1.5%	Nuclear	Nuclear 69%, hydro 10%, wind 8%	Europe's largest power exporter
Nigeria	Under 0.5%	Traditional biomass and oil	Gas about three-quarters, hydro most of the rest	87 million people without electricity, the most of any country
World	600 EJ	Oil (33.5%)	Coal 33%, gas 22%, hydro 14%, nuclear 9%, solar 9%, wind 8.5%	

Energy shares approximate, from the Energy Institute (2026 edition for China, India, and the world); electricity mixes from Ember's 2025 data, rounded; Saudi and Nigerian mixes approximate. Oil import shares: Energy Institute. Nigeria: *Tracking SDG 7* (2026).

1d. Energy Return and the Shape of the System

Every energy source costs energy to obtain, and the ratio of energy delivered to energy invested, called energy return on investment (EROI), is a first test of a source's usefulness. Estimates vary with what is counted and researchers dispute them, so the ranges below are a common set rather than settled values.

Source	EROI: energy delivered for each unit invested
Conventional oil	About 20-30, down from about 100 in the 1930s
Shale oil	10-20
Oil sands	3-5
Coal	30-80
Hydro	50-100
Nuclear	20-80
Wind	15-30
Solar	10-20, and rising
Corn ethanol	Barely above 1

Published estimates; each study draws the boundary of what counts as energy invested differently.

Some researchers argue that a modern society needs a system-wide EROI of roughly 5-10 or more, an estimate rather than a law. For a system built on wind, solar, and storage, whose EROI falls as the best sites are used and rises as the technology improves, the engineering question is whether it clears that bar. The other structural fact is the shape of the system: the world runs on fuels burned directly, oil, gas, coal, and biomass, around a growing electric core, and the question of the next thirty years is how large that core grows and how much of the outer shell it replaces.

Module 1 Key Points

Foundations

• Power is a rate, energy an amount: 1 GW running flat out makes 8,760 GWh a year; solar manages about a quarter.

• The world used about 600 EJ of energy in 2025; fossil fuels supplied 86%, only a few points below their 1990 share.

• Clean sources look small in energy accounts that count fuels by their heat; in electricity, low-carbon sources supplied about 43% in 2025.

• Coal remained the largest single source of electricity in 2025, at 33%, though renewables together edged past it on Ember's count.

• Energy return on investment runs from about 1 for corn ethanol to 50-100 for hydro; modern societies may need 5-10.

Module 1 Quiz

Check Your Understanding

1. What is the difference between a kilowatt and a kilowatt-hour?

A) A kilowatt measures electricity sold at wholesale; a kilowatt-hour measures it at retail
B) A kilowatt-hour is a thousand kilowatts, the way a megawatt is a thousand kilowatts
C) A kilowatt measures a plant's capacity; a kilowatt-hour measures its capacity factor
D) A kilowatt is a rate; a kilowatt-hour is an amount

2. On the Energy Institute's count, what share of the world's energy did fossil fuels supply in 2025?

A) About 60%
B) About 86%, a few points below their 1990 share
C) About 70%, down from 90% in 1990
D) About 50%, after two decades of record growth in renewables

3. Why do wind and solar look small in the Energy Institute's measure of world energy supply?

A) It counts their electricity, but counts fuels by the heat they release
B) They supplied under 1% of the world's electricity in 2025
C) It leaves out rooftop solar and small turbines, which most countries do not meter
D) It counts only the capacity installed in a year, not the electricity the plants generated

4. What was the largest single source of the world's electricity in 2025?

A) Natural gas, at about 22%
B) Hydropower, at about 14%
C) Coal, at about 33%, though renewables together edged past it on Ember's count
D) Solar, which passed both nuclear and wind in 2025

5. What does EROI measure?

A) Energy delivered per unit of energy invested
B) A fuel's emissions per unit of energy
C) The share of a plant's capacity that it actually produces in a year
D) The price of a fuel's energy relative to oil's, on a per-joule basis

Module 2 — A Brief History

Transitions That Were Additions

Recommended Reading / Reference

Book: Daniel Yergin, *The Prize* and *The New Map*

Book: Jean-Baptiste Fressoz, *More and More and More: An All-Consuming History of Energy*

Era	Dominant source	What arrived	What it displaced	Shock or turning point
To 1800	Wood, muscle, water, wind	—	—	Deforestation; the pre-industrial ceiling
1800-1900	Coal	Steam engines, railways, steel, gas lighting, the first power stations (1882)	Wood in industry, though wood use kept rising	Britain's coal-based empire; coal about half of world energy by 1900
1900-1950	Coal, with oil rising	The internal combustion engine, the car, oil-fired navies, aviation, electric cities	Nothing: coal use kept rising	Churchill commits the Royal Navy's new battleships to oil (1912); the Texas and Persian finds
1950-1973	Oil	Cheap Middle East oil, petrochemicals, suburbs, jet travel; the first nuclear plants (1954-57); gas pipelines	Coal's share fell; its volume did not	The 'Seven Sisters' oil majors; the Organization of the Petroleum Exporting Countries (OPEC) founded (1960); US output peaks (1970)
1973-1986	Oil under stress	The 1973 embargo (price ×4) and the 1979 Iranian revolution (×2 again); France's reactors; the North Sea and Alaska; efficiency	Oil demand fell for the first time	Price controls end; the price collapses to about $10 (1986)
1986-2005	Cheap oil and gas	Gas turbines; electricity market reforms; Chernobyl (1986) halts reactor building; China's coal boom begins	—	Asian growth; the 2005-08 run to $147
2005-2020	Shale and renewables	US shale oil and gas (the US becomes the largest producer of both); solar's cost falls 90%; wind; the LNG boom; Fukushima (2011)	Coal in the US and Europe	2008's $147 and crash; the 2014-16 price war; a negative price in 2020
2020-2026	The security turn	Russia's invasion and Europe's gas break (2022); the Inflation Reduction Act (2022) and its partial rollback (2025); solar at 600-700 GW a year; the AI load; nuclear's revival; the Iran war (2026)	—	2022's gas crisis; 2026's oil and LNG shock

2a. Additions, Not Transitions

The word 'transition' misdescribes energy history. Coal did not replace wood, since the world burns more wood today than it did in 1800, and oil did not replace coal, whose use set a record in 2025. Gas, nuclear, and renewables have each been added to a growing total, their shares shifting while the volumes of the older sources kept rising, a pattern the historian Jean-Baptiste Fressoz calls accumulation.

That is why predictions of 'peak' production have failed for nearly every fuel; the clear exception was American conventional oil, which peaked in 1970, and shale reversed even that forty years later. The transitions that did happen were of use rather than of source: kerosene replaced whale oil for lighting, oil replaced coal in ships and cars, and gas replaced coal in American power plants. Each change came from a cheaper or better option for a particular job, not from policy.

The question of the 2020s is new: whether electricity from wind, solar, and nuclear can do to oil, gas, and coal what nothing has yet done to any fuel, which is to shrink its absolute volume while the world economy grows.

2b. The Shocks

Five shocks shaped the modern system, and the first is the template for the rest. In October 1973, after the Yom Kippur War began, Arab producers embargoed the United States and the Netherlands and cut their output, and by early 1974 the price had quadrupled, from about $3 a barrel to about $12, while American price controls turned the shortage into gasoline lines.

The responses outlasted the embargo, which ended in March 1974: importers founded the IEA in 1974, built strategic petroleum reserves, and wrote fuel-economy rules, and a decade of efficiency followed while the North Sea, Alaska, and France's reactors added supply. The lesson recurs through this course: a cartel's power lasts until the responses it provokes arrive.

The 1979 Iranian revolution doubled the price again, demand then fell for several years, and the price collapsed to about $10 in 1986. High prices from 2005 to 2008, peaking at $147 a barrel, financed the shale boom, which made the United States the largest oil and gas producer within a decade and then caused the 2014-16 price collapse (Module 4). Russia's 2022 invasion of Ukraine broke Europe's gas supply, sent European gas to ten times the American price, and turned energy policy everywhere toward security.

The fifth shock is the war with Iran that began on February 28, 2026, which closed and then crippled the Strait of Hormuz, the world's most important energy chokepoint. As of September 2026 the IEA expects world oil demand to fall by about 2.5 mb/d in 2026, the first annual fall since the pandemic year of 2020 (Module 4).

2c. What Each Era Left Behind

Each era's infrastructure outlives the era: the coal age left railways, steel, and the grid, and the oil age left the car, the suburb, and a petrochemical industry that makes plastics, fertilizer, and medicines. The gas age left pipelines and the turbines that now balance renewable grids, and the nuclear age left a fleet whose life extensions are the cheapest clean power available.

The shale decade left an American production base that acts as the world's swing supplier in a crisis, and in May 2026 the United States exported a record 5.9 mb/d of oil and products more than it imported. The system of 2026 is all of these layers at once, and any transition will be built on top of them.

Module 2 Key Points

A Brief History

• Energy history is addition, not transition: the world burns more wood than in 1800, and coal use set a record in 2025.

• The transitions that happened were of use, such as kerosene for whale oil, each driven by a cheaper or better option.

• The 1973 embargo quadrupled oil's price; its power lasted only until efficiency and new supply arrived.

• Five shocks shaped the system: 1973, 1979, 2008, 2022, and 2026, when Hormuz closed and oil demand is forecast to fall 2.5 mb/d.

• Old infrastructure outlives its era; shale made the US the swing supplier, with record net exports of 5.9 mb/d in May 2026.

Module 2 Quiz

Check Your Understanding

1. Why does the course call energy history a story of additions?

A) Each new fuel replaced the last within about fifty years of its arrival
B) New sources were added to a growing total
C) Policy, not cost, drove each change of fuel from wood to gas
D) Each source's volume fell once a cheaper one reached a fifth of the market

2. What does the 1973 embargo show about a cartel's power?

A) It is lasting once a cartel controls half of world exports
B) It ends only when importers ration fuel
C) It depends on members cutting output together, which they rarely manage for long
D) It lasts until the responses it provokes, efficiency and new supply, arrive

3. What did the high prices of 2005-08, peaking at $147, help produce?

A) OPEC's founding and its first quotas
B) France's nuclear building program
C) The shale boom that made the United States the world's largest oil and gas producer
D) The IEA and its members' strategic oil stocks

4. Which fuel's production clearly peaked, according to the module, and what followed?

A) US conventional oil in 1970, which shale reversed some forty years later
B) World coal in 2013, before India's growth
C) North Sea gas in 2000, never reversed
D) Wood in 1900, replaced by coal

5. What made the 2026 shock historically distinct?

A) It was the first oil price spike since the 2008 peak
B) It ended OPEC as a cartel when Saudi Arabia left
C) It closed the Strait of Hormuz
D) It cut American production more than any other country's

Module 3 — Oil: The Resource and the Industry

Where Oil Comes From, Who Produces It, and How the Industry Is Built

Recommended Reading / Reference

Book: Gregory Zuckerman, *The Frackers*

Reference: EIA *Short-Term Energy Outlook* (October 2026) and *International Energy Statistics*; OPEC *Annual Statistical Bulletin*; the Energy Institute's *Statistical Review of World Energy 2026*; company annual reports

3a. The Resource

Country	Proved reserves (billion bbl)	Production, 2025 (mb/d, all liquids)	Consumption, 2025 (mb/d)	Position	Note
United States	~45	23.7 (crude 13.7)	20.7	Net exporter of petroleum since 2020; a record 5.9 mb/d net in May 2026	Shale; the Permian Basin yields about half of US crude
Saudi Arabia	~267	11.2 (capacity about 12)	~4	The swing producer; crude output 6.0 mb/d in August 2026	Aramco; the East-West pipeline to Yanbu on the Red Sea
Russia	~80	10.5	~3.7	Exports redirected to India, China, and Turkey since 2022	Price cap; shadow fleet; US sanctions on Rosneft and Lukoil (2025)
Canada	~170 (oil sands)	6.3	~2.4	The largest source of US imports	The Trans Mountain expansion (2024)
Iraq	~145	4.5	~1	Exports almost all its crude through Hormuz	The largest shut-in of 2026: 2.8 mb/d in March
China	~26	5.5	16.6	The largest importer; imports 73% of its oil	Stockpiles; dependence on the Strait of Malacca
Iran	~209	4.8 (crude about 3.3 before the war)	~1.9	Sanctioned; sells mostly to China	The war's target; crude 2.2 mb/d in August 2026
United Arab Emirates	~113	4.3	~1	Left OPEC and OPEC+ on May 1, 2026	The Habshan-Fujairah pipeline bypasses Hormuz
Brazil	~15	4.7 (rising)	~2.5	The largest growth outside the US	Petrobras; deepwater 'pre-salt' fields
Kuwait	~102	2.8	~0.4	No route around Hormuz	Shut in during the closure
Venezuela	~303 (heavy)	1.0	~0.4	Sanctions eased in January 2026 after Maduro's capture	The largest reserves, little produced
Guyana	~11	0.75	—	The fastest-growing producer	Offshore fields led by ExxonMobil

Country	Proved reserves (billion bbl)	Production, 2025 (mb/d, all liquids)	Consumption, 2025 (mb/d)	Position	Note
India	~5	~0.7	~5.6	The third-largest importer; imports 86% of its oil	Jamnagar, the world's largest refining complex
Japan, Korea, Germany	small	small	1-3 each	Importers	Asia's dependence on the Gulf
World	~1,600-1,700	106.3	104.4 (2025); 102.4 forecast (2026)		Reserves equal 40-45 years of output

Production and the US, Chinese, and world consumption figures from the EIA's *Short-Term Energy Outlook* (October 2026); other consumption figures approximate. Reserves from OPEC and the *Oil & Gas Journal*, end of 2024; OPEC's world total leaves out most of Canada's oil sands. Import shares: Energy Institute.

The world produced about 106 million barrels a day of oil and other liquids in 2025 and used about 104 mb/d, according to the EIA, and the surplus filled storage tanks and pushed prices down through the year. Proved reserves, the oil known to be recoverable at today's prices and technology, are about 1.6-1.7 trillion barrels, or 40-45 years of current output. That ratio has stayed near 40-50 years for half a century, because discovery and technology keep replacing what is pumped.

Producers fall into three groups. The Gulf's national oil companies hold the largest reserves at the lowest costs, lifting a barrel in Saudi Arabia for under $10. The United States became the largest producer through shale, where firms needed $62-70 a barrel, $66 on average, to drill a new well profitably in the Dallas Fed's March 2026 survey. A long tail of national and international producers, from Russia to Brazil to Guyana, makes up the rest.

3b. The Shale Revolution

Shale oil and gas sit in rock too tight to flow on its own, and two techniques unlocked them. Horizontal drilling runs a well sideways through the rock for a mile or more, and hydraulic fracturing, or 'fracking,' cracks the rock with water, sand, and chemicals pumped at high pressure. George Mitchell's company made fracking pay in the Barnett Shale of Texas in the late 1990s, after years of trials, and Devon Energy, which bought the company in 2002, added horizontal wells. The method spread to Pennsylvania's Marcellus gas and to tight oil in North Dakota and the Permian Basin of West Texas and New Mexico.

Three conditions made the revolution American: landowners own the minerals beneath their land and can lease them, which few other countries allow, capital was cheap while oil sold above $100 a barrel from 2011 to 2014, and a deep industry of small independent drillers and service firms experimented quickly. US gas output roughly doubled, and crude output nearly tripled, from about 5 mb/d in 2008 to a record 13.66 mb/d in 2025.

A shale well costs about $6-10 million and pays back in one or two years, but its output falls steeply, so producers must keep drilling to stand still. That short cycle makes shale the most price-responsive supply in the world, the property that decided the 2014-16 price war (Module 4).

3c. The Industry

Segment	What it does	Economics	Leaders
Upstream (exploration and production)	Finds and extracts crude and gas	High capital and high risk; a deepwater well can cost over $100 million; a shale well $6-10 million, paying back in 1-2 years	Saudi Aramco, Abu Dhabi's ADNOC, Brazil's Petrobras, China's CNPC, Russia's Rosneft; ExxonMobil (with Pioneer), Chevron (with Hess), Shell, BP, TotalEnergies; shale firms such as ConocoPhillips, EOG, and Diamondback
Midstream (transport and storage)	Pipelines, tankers, terminals, storage	Toll-road economics: long contracts and regulated returns	Enbridge, Kinder Morgan, Energy Transfer, Enterprise Products; the tanker owners
Downstream (refining and marketing)	Turns crude into gasoline, diesel, jet fuel, and petrochemicals, and sells them	Thin, volatile margins ('crack spreads'); a refinery's complexity decides which crudes it can run	Sinopec, ExxonMobil, Shell, Reliance, Valero, Marathon, Phillips 66; the Gulf's new mega-refineries
Oilfield services	Drilling, fracking, seismic surveys, equipment	Cyclical with producers' spending	SLB, Halliburton, Baker Hughes; Chinese and Russian state firms
Trading	Moves cargoes between prices and places	Information and logistics; record private profits in 2022	Vitol, Trafigura, Glencore, Gunvor, Mercuria; the majors' and the Gulf companies' trading arms

The industry runs in three stages, upstream, midstream, and downstream, and a company can be integrated across all three, as ExxonMobil, Shell, and Aramco are, or specialize in one, as a shale producer, a pipeline operator, or an independent refiner does. The structure explains why the same price move helps some firms and hurts others: a crash in crude cuts producers' profits, but by lowering refiners' input costs it can widen their margins.

The largest producers are national companies, and Saudi Aramco alone produced about a tenth of the world's oil before the 2026 war. The service companies rent out the drilling and completion work that producers need, while the traders move the cargoes and earned the largest private profits in the industry's history in 2022.

3d. Crude Grades and Refining

Crude oil is not one product: it varies by density, from light to heavy on the gravity scale of the American Petroleum Institute (API), and by sulfur content, from 'sweet' to 'sour,' and every cargo is priced at a premium or discount to a benchmark. Brent, a light, sweet North Sea blend, prices about two-thirds of internationally traded crude, and West Texas Intermediate (WTI), delivered at Cushing, Oklahoma, is the American benchmark. Dubai and Oman, both sour, are the Gulf's benchmarks for sales to Asia.

Refineries are built for particular grades. America's Gulf Coast refineries were designed for heavy, sour crude from Venezuela and Mexico and run light shale oil less efficiently, while Asia's and the Gulf's new mega-refineries, such as Reliance's Jamnagar complex in India, can run almost anything. Refining capacity has shifted from Europe and North America, where old plants closed, to Asia and the Middle East.

That shift is why markets for diesel and jet fuel can tighten even when crude is ample. In 2026 the war cut off the Gulf refineries' product exports along with their crude, so diesel and jet fuel tightened first, and US exports of crude and products reached a record 13.6 mb/d in April.

Module 3 Key Points

Oil: The Resource and the Industry

• Proved reserves of 1.6-1.7 trillion barrels equal 40-45 years of output, a ratio stable for fifty years.

• The world produced about 106 mb/d of oil and liquids in 2025 and used 104 mb/d; the surplus pushed prices down.

• Horizontal drilling and fracking, on privately owned mineral rights, nearly tripled US crude output, to a record 13.66 mb/d in 2025.

• A shale well costs $6-10 million and declines fast, which makes shale the world's most price-responsive supply.

• Refineries are built for particular crudes; in 2026 the loss of Gulf product exports tightened diesel and jet fuel first.

Module 3 Quiz

Check Your Understanding

1. Why have proved oil reserves stayed near 40-50 years of output for half a century?

A) Demand has fallen each decade since 1970
B) Discovery and technology keep replacing what is pumped
C) OPEC's members report reserve figures that they have not revised since the 1980s
D) Consumption has been flat since the 1970s while the largest fields were still being found

2. What made the shale revolution an American story?

A) Federal drilling programs in Texas and North Dakota
B) Larger shale deposits than anywhere else on earth
C) A ban on oil imports after 1973 that forced domestic drilling and paid for new techniques
D) Private mineral rights, cheap capital, and many small independent drillers

3. Why does shale respond to prices faster than other oil supply?

A) It is exempt from OPEC+ quotas
B) Its oil is lighter and refines faster
C) Its producers hedge every barrel two years ahead, so they can drill whenever prices rise
D) Its wells are cheap, quick to drill, and decline fast

4. How can a crash in crude prices help a refiner?

A) Its input costs fall faster than its product prices
B) Governments pay refiners a subsidy whenever crude falls below $50
C) Demand for gasoline and diesel rises enough to fill every refinery to capacity
D) Producers must sell to refiners at a fixed discount when prices fall

5. Why did the 2026 war tighten diesel and jet fuel before crude?

A) Europe raised diesel taxes
B) Gulf refineries' product exports were cut off
C) A strike shut a third of the refining capacity on the Texas coast in the spring
D) Gasoline demand fell in the spring while diesel demand held at its winter peak

Module 4 — Oil Markets: OPEC+, Prices, and the 2026 Shock

How the Price Forms, and What the War Did to It

Recommended Reading / Reference

Reference: IEA *Oil Market Report* (monthly; September 2026); EIA *Short-Term Energy Outlook* (monthly; October 2026); EIA *Today in Energy* price reviews (July and October 2026); OPEC *Monthly Oil Market Report*; Kpler and Lloyd's List on Hormuz traffic

4a. The Price Record

Date	Brent ($ a barrel)	Event
1970	~2	Before the embargo; US output peaks
1974	~12	The Arab embargo quadruples the price
1980	~37 (about $140 in today's dollars)	The Iranian revolution
1986	~14 (lows near 10)	Saudi Arabia abandons its swing role; the collapse
1998	~13	The Asian financial crisis
July 2008	147 (peak)	The commodity boom's top; under $40 by December
2011-14	~110	The $100 plateau; shale's build-out
January 2016	~28	The low of the 2014-16 price war
April 2020	~20 (WTI futures −37 for a day)	The pandemic; negative prices at Cushing
June 2022	~120	Russia's invasion of Ukraine
2025 average	69 (spot)	OPEC+ unwinds cuts; supply exceeds demand
January 2026	67 (spot average)	Before the war; the EIA had forecast $56-58 for 2026
March 9, 2026	94 (futures)	Hormuz effectively closed
April 2026	117 (spot average); spot peak 138 on April 7	Gulf output shut in; spot runs a record $35 above futures
June 2026	85 (spot average)	The June 17 memorandum; flows recover
July 2, 2026	69 (spot)	The low before the memorandum collapses
July 23, 2026	Above 100 (futures)	Strikes resume July 7-8; the Houthis declare a blockade of Saudi Arabia
September 2026	114 (spot average); futures 100-109	The East-West pipeline shut on September 10-11
October 8, 2026	104.28 (futures settlement)	Record tanker attacks; the EIA forecasts $105 for the fourth quarter

Spot prices are the EIA's Brent series, a physical price; futures are ICE settlements. Sources: EIA, IEA, ICE.

4b. How the Price Forms

Oil's price is set at the margin by supply and demand for a commodity that is used almost as fast as it is produced, with a few months of inventories as the only buffer. In normal years demand grows about 1% and falls only in recessions, pandemics, and, in 2026, war.

Supply responds to price with a lag of months for shale and years for deepwater fields, and OPEC+ manages a large share of it by quota. Inventories rise and fall daily, and those builds and draws are the market's running signal, while Brent and WTI futures trade many times the volume of physical oil and are where the price is discovered.

The cushion is spare capacity, production that can be started within months, held almost entirely by Saudi Arabia and, before 2026, the United Arab Emirates (UAE). The war showed what happens when that cushion sits behind a closed strait: in August 2026 the IEA put OPEC+'s usable spare capacity at only 0.2 mb/d.

The war also split the physical price from the futures price, because a refiner that needed a cargo that week paid for scarce physical barrels while the futures price reflected expectations of a reopening. In mid-April the physical premium reached a record $35 a barrel.

4c. OPEC+

Member	Crude production	Role	2025-26
Saudi Arabia	9-10 mb/d before the war; 6.0 in August 2026 (capacity 12.1)	The swing producer; holds most spare capacity	Led the 2025 unwinding of cuts; rerouted exports to Yanbu
Russia	~9 mb/d; 8.4 in August 2026	Co-leader since 2016	Sanctioned; exports redirected to Asia
Iraq	~4.3 before the war	A chronic over-producer	2.8 mb/d shut in during March 2026
Kuwait	~2.5	A loyal member	Shut in during the closure
Iran	~3.3 before the war; 2.2 in August 2026	Exempt from quotas under sanctions	The war's target
Kazakhstan	~1.8	A chronic over-producer (the Tengiz field)	Quota disputes
Nigeria, Algeria, Libya, Venezuela, Oman, and others	0.5-1.5 each	The rest	Angola left OPEC in January 2024
United Arab Emirates	~3.5 (capacity about 5)	Wanted a larger quota	Left OPEC and OPEC+ on May 1, 2026
OPEC+ total	39.4 of 106.3 mb/d of world liquids in 2025; 34.8 of 101.1 in 2026 without the UAE	About 37% of supply in 2025	Cuts of 2.2 mb/d unwound by September 2025; spare capacity 0.2 mb/d in August 2026

EIA *Short-Term Energy Outlook* (October 2026); IEA *Oil Market Report* (September 2026); pre-war figures approximate.

OPEC was founded in 1960, and in 2016 it joined Russia and nine other producers to form OPEC+, which managed about 37% of world supply in 2025. Its record alternates between discipline and collapse: the 1986 price war, the 2014-16 attempt to break shale, the 2020 Saudi-Russian price war during the pandemic, and the cuts of 2022-24 that held Brent near $80.

The 2014-16 episode shows the limits of a cartel. As US shale added about 4 mb/d, Saudi Arabia refused to cut output, betting that a low price would kill high-cost shale, and Brent fell from about $115 in June 2014 to $28 in January 2016 as more than 100 North American producers went bankrupt. Shale did not die but cut costs through faster, longer, cheaper wells and resumed growing, so a falling cost curve beat the cartel's strategy, and OPEC then formed OPEC+ with Russia to cut together.

In 2025 the group reversed course, returning 2.2 mb/d of voluntary cuts to the market by September, a year ahead of plan, to regain market share and punish members producing over quota. Supply outran demand,

and Brent averaged $69 for the year. Then the war rewrote the group: Saudi, Iraqi, and Kuwaiti barrels were trapped behind the strait, and the UAE, long unhappy with its quota, left OPEC and OPEC+ on May 1, 2026. The seven members still adding barrels raised quotas by small steps, but in August 2026 the quota-bound members produced 7.3 mb/d below their targets, so the quotas had become theoretical.

4d. The 2026 Shock

Before the war about 20 mb/d of crude and oil products, a fifth of world use, passed through the Strait of Hormuz, along with about a fifth of the world's LNG. On February 28, 2026, American and Israeli strikes on Iran killed its Supreme Leader, Ali Khamenei, and Iran's Revolutionary Guards declared the strait closed to shipping.

Flows collapsed: in March crude and condensate through the strait fell by about 14 mb/d, to under 2 mb/d, and Qatar halted its LNG plants on March 2. The EIA estimates that Gulf producers shut in 7.5 mb/d that month, led by Iraq (2.8 mb/d), Saudi Arabia (1.9), Kuwait (1.3), and the UAE (1.1), and that shut-ins peaked near 11 mb/d in May.

Producers with pipelines around the strait used them. Saudi Arabia's East-West line, rated at 5 mb/d and expandable to about 7, carried crude to Yanbu on the Red Sea, where loadings reached 5.3 mb/d in April, and the UAE's Habshan-Fujairah line, rated at about 1.5-1.8 mb/d, reached the Gulf of Oman. Iraq, Kuwait, and Qatar had no such routes.

Governments drew on their stocks: on March 11 the IEA's members agreed to release 400 million barrels, the largest emergency release in its history, with 172 million from the United States. A two-week ceasefire began on April 7-8, but talks failed, and the US Navy blockaded Iran's ports from April 13. Iran declared the strait open on April 17 and futures fell 9%, but ships did not follow, and flows through the strait were only 2.7 mb/d in April and 1.9 mb/d in May.

A memorandum signed on June 17 restored passage for sixty days of talks, and Gulf exports rose to 16.1 mb/d in June, against about 24 mb/d before the war, while the spot price fell to $69 on July 2. The truce lasted three weeks: on July 7-8 Iran struck three tankers, the United States struck back, and the memorandum was declared over. On July 20 Yemen's Houthis declared a naval blockade of Saudi Arabia, threatening the Red Sea route that the Saudi bypass depended on.

September brought escalation: on September 9 tankers were attacked and the United States blockaded Iran's oil exports, and on September 10-11 Houthi strikes shut the East-West pipeline, which was partly restarted on September 22. The spot price averaged $114 for the month.

As of early October 2026, Iran says the strait stays closed until its conditions are met. Ships tracked by their transponders fell to 7-10 a day on October 6-7, against about 125 a day before the war, and a record ten tankers were struck in the week to October 4. Yet the oil moves in the dark: Kpler estimates that about 10 mb/d of crude still crossed in September on ships with transponders switched off, and the EIA puts the remaining shut-in at 4.8 mb/d.

The feared global shortage did not come, for three reasons. Demand fell, since as of September the IEA expects 2026 consumption to drop about 2.5 mb/d as high prices bite and the Gulf loses its own consumption. Stocks were drawn, as observed inventories fell by about 507 million barrels from February through August and the US Strategic Petroleum Reserve fell to 283 million barrels, its lowest since 1982. And supply shifted, with bypass pipelines running near capacity and American exports setting records. The EIA's October outlook has Brent at $105 in the fourth quarter, $96 for 2026, and $84 in 2027.

Worked example — A Netback From the Permian in the Shock

A netback is what a producer keeps from a barrel after transport, at the wellhead. A Permian producer sells crude at Midland, Texas, at WTI less a local discount of $1-2, and on October 8, 2026, WTI settled at $91.49 and Brent at $104.28, so the Midland barrel fetched about $90. Against it stand a lifting cost of about $12, a pipeline tariff to the Gulf Coast of about $3, and, for a new well, a full-cycle break-even of about $60-70 including the well's capital, so a new well earns $20-30 a barrel. At 2025's average WTI price of $65, the same well barely broke even. The industry's response is the market's response: the EIA expects US crude output to reach a record 13.87 mb/d in 2026. The gap between Brent and WTI also widened, from its usual $4-6 to about $13, a sign that the shortage is in seaborne crude and that American export capacity limits how much can reach it. A Gulf producer's netback is the mirror image, because Saudi crude loaded at Yanbu earned a premium while it flowed and Iraqi and Kuwaiti crude behind the strait earned nothing. The barrel's price is set globally; who earns it is set by geography.

Module 4 Key Points

Oil Markets: OPEC+, Prices, and the 2026 Shock

• Spare capacity is the market's cushion, but in August 2026 OPEC+ had only 0.2 mb/d it could actually deliver.

• OPEC+ unwound 2.2 mb/d of cuts in 2025, Brent averaged $69, and the UAE left the group in May 2026.

• The 2014-16 price war took Brent from $115 to $28, but shale cut costs and survived, and OPEC+ was born.

• The war shut in up to 11 mb/d of Gulf oil in May 2026; about 4.8 mb/d was still shut in during September.

• A record 400-million-barrel stock release, falling demand, and bypass pipelines averted a shortage; US strategic stocks hit a 1982 low.

• Brent futures settled at $104 on October 8, 2026; the EIA forecasts $105 for the fourth quarter and $84 for 2027.

Module 4 Quiz

Check Your Understanding

1. Why did spare capacity fail to cushion the 2026 shock?

A) OPEC+ refused to use it to punish importers
B) It had been sold forward to China years before
C) Most of it sat in Saudi Arabia and the UAE, behind the closed strait
D) Shale producers had already used it up in 2025

2. What did OPEC+'s return of 2.2 mb/d of cut output in 2025 do?

A) Raised Brent above $90
B) Ended the alliance with Russia that had held since 2016
C) Helped push Brent down to a $69 average
D) Cut US shale output by half within the year as drillers stopped work

3. What happened after Iran declared the strait open on April 17, 2026?

A) Futures fell, but tanker flows stayed low
B) Flows returned to normal within a week as insurers came back
C) Prices rose because traders doubted the declaration would hold for long
D) The IEA cancelled the rest of its stock release, since the strait was open

4. Why did the closure not produce a global oil shortage, on the module's account?

A) Iran kept exporting through the strait
B) OPEC+ raised its quotas
C) China sold its stockpiles to Europe under an emergency agreement with the IEA in March, ending the gap
D) Demand fell, stocks were drawn, and bypass pipelines and US exports filled part of the gap

5. In the netback example, why did US producers gain from the shock while Iraqi and Kuwaiti producers lost?

A) US crude is lighter and sells at a premium
B) Their barrels could reach the sea, while Gulf barrels behind the strait could not be sold
C) Washington paid them a wartime bonus
D) Their costs fell as the war cut demand for rigs

Module 5 — Natural Gas: Pipelines and Regional Markets

The Fuel That Runs on Pipes, and the Three Prices It Has

Recommended Reading / Reference

Reference: The Energy Institute's *Statistical Review of World Energy 2026*; IEA *Gas Market Report* (quarterly; third quarter of 2026); EIA *Short-Term Energy Outlook* (October 2026); Oxford Institute for Energy Studies, *Quarterly Gas Market Review*; the European Commission on the Russian gas phase-out

5a. The Resource and the Producers

Country	Production, 2025 (bcm)	Consumption, 2025 (bcm)	Reserves (tcm)	Position	Note
United States	1,074 (the largest)	913	~17	Exporter of LNG and pipeline gas	Shale gas: Marcellus, Permian, Haynesville
Russia	609	480	~48 (the largest)	Exporter that lost most of Europe	EU imports from Russia: 152 bcm (2021), 36 bcm (2025)
Iran	265	256	~34	Mostly domestic	South Pars, shared with Qatar
China	264	442	~7	The largest importer, about 178 bcm by pipeline and LNG	Imports more than a third of its gas
Canada	206	~125	~2	Exporter to the US; LNG from 2025	The Montney formation
Qatar	184	~45	~24	LNG exporter: 77 million tonnes a year before the war	LNG halted from March 2, 2026
Australia	149	~40	~2	LNG exporter	Gorgon, Wheatstone, Ichthys
Saudi Arabia	134	134	~9	Domestic	Replacing oil burned for power
Norway	121	~5	~1.5	Europe's largest pipeline supplier	The Troll field; pipelines to Germany and Britain
European Union	34 (falling)	329	small	Imports about 90% of its gas	Norway, LNG, North Africa, and a little Russian gas
Japan, Korea, Taiwan	negligible	90, 63, 31	none	LNG importers	The Gulf's customers
India	31	67	~1	Imports about half	City gas and fertilizer
World	4,197	4,186 (up 1.6%)	~200		LNG about 14% of use

Production and consumption: Energy Institute, *Statistical Review of World Energy 2026*. Reserves approximate, from the *Oil & Gas Journal* and the EIA; the Energy Institute no longer publishes them. bcm = billion cubic meters; tcm = trillion cubic meters (1 tcm = 35.3 trillion cubic feet).

Natural gas supplied about a quarter of the world's energy and a fifth of its electricity in 2025, when the world produced and used about 4,190 billion cubic meters. It fuels power plants, home heating, industrial heat, petrochemicals, and fertilizer, since the Haber-Bosch process that makes ammonia runs on it.

The United States produced a quarter of it from shale, while Russia, which holds the largest reserves, lost its main market. Iran and Qatar share the largest single field, South Pars-North Field, and China is the largest importer. Gas is cheap to burn but expensive to move, because it is a gas, not a liquid, so until LNG (Module 6) it was a regional fuel with regional prices, and it still has three.

5b. The Three Prices

Benchmark	Market	Price, early October 2026	2025 average	Set by	Note
Henry Hub	United States (a Louisiana pipeline hub; NYMEX futures)	About $3.0 per MMBtu	$3.53/MMBtu	Shale supply against US demand and LNG feedgas	EIA forecast: $3.48 for 2026, $3.16 for 2027
TTF (Title Transfer Facility)	Europe (the Dutch hub)	About €80/MWh (about $26/MMBtu)	About €36/MWh ($12/MMBtu)	LNG imports, Norwegian pipelines, storage, weather	About €30 before the war; September 2026 the highest month since December 2022
JKM (Japan Korea Marker)	Asia (spot LNG delivered to Northeast Asia)	About $26/MMBtu	About $12-13/MMBtu	Competition with Europe for cargoes; Chinese demand	Most Asian gas moves on oil-linked contracts
Oil-linked contracts	Asia and some of Europe	About 12-14% of the Brent price per MMBtu	—	Brent	A $100 barrel implies gas at $12-14

EIA (Henry Hub spot, October 6, 2026); ICE (TTF, October 9); Platts JKM via market data (October 8); 2025 averages from the EIA and the World Bank.

American gas costs a fraction of European and Asian gas because shale made the United States self-sufficient, and only as much gas can leave as its LNG terminals can liquefy, so Henry Hub is set by domestic supply and demand plus the gas fed to those terminals. Europe, having lost Russian pipeline gas, pays the world LNG price plus whatever it takes to draw cargoes away from Asia, which pays that price or oil-linked contract prices.

The three prices converge only through LNG, and in October 2026 European gas cost about $26 per MMBtu against about $3 in Louisiana. That gap of about $23 is the arbitrage that built the American LNG industry and the reason European chemical and fertilizer plants have been closing since 2022.

5c. Europe's Break With Russia

In 2021 Russia supplied 152 billion cubic meters, about 45% of the EU's gas imports, through pipelines built over fifty years, and Germany's industrial policy rested on the belief that mutual dependence made that supply safe. Russia cut flows through 2021-22, the Nord Stream pipelines were sabotaged in September 2022, and the Dutch TTF price closed near €340/MWh in August 2022, about ten times its usual level, with electricity prices following (Module 9).

Europe replaced the volume with Norwegian pipeline gas, with American and Qatari LNG landed at floating terminals built in months, and with demand cuts of 15-20%, while coal and nuclear plants served as

stopgaps. EU governments spent about €650 billion shielding households and firms by early 2023, on the Bruegel think tank's count. Ukraine's transit of Russian gas ended on January 1, 2025, and by 2025 Russia supplied 36 billion cubic meters, 12% of EU imports, mostly as LNG and through the TurkStream pipeline under the Black Sea.

An EU regulation that became law on January 26, 2026 ends the rest in stages, banning new contracts from March 2026 and short-term contracts from April (LNG) and June (pipeline gas). Long-term LNG contracts end on January 1, 2027, and long-term pipeline contracts on September 30, 2027, or November 1, 2027 if storage targets are at risk. Gazprom, which recorded its first annual loss in more than twenty years in 2023, returned to profit in 2025. The lesson every importer drew, Europe first and Asia in 2026, is that a single supplier is a single point of failure.

5d. Bridge, Backstop, and the Methane Problem

Gas is called a bridge fuel because a gas plant emits about half of a coal plant's CO2 per megawatt-hour and can be started in minutes, which makes it the backstop for wind and solar. It is how the United States cut its power-sector emissions by about a third since 2005, as gas displaced coal, and it is the fuel many data centers are building on (Module 18) as well as the feedstock of fertilizer.

The bridge's weak plank is methane, the main component of natural gas, which warms the climate about eighty times as much as CO2 over twenty years, so leaks from wells and pipelines above roughly 3% of output would erase gas's near-term climate advantage over coal. Satellite studies have found losses of 3.7% in the Permian Basin (2018-19 data) and about 1.6% averaged across twelve US basins. In March 2025 Congress voided the Environmental Protection Agency's (EPA's) rule for a federal methane fee, and the July 2025 budget law postponed the fee for ten years, while EU rules phase in methane-monitoring requirements for imported gas from 2027.

The 2026 war tested the backstop: Qatar halted its LNG plants on March 2, and the TTF price rose from about €30/MWh before the war to about €70 by March 9 and about €80 in October. The IEA expects Qatar's and the UAE's LNG output to fall about 45% in 2026, a loss of about 54 billion cubic meters, and EU storage stood about 73% full in early October, against a five-year average near 87%, with winter ahead. Pakistan imposed austerity measures, Bangladesh rationed gas, and Asian utilities burned more coal (Module 7).

Module 5 Key Points

Natural Gas: Pipelines and Regional Markets

• The world used about 4,190 bcm of gas in 2025, and the United States produced a quarter of it.

• Gas has three regional prices; in October 2026, TTF and JKM near $26/MMBtu were about eight times Henry Hub.

• Russia supplied 45% of EU gas imports in 2021 and 12% in 2025; an EU law ends the rest by late 2027.

• A gas plant emits about half of coal's CO2, but methane leaks above about 3% would erase that advantage.

• Losing Qatar's LNG lifted TTF from about €30 to €80/MWh and left EU storage near 73% before winter 2026.

Module 5 Quiz

Check Your Understanding

1. Why is American gas so much cheaper than European or Asian gas?

A) Shale supply, with exports capped by LNG capacity
B) American producers receive federal subsidies on every cubic meter
C) European gas is taxed at the border at rates set by the Commission
D) US gas is lower in energy content, so it sells at a discount on every unit

2. What does the EU regulation that became law in January 2026 do?

A) Caps TTF at €100 per MWh
B) Requires members to buy a quarter of their LNG from the US
C) Bans Russian gas in stages, ending long-term pipeline contracts by late 2027
D) Taxes imported LNG by its methane intensity

3. What share of the EU's gas imports came from Russia in 2025?

A) About 3%
B) About 12%, against 45% in 2021
C) About 30%, through TurkStream and LNG cargoes
D) About 40%, unchanged since 2021 because of long-term contracts

4. What is gas's weak point as a 'bridge' fuel?

A) Its price swings
B) It cannot be dispatched quickly
C) Its reserves will run out within a decade in the main exporting countries
D) Methane leaks, which above about 3% erase its advantage over coal

5. What did the 2026 loss of Qatar's LNG do to Europe's gas market?

A) Ended Europe's imports of US LNG
B) Lowered TTF as cargoes moved from Asia
C) Pushed TTF above its 2022 record of €340 in March, when Qatar's plants closed
D) Lifted TTF from about €30 to about €80 and slowed storage filling

Module 6 — LNG: The Global Gas Market

The Ships and Terminals That Made Gas a World Commodity

Recommended Reading / Reference

Reference: GIIGNL *Annual Report 2026*; EIA reporting on US LNG exports and on Hormuz LNG flows (2026); the IEA *Gas Market Report, Q3-2026*; Oxford Institute for Energy Studies, *Quarterly Gas Market Review*; Cheniere and Venture Global filings

6a. Exporters and Importers

Exporter	Exports, 2025	Share of world trade	Model	2026
United States	15.1 Bcf/d, about 115 Mt; peak capacity about 18 Bcf/d (140 Mt) by April 2026	~27%	Tolling: buyers pay a fee to liquefy gas priced off Henry Hub and ship it anywhere	Golden Pass's first cargo in April; Corpus Christi Stage 3 finished in August; exports forecast at 17.6 Bcf/d
Qatar	About 80 Mt (nameplate capacity 77 Mt a year)	~19%	QatarEnergy; oil-linked long-term contracts	Halted March 2; two of 14 trains damaged; force majeure extended through November
Australia	About 80 Mt	~18%	Long-term contracts to Japan, China, and Korea	Exports dipped in 2025 for maintenance
Russia	About 30 Mt (down 8%)	~7%	Yamal and Sakhalin; Arctic LNG 2 sanctioned	EU ban on long-term contracts from January 1, 2027
Others: Malaysia, Nigeria, Algeria, Indonesia, Oman, the UAE, Trinidad, Papua New Guinea	5-30 Mt each	~29% together	Mixed	The UAE's exports also cut by the war
Canada	LNG Canada's first cargo in June 2025	new	US-style gas shipped to Asia across the Pacific	The Pacific shortcut
World	About 428 Mt (56.3 Bcf/d), a record	100%		

Importer	Imports, 2025 (approximate)	Share	Main sources	Note
Europe (EU, Britain, Turkey)	About 128 Mt (up 29%)	~30%	US (the largest), Qatar, Russia, Algeria, Nigeria	Replacing Russian pipeline gas
China	About 65 Mt (down 15%)	~15%	Australia, Qatar, Russia, Malaysia	Fell on price and more pipeline gas
Japan	About 66 Mt	~15%	Australia, Malaysia, US	Declining as reactors restart
Korea	About 46 Mt	~11%	Qatar, Australia, US	Long-term contracts
India	About 26 Mt	~6%	Qatar, US	Price-sensitive
Egypt	About 9 Mt (1.2 Bcf/d, up from 0.3)	~2%	US, Qatar	Turned importer; the top destination for US LNG in early 2026

Importer	Imports, 2025 (approximate)	Share	Main sources	Note
Taiwan, Thailand, Bangladesh, Pakistan, and others	5-30 Mt each	~20% together	Spot and contract	Priced out in 2022 and again in 2026

EIA, from GIIGNL data (July 2026); Japan, Korea, and India estimated from Energy Institute consumption data. 1 Mt of LNG ≈ 1.36 bcm of gas.

Liquefied natural gas (LNG) is gas cooled to −162°C (−260°F), which shrinks it about 600-fold so it can cross oceans in insulated tankers, and it turned a regional fuel into a global commodity. About 428 million tonnes moved by sea in 2025, a record and about 14% of the world's gas use, and three exporters, the United States, Qatar, and Australia, supplied about two-thirds of it. Asia took about 63% of imports and Europe about 30%, after a 29% jump in 2025.

The United States became the largest exporter in 2023 on the tolling model, in which buyers pay a fixed fee for liquefaction and take gas priced at about 115% of Henry Hub, free to ship it anywhere. That freedom is why American cargoes went to Europe in 2022 and to Asia and Egypt in 2026, and the EIA expects US export capacity to nearly double between 2025 and 2031.

6b. Project Economics, Worked

Worked example — A US Gulf Coast LNG Train

A liquefaction 'train' is one processing line, and one that makes 5 million tonnes of LNG a year costs about $5-6 billion to build and buys about 0.7 billion cubic feet of gas a day. In October 2026 that gas cost about $3.45 per MMBtu (115% of a $3.00 Henry Hub), plus about $0.50 to bring it to the plant. Liquefaction uses about a tenth of the gas as fuel, and the buyer pays a tolling fee of $2.50-3.00 per MMBtu, the terminal's return on its capital. Shipping costs about $1.00-1.50 to Europe and $2.00-3.00 to Asia, and turning the LNG back into gas at the destination about $0.50, so the delivered cost is about $8-9 in Europe and $9-10 in Asia. Against TTF and JKM near $26 in early October 2026, a cargo of about 3.5 million MMBtu earned roughly $55-60 million, and in 2022, with European prices near $100 at the peak, a cargo could earn over $200 million. In a glut, with TTF at $8, the cargo earns little above its cash costs while the buyer still owes the tolling fee, which is the terminal owner's protection and the buyer's risk. A train pays back in 8-12 years on a 20-year contract, so the terminals built in 2026 will run into the 2050s.

6c. Contracts and the Spot Market

About two-thirds of LNG moves on long-term contracts of 15-20 years, historically oil-linked at about 12-14% of the Brent price per MMBtu, with destination clauses that forbade resale, and Qatar and Australia built their industries on that model, financed by Japan's utilities. The American model broke it: priced off Henry Hub, free of destination limits, and based on tolling, so a buyer can resell a cargo to whoever pays most.

The spot market, about a third of trade, is where prices spike, and in 2022 JKM reached about $70 per MMBtu and TTF about $100. The price-sensitive buyers, Pakistan, Bangladesh, and India, were outbid by Europe and went without, burning fuel oil and coal and cutting fertilizer output. The year 2026 repeated the pattern: Qatar cancelled cargoes to Pakistan and Bangladesh through November, and India, China, and Pakistan took about 80% of the few cargoes that did clear Hormuz.

6d. The Loss of Qatar's Exports

Qatar's LNG, about a fifth of world supply, can leave the Gulf only through Hormuz, and QatarEnergy halted production on March 2, 2026 and declared force majeure. On March 18-19 missile strikes damaged two trains with 12.8 Mtpa of capacity, about 17% of the total, and repairs will take three to five years. No laden LNG tanker crossed the strait between March 1 and April 24, and the first Qatari cargo to leave the Gulf sailed for Pakistan around May 10.

Exports stopped again in early July after a tanker attack, transits picked up only in late September, and on September 28 Qatar extended its force majeure through November. LNG flows through Hormuz, about 11 Bcf/d in 2025, averaged 0.8 Bcf/d in the second quarter of 2026, and the first train of the North Field East expansion, due in late 2026, will be late.

Prices tracked the strait: TTF rose about 59% in March and nearly doubled at its peak on March 19, Asian spot prices more than doubled, and after hostilities resumed in July, September's TTF averaged about 130% above its pre-war level. The structural outlook is postponed rather than changed, since some 200 million tonnes of new American and Qatari capacity due by 2030 had been expected to create a buyers' market from 2027. The war has taught every buyer to want that capacity, and a second supplier.

Module 6 Key Points

LNG: The Global Gas Market

• LNG, gas chilled to −162°C, moved a record 428 million tonnes in 2025, about 14% of world gas use.

• The US tolling model, gas at 115% of Henry Hub shipped anywhere, made America the largest exporter: about 115 Mt in 2025.

• A Gulf Coast cargo delivered for $8-10 per MMBtu earned roughly $60 million at October 2026's $26 prices.

• About two-thirds of LNG moves on 15-20-year contracts; South Asian spot buyers lose out in every squeeze.

• Qatar's exports, a fifth of world LNG, stopped in March 2026; two damaged trains need three to five years of repairs.

Module 6 Quiz

Check Your Understanding

1. What is the American LNG model?

A) Oil-linked contracts with destination clauses that forbid resale of cargoes
B) State-owned exports under quotas set by the Energy Department each year
C) Tolling: buyers pay to liquefy gas and ship it anywhere
D) Spot sales only, priced at the Dutch TTF hub less the cost of shipping

2. In the worked example, why does the terminal's owner carry little risk in a glut?

A) Gluts never last a year
B) The buyer pays the tolling fee regardless
C) Its contracts are indexed to Asian prices, which stay high during a glut
D) It can sell the gas back into the US pipeline network at Henry Hub plus 15%

3. What happened to Qatar's LNG exports in 2026?

A) They stopped in March, and strikes damaged two trains, a 17% cut in capacity lasting three to five years
B) They rose as Europe paid record prices
C) They moved by pipeline through Saudi Arabia
D) They continued under naval escort through the strait

4. Who loses most when LNG spot prices spike?

A) Price-sensitive buyers such as Pakistan
B) The American exporters, whose tolling fees are fixed while spot prices run
C) Qatar, whose oil-linked contracts lag the spot market by six months or more
D) Japan's utilities, which buy almost all their gas on the spot market at the peak

5. What share of world gas use did LNG account for in 2025?

A) About 2%
B) About 40%, now larger than pipeline trade
C) About 60%, most of it bound for Europe and Asia
D) About 14%, a record 428 Mt

Module 7 — Coal: The Fuel That Will Not Die

The Largest Single Source of Electricity and Emissions

Recommended Reading / Reference

Reference: IEA *Coal 2025* (December 2025) and *Coal Mid-Year Update 2026* (September 2026); the Centre for Research on Energy and Clean Air (CREA) and Global Energy Monitor, China coal-power reports (February and August 2026); the US Department of Energy's Section 202(c) orders; EIA *Short-Term Energy Outlook*

Country	Production, 2025 (Mt)	Consumption, 2025 (Mt)	Coal's share of electricity, 2025	Trend	Note
China	~4,720	~4,960 (more than half the world)	55%	Flat in 2025; up about 1% forecast for 2026	Began building 83 GW of coal plants in 2025
India	1,089	1,299	71%	Down 1% in 2025; up about 4% forecast for 2026	Coal India; coal treated as energy security
Indonesia	~778	~250	~60%	Output down in 2025	The largest exporter: 517 Mt of thermal coal
United States	473 (528 million short tons)	410 (452 million short tons)	17%	Up about 10% in 2025; down about 7% forecast for 2026	Federal orders keep old plants open
Australia	446	~100	~45%	Flat	Exports 209 Mt of thermal and about 142 Mt of coking coal
Russia	~430	~230	~18%	Exports (~130 Mt) redirected east	Sanctioned
South Africa	~230	~180	~80%	Flat	Eskom; the 2020s' blackouts
European Union	small and falling	Down 6% in 2025	9%	276 Mt forecast for 2026	Germany's legislated exit by 2038
World	9,111	8,845 (a record)	33%	8,940 Mt forecast for 2026, another record	About 15 Gt of CO2, some 40% of energy emissions

IEA, *Coal 2025* and *Coal Mid-Year Update 2026*; EIA for US short tons; electricity shares from Ember; Russian, South African, and some Indonesian and Australian figures approximate. Mt = million tonnes (1 tonne = 1.1 short tons).

7a. Why It Persists

Coal is the fuel the transition was supposed to retire first, yet the world burned a record 8.84 billion tonnes of it in 2025, according to the IEA, and China mines and burns more than half of it. India's grid runs on coal for about 70% of its power, its government treats coal as energy security, and Indonesia, Vietnam, and much of developing Asia build coal plants because the fuel is domestic, cheap, and dispatchable.

2025 brought a first sign of the turn. Coal-fired generation fell in both China and India, the first time both had fallen in the same year in about half a century, as solar and wind covered demand growth. China still permitted 45 GW of new coal plants and began building 83 GW, on the Centre for Research on Energy and Clean Air's count, to back up a grid whose solar arrives at noon and whose hydro fails in droughts.

The West's exit has been real but small against Asia's growth. American coal use has roughly halved since 2008 as gas displaced it, Britain closed its last coal plant in 2024, and Germany's exit is legislated for 2038. Coal persists because it is the cheapest firm power where gas must be imported, because it is mined at home in the countries that use the most, and because nothing else yet supplies dispatchable power at its scale in Asia.

7b. The Economics and the Politics

Thermal coal shipped from Newcastle, Australia, the Asian benchmark, averaged about $112 a tonne in 2025, according to the International Monetary Fund (IMF), about a quarter of its 2022 monthly peak of $468, and by October 2026 the gas shortage had lifted it to about $150. A modern coal plant generates power for roughly $40-80 per MWh, depending on fuel price and use, which is cheaper than power from imported LNG in Asia and dearer than new solar and wind almost everywhere. Coal's growth therefore comes where the plants and mines already exist.

In the United States, politics has run against the economics since 2025. The Energy Department used Section 202(c) of the Federal Power Act to order six coal plants and one oil-and-gas plant to keep running past their planned retirement, renewing each order every ninety days; the first, for Michigan's Campbell plant, came in May 2025. On September 11, 2026, a federal appeals court ruled that the department had exceeded its authority in the Campbell case, though the order stayed in effect for the moment.

The Environmental Protection Agency repealed the 2024 tightening of its mercury rule in February 2026 and partly repealed its carbon standards for power plants in September 2026. The Energy Department and the US Geological Survey listed metallurgical coal, the kind used in steelmaking, as a critical material and a critical mineral in 2025. US coal generation rose about 10% in 2025, helped by higher gas prices and rising demand. The measures slowed a decline driven by cheap gas and by old plants, most more than forty years old, without reversing it.

Metallurgical coal, about 15% of the market, has no large-scale substitute in steelmaking until hydrogen-based processes mature (Module 16), and Australia exports about 142 million tonnes of it a year.

7c. The 2026 Record

In December 2025 the IEA judged that coal demand had reached a plateau and would edge down by 2030, but nine months later the war changed the forecast. In its September 2026 update the IEA expects world coal use to rise 1.2% in 2026, to a new record of 8.94 billion tonnes, because the loss of Gulf LNG raised gas prices and Asian utilities burned coal instead, and it expects a small fall in 2027 if LNG flows recover.

Coal's decline remains the transition's largest single lever: coal produces about 15 gigatonnes of CO2 a year, some 40% of energy emissions, and the lever sits almost entirely in Beijing and New Delhi.

Module 7 Key Points

Coal: The Fuel That Will Not Die

• The world burned a record 8.84 billion tonnes of coal in 2025, and China used more than half of it.

• Coal persists in Asia because it is domestic, dispatchable, and cheaper than imported LNG; China began building 83 GW of plants in 2025.

• Newcastle coal averaged $112 a tonne in 2025, about a quarter of its 2022 peak, and reached about $150 by October 2026.

• Federal orders kept seven US plants from retiring; in September 2026 a court ruled the first exceeded the Energy Department's authority.

• The 2026 LNG shortage turned an expected decline into a record: the IEA forecasts 8.94 billion tonnes in 2026.

Module 7 Quiz

Check Your Understanding

1. Why does coal persist in Asia while the West retires it?

A) Asian coal is lower in sulfur
B) It is domestic, dispatchable, and cheaper than imported LNG
C) Asian governments ban gas in power plants
D) International lenders still finance new coal plants across the region at concessional rates

2. Why does the IEA now expect world coal use to set another record in 2026?

A) India doubled its coal imports
B) China opened a fleet of new mines in Xinjiang
C) The loss of Gulf LNG raised gas prices, and Asian utilities burned more coal instead
D) European plants reopened under the Russian gas ban

3. What did a federal appeals court rule in September 2026 about the order keeping Michigan's Campbell coal plant running?

A) That it was lawful
B) That Michigan must pay its costs
C) That the plant must close within thirty days and its owner repay its costs
D) That the Energy Department exceeded its authority

4. Roughly what did Newcastle thermal coal average in 2025?

A) About $450 a tonne, near its 2022 peak
B) About $112 a tonne
C) About $40 a tonne, below US mine-mouth prices
D) About $250 a tonne, double its pre-pandemic level

5. What happened to coal-fired generation in China and India in 2025?

A) It fell in both, the first time both fell in the same year in about half a century
B) It rose in both by over 10%
C) China's fell; India's doubled
D) Both stopped building new coal plants

Module 8 — The Grid: How Electricity Moves

The Machine That Must Balance Its Product Every Second

Recommended Reading / Reference

Book: Gretchen Bakke, *The Grid: The Fraying Wires Between Americans and Our Energy Future*

Reference: The IEA's *Electricity 2026* (February 2026); Lawrence Berkeley National Laboratory's *Queued Up* reports; the North American Electric Reliability Corporation's (NERC's) *2025 Long-Term Reliability Assessment*; the final report of the European Network of Transmission System Operators for Electricity (ENTSO-E) on the April 28, 2025 Iberian blackout (March 2026); the Federal Energy Regulatory Commission (FERC) and NERC on Winter Storm Uri (2021)

8a. Generation, Transmission, Distribution

The grid moves electricity from where it is made to where it is used in the same instant, so supply and demand must balance second by second, or the frequency drifts from its standard (60 hertz in the Americas, 50 elsewhere) and equipment trips offline. Voltage must also be held within limits at every point, which generators and other equipment do by supplying or absorbing what engineers call reactive power.

Power plants feed high-voltage transmission lines, at 110-765 kilovolts (kV), which carry power hundreds of miles with low losses to substations that step the voltage down to distribution lines and finally to the 240/120 volts of an American home. A grid operator, such as the Electric Reliability Council of Texas (ERCOT), PJM Interconnection in the Mid-Atlantic and Midwest, the operators of Europe's ENTSO-E network, or China's State Grid, dispatches generators against a demand forecast every few minutes and buys reserves to cover the errors.

Engineers call the North American grid the largest machine ever built, and with much of its equipment decades old it is the transition's bottleneck, because every new source and every new load must connect to it.

8b. The Mix by Country

Country	Generation (TWh, 2025)	Coal	Gas	Nuclear	Hydro	Wind	Solar	Other	Note
China	10,580	55%	3%	5%	13%	11%	11%	3%	Coal generation fell in 2025
United States	4,520	16%	40%	17%	5%	10%	9%	2%	Demand rising on data centers
India	2,082	71%	2%	3%	9%	5%	9%	1%	The fastest growth among large grids
European Union	~2,770	9%	17%	23%	12%	17%	13%	9%	Wind and solar (30%) passed fossil fuels (29%)
Russia	1,193	18%	45%	18%	17%	<1%	<1%	1%	Gas and nuclear
Japan	1,030	32%	33%	9%	7%	1%	10%	8%	Reactors restarting
Brazil	751	2%	7%	2%	52%	16%	12%	9%	The cleanest large grid
Germany	500	21%	17%	0%	4%	27%	18%	14%	No nuclear since 2023

Country	Generation (TWh, 2025)	Coal	Gas	Nuclear	Hydro	Wind	Solar	Other	Note
France	570	<1%	3%	69%	10%	8%	6%	4%	Europe's largest exporter
World	~31,750	33%	22%	9%	14%	8.5%	8.7%	5%	Low-carbon sources 43%

Ember, *Global Electricity Review 2026* and country data for 2025, rounded; the EU figure is demand. 'Other' is mostly bioenergy and oil.

8c. The Bottlenecks

Bottleneck	Measure (2025-26)	Consequence
Connection queues	More than 2,500 GW of projects wait in grid queues worldwide (IEA); in the US, generation and storage waiting to connect exceed the entire existing fleet (LBNL)	Projects wait years, and most are never built
Transmission	New high-voltage lines take seven years or more to permit and build (IEA)	Plains wind and desert solar cannot reach cities; congestion rises
Grid equipment	Prices of transformers, cables, and switchgear nearly doubled in five years (IEA); large transformers take years to deliver	Every project is delayed
Gas turbines	Orders reached 130 GW in 2025, a 25-year high; new orders can take about five years to deliver (IEA)	Data centers cannot get firm power quickly (Module 18)
Europe	About €584 billion of grid investment needed this decade (European Commission, 2023); limited cross-border capacity	Northern wind is curtailed while the south burns gas
China	State Grid builds ultra-high-voltage lines, at 800-1,100 kV, ahead of demand	Western solar, wind, and hydro reach the coast
Reliability	NERC's 2025 assessment rates several regions, PJM and the Midcontinent Independent System Operator (MISO) among them, at high risk of shortfalls within five years	A grid running at its limits (8d)

The grid is where both the energy transition and the AI boom stall. Projects must wait to be studied for their effect on a system with little spare transmission, new lines take most of a decade, equipment prices have nearly doubled, and the turbines that data centers want are booked years ahead. Europe curtails northern wind while its south burns gas, and China is the exception, because State Grid builds ultra-high-voltage lines ahead of demand and carries western power about 2,000 kilometers (1,200 miles) to the coast. The grid, more than the generator, is the binding constraint.

8d. When Grids Fail: Texas 2021 and Iberia 2025

In February 2021 Winter Storm Uri brought days of deep cold to Texas, freezing gas wells, pipelines, and gas plants as well as wind turbines and one nuclear unit, and failures in the gas supply chain were the largest single cause of lost generation. ERCOT, the Texas grid operator, ordered utilities to cut about 20 GW of load, millions of homes lost power for days, and Texas officials counted 246 deaths.

Wholesale prices sat at the $9,000/MWh cap for nearly four days, and the costs ran to tens of billions of dollars. Texas then required winterization, reformed ERCOT, and lowered the cap to $5,000/MWh, but kept its grid largely isolated from its neighbors, and it has since built solar and batteries faster than any other state. The lesson is that reliability is a design choice, and the cheapest market is not the most resilient.

On April 28, 2025, the grids of Spain and Portugal collapsed in seconds. Solar was supplying about 59% of Spain's power at the time, and early commentary blamed a lack of inertia, the stabilizing spin of large turbines, but the official investigations found otherwise. Spain's government (June 2025) and the European network of grid operators, ENTSO-E (final report, March 2026), traced the collapse to a failure of voltage control, in which oscillations were followed by a rise in voltage that tripped generators one after another.

ENTSO-E listed fifteen interacting causes: too few conventional plants were online to regulate voltage, and many renewable plants were set to provide none. The panel found that even much higher inertia would not have prevented the loss of synchronism, and its chair summed up: 'The problem is not renewable energy, but voltage control.' The fix is in the rules and the equipment, meaning inverters that support voltage and operators who schedule enough of it.

8e. Operators and Ownership

Grids are owned and run in three patterns. Vertically integrated utilities own generation, wires, and customers under rate regulation, as in most of the American South and West (Duke, Southern, Dominion), Japan's regional utilities, and most developing countries.

Unbundled systems separate competitive generation, regulated transmission, and, in some places, competitive retail, with an independent operator running the market and the dispatch. Texas and much of the Northeast work this way, and the independent operators' wholesale markets, such as PJM, MISO, ERCOT, and the California Independent System Operator (CAISO), serve about two-thirds of American demand, even where utilities remain integrated. The EU, Britain, and Australia are unbundled too, while state grids, such as China's State Grid, the world's largest utility, plan and build centrally.

The pattern decides who pays for the transition and the AI load: in an integrated utility the ratepayer pays, through regulated returns on new plants and lines, in a market whoever wins the auction builds and recovers its costs there, and in China the state pays.

Module 8 Key Points

The Grid: How Electricity Moves

• The grid must balance supply and demand every second at 50 or 60 hertz and hold voltage within limits everywhere.

• More than 2,500 GW of projects wait in connection queues worldwide; in the US the queue exceeds the existing fleet.

• Gas turbine orders hit a 25-year high of 130 GW in 2025, and new turbines can take about five years to arrive.

• Texas's 2021 freeze, led by failures in gas supply, forced about 20 GW of outages and killed 246 people.

• Iberia's April 2025 blackout came from failed voltage control, not low inertia; investigators listed fifteen interacting causes.

Module 8 Quiz

Check Your Understanding

1. Why must a grid operator balance supply and demand every second?

A) To keep prices low
B) Because generators need hours of notice to change their output in either direction
C) Electricity is not stored in the wires
D) Because federal rules from the 1930s require utilities to match their forecasts each hour

2. What did ENTSO-E's final report find behind Iberia's April 2025 blackout?

A) A failure of voltage control
B) Too little inertia from spinning machines on a grid running mostly on solar
C) A cyberattack on the Spanish operator's control systems, traced to Russia
D) A heat wave that overloaded the lines carrying power to Madrid

3. What was the largest single source of failure in Texas during Winter Storm Uri in 2021?

A) Frozen wind turbines
B) Solar panels under snow
C) Gas supply: frozen wells and pipelines starved gas plants of fuel
D) Imports cut off at the Mexican border

4. How large are grid connection queues, on the module's account?

A) About 100 GW, mostly in Texas
B) Over 2,500 GW worldwide; in the US, more than the whole existing fleet
C) Near zero, after US and EU reforms in 2025
D) About 500 GW worldwide, most of it gas plants waiting for turbines already on order

5. Who pays for new generation in an unbundled electricity market?

A) The state
B) Ratepayers, through the utility's regulated return on its capital
C) Taxpayers, through federal grants that cover the plants' construction costs
D) Whoever wins the auction

Module 9 — Electricity Markets and Prices

How the Price of a Megawatt-Hour Forms, and Who Pays It

Recommended Reading / Reference

Reference: PJM's Base Residual Auction reports (2025/26 through 2028/29, the last published July 14, 2026); the IEA's *Electricity 2026* and *Electricity Mid-Year Update 2026*; EIA *Short-Term Energy Outlook* (October 2026); the wholesale market monitoring of the EU Agency for the Cooperation of Energy Regulators

9a. The Merit Order, Worked

In a competitive wholesale market the price is set for each hour, or each five minutes, by the most expensive generator needed to meet demand, the marginal plant, and every generator running in that interval is paid that price. Plants are stacked by their running cost, an order called the merit order: wind, solar, nuclear, and hydro come first, because their fuel is free or already paid for, then coal and combined-cycle gas plants at the cost of their fuel, with gas 'peakers' and oil-fired units at the top.

When demand is low and the wind is strong, a zero-cost plant sets the price, which can fall to zero or below, and when demand peaks on a still, hot evening a peaker sets it, so that in a shortage the price can reach the market's cap.

Worked example — A Summer Day in Texas

At 3 p.m. on a July day, demand on ERCOT, the Texas grid, is 85 GW, against a record peak of 91.1 GW set on July 22, 2026, and 30 GW of solar is producing. The marginal plant is a combined-cycle gas unit that burns 7 MMBtu of $3.00 gas per MWh, $21 of fuel plus about $5 of other running costs, so the price is about $26/MWh. Every plant running earns $26: the solar farm earns it on almost no running cost, while the gas plant setting the price earns almost nothing above its fuel. At 8 p.m. demand is 88 GW, the solar is gone, and wind supplies 12 GW, so the last 5 GW come from peakers that burn 11 MMBtu per MWh, $33 of fuel plus $10, and the price rises to about $43. If a plant trips and reserves run short, ERCOT's scarcity pricing can lift the price toward its $5,000/MWh cap for an hour, and every generator running is paid $5,000. A year's average price hides a distribution in which most hours are cheap and a few dozen carry a large share of the revenue. That is why batteries pay, charging at $20 and discharging at $500, and why solar's value falls as more solar arrives, because it depresses the price in the very hours it produces, an effect called cannibalization. It is also why a gas peaker that runs a few hundred hours a year needs a separate capacity payment to exist at all.

9b. The Markets

Market	Region	Design	Prices (2025-26)	Distinguishing feature
ERCOT	Texas	Energy only, with no capacity market; a $5,000/MWh offer cap	US wholesale hubs averaged about $52/MWh in 2026, up 11% (EIA)	The fastest solar and battery build in the US; a 2026 pause on new data-center connections
PJM	13 states and Washington, D.C. (65 million people)	Energy plus a capacity auction	Wholesale prices up about 41% in 2026 (EIA); capacity at the cap in three straight auctions	The world's largest data-center cluster, in northern Virginia
CAISO	California	Energy plus resource-adequacy contracts	Midday prices often negative	Solar plus batteries met over a quarter of 7-9 p.m. demand in the first half of 2026 (Ember)
MISO; Southwest Power Pool (SPP); New York (NYISO); New England (ISO-NE)	Midwest, Plains, New York, New England	Mixed	Vary with gas and winter constraints	MISO rated at high risk of shortfalls by NERC
Europe (coupled day-ahead market)	EU plus Norway and Switzerland	Marginal pricing across linked zones; the carbon price added (Module 20)	About $95/MWh in 2025, about twice the US (IEA); first-half 2026 Germany up 17%, the Nordics more than doubled	Gas sets the price in many hours
Britain	Great Britain	Marginal pricing plus a capacity market and contracts for difference (CfDs)	High, set by gas in most hours	CfDs fix prices for new offshore wind
Australia (NEM)	Eastern states	Energy only, with a very high cap	First-half 2026 prices down about 30% (IEA)	Rooftop solar; about a fifth of South Australia's hours negative
China	National	Provincial spot markets; from June 2025 new wind and solar sell through market-based contracts, not fixed tariffs	Regulated retail prices	The largest market reform of the decade
India	National, with state utilities	State utilities buy most power; exchanges growing	Regulated	State distribution companies' chronic losses

IEA *Electricity 2026* and *Electricity Mid-Year Update 2026*; EIA; Ember; PJM.

9c. What Households and Industry Pay

Retail prices bear little relation to wholesale ones, because a bill adds transmission and distribution, often a third to a half of it, plus taxes, levies, and the utility's return. American households paid an average of 17.3 cents per kWh in 2025, and the EIA expects 18.2 cents in 2026, a rise of about 5%, as data-center demand, wildfire costs, and grid spending push prices up at their fastest pace in decades.

German households paid 39.6 euro cents per kWh on average in 2025, on the October 2025 price analysis of BDEW, the German energy industry's association, more than twice the American price, because of taxes, levies, grid fees, and gas-set wholesale prices. Germany's largest industrial users pay much less, thanks to

exemptions, but still far more than American industry, and that difference drives the deindustrialization debate in the Ruhr.

Elsewhere, hydro-rich Canada and Norway pay among the lowest prices in the rich world, while China and India hold household prices down by regulation, with industry paying more. In Nigeria, Pakistan, and South Africa the problem is reliability rather than price, and families and firms run diesel generators at 30-50 cents per kWh when the grid fails.

9d. Capacity Auctions, Negative Prices, and the 2022 Crisis

Capacity markets pay generators to exist: a peaker cannot recover its capital from a few hundred hours of energy sales, so PJM and other operators auction 'capacity,' a promise to be available, a few years ahead. PJM's auction for 2025/26 cleared at $269.92 per megawatt-day, about nine times the $28.92 of the year before, as data-center demand met a shrinking fleet.

The next three auctions, for 2026/27 through 2028/29, cleared at a price cap that Pennsylvania's governor had won in a complaint to regulators: $329.17, $333.44, and $325.00 per megawatt-day. The 2028/29 auction, published on July 14, 2026, fell 6.8 GW short of PJM's reliability target, and without the cap its price would have been $554.72. PJM then proposed a 'backstop' purchase of 6.8 GW on fifteen-year contracts, which the Federal Energy Regulatory Commission (FERC) accepted on September 29, 2026, but suspended until February 28, 2027. The costs flow into retail bills, and electricity prices became a campaign issue in Virginia and New Jersey in 2025.

Negative prices pay consumers to take power, because on windy or sunny hours of low demand, subsidized or inflexible generators bid below zero. Germany recorded 573 negative-price hours in 2025, up from 459 in 2024, and in California and South Australia about a fifth of hours were negative in the first half of 2026, each one a signal that storage and flexible demand are worth building.

Europe's 2022 crisis exposed the cost of marginal pricing. Gas set the price in most hours, so a tenfold rise in gas prices raised the price of every megawatt-hour, including the roughly 45% from renewables and nuclear whose costs had not changed, and their owners earned windfall profits that governments then taxed.

The case for marginal pricing, as most economists and the EU's energy regulator, ACER, made it in 2022. A single price for each hour dispatches the cheapest plants first, signals where new supply is needed, and lets power flow across borders, and any other design, they argued, would raise costs over time.

The case against, as Spain, France, and consumer groups made it. Households paid gas prices for power that cost far less to make, so Spain and Portugal capped the gas price used in power markets in 2022-23 to break the link.

The evidence between them. The design kept the lights on and drew imports to where they were needed, while the windfalls were real and large. The EU's 2024 reform kept marginal pricing for short-term trading and pushed new plants toward long-term contracts, including two-sided contracts for difference that pay back windfalls.

The course's reading. The price signal is worth keeping; the exposure of households to it is not, and long-term contracts are the better answer than a redesign.

Module 9 Key Points

Electricity Markets and Prices

• Power is priced at the marginal plant, so a few scarce hours, capped at $5,000/MWh in ERCOT, carry much of the year's revenue.

• PJM's capacity price jumped from $28.92 to $269.92 per MW-day in one auction, then hit the cap three times running.

• The 2028/29 PJM auction fell 6.8 GW short of its reliability target; uncapped, it would have cleared at $554.72.

• US households paid 17.3 cents per kWh in 2025, and the EIA expects about 5% more in 2026.

• Germany had 573 negative-price hours in 2025, a signal that storage and flexible demand are worth building.

• In 2022 gas set Europe's power price in most hours, so a tenfold gas spike repriced electricity from every source.

Module 9 Quiz

Check Your Understanding

1. How is the wholesale electricity price set in a competitive market?

A) By the regulator
B) By the average cost of every plant running in that hour, weighted by output
C) By the cheapest plant running in the hour, plus a markup set in the market rules
D) By the costliest plant needed that hour

2. Why does a gas peaker need a capacity payment to exist?

A) Gas is expensive
B) It runs so few hours that energy sales cannot repay its capital
C) Its emissions are taxed
D) Federal rules require every peaker to be paid a fixed fee for standing by, whatever the market

3. What did PJM's 2025/26 capacity auction do?

A) Cleared at zero as new gas plants flooded the auction
B) Was cancelled after the regulator found too few bidders for the year
C) Raised the price about ninefold
D) Lowered the price as batteries undercut the incumbent gas plants

4. What does the module say Europe's 2022 crisis exposed about marginal pricing?

A) Gas set the price in most hours, so a tenfold gas spike repriced power from every source
B) Renewables set the price too often
C) Price caps were set too low
D) Nuclear plants bid above gas plants

5. Why are negative wholesale prices useful, on the module's account?

A) They signal that storage and flexible demand are worth building where they occur
B) They lower every household's bill
C) They punish solar farms for overbuilding
D) They prove the market has failed

Module 10 — Nuclear: The Fleet and the Revival

The Largest Source of Clean Firm Power, and Its Second Life

Recommended Reading / Reference

Reference: World Nuclear Association, *World Nuclear Outlook Report 2026* and reactor database (October 2026); IAEA Power Reactor Information System; *World Nuclear Industry Status Report 2026*; the Japanese Diet's Fukushima investigation report (NAIIC, 2012); the May 2025 US executive orders on nuclear energy

10a. The Fleet

Country	Reactors operating	Capacity (GW)	Share of electricity, 2025	Under construction	Note
United States	94	~97	18%	None of large size	Palisades restart delayed; Crane due 2027; Duane Arnold end-2028 or 2029
France	57	~63	68%	None (Flamanville 3 reached full power in December 2025)	Six EPR2 reactors planned, a simplified European Pressurized Reactor (EPR); Europe's largest exporter
China	65	~65	5%	38, the most	10 units approved in April 2025 and 8 in July 2026; target 110 GW by 2030
Russia	34	~28	19%	7	Rosatom, the largest exporter of reactors and enrichment
South Korea	26	~26	~30%	4	The APR-1400 at home and in the UAE; a Czech order
Japan	15 restarted of 33 operable	~32 operable	9%	2 (suspended)	Kashiwazaki-Kariwa 6 back in commercial service April 2026; a 20% target for 2040
India	24	~8	3%	8	A December 2025 law opened the sector to private firms
Canada, Ukraine, Britain, Spain, Sweden, Belgium, Finland, Czechia	4-19 each	2-14 each	10-55%	Britain's Hinkley Point C and Sizewell C	Belgium repealed its phase-out law (May 2025); Spain extended Almaraz to 2030
Germany	0	0	0%	0	Closed its last three reactors in April 2023
UAE, Turkey, Egypt, Bangladesh, Poland, Kazakhstan	0-4	0-5.6	0-25%	Building or planning	The newcomers, on Russian, Korean, Chinese, and American designs
World	413 (end-2025)	377	~9%	72-80, about half in China	Record output of 2,702 TWh in 2025; average age about 33 years

Country counts: World Nuclear Association (October 8, 2026), which lists idle Japanese reactors as operable. World: IAEA (end-2025) and WNA. Shares: Ember and WNA, 2025.

About 413 reactors in some 31 countries produced a record 2,702 TWh in 2025, about 9% of the world's electricity and a fifth of its low-carbon electricity, from a fleet averaging about 33 years old. Nuclear is the largest source of clean firm power: it can run around the clock, its capacity factor is high, and its land footprint is a fraction of wind's or solar's.

The fleet's geography tracks the transition: the United States has the most reactors but built none for three decades before Vogtle, France runs on them, Russia exports them, Japan is restarting them, and Germany closed them. China builds most of the world's new ones, with about 38 under construction in October 2026, and it connected Tianwan 7 to its grid on October 8. Nuclear's history has been defined by two things, accidents and cost.

10b. The Accidents

On April 26, 1986, a botched test destroyed Unit 4 at Chernobyl in Soviet Ukraine; the Soviet RBMK design was unstable at low power, it was run outside its limits, and it had no containment building. A radioactive plume crossed Europe, thirty-one people died in the immediate aftermath, about 350,000 were eventually resettled, and the long-term toll from cancers is disputed. Western reactor orders largely stopped for two decades, and Italy voted to abandon nuclear power in 1987.

On March 11, 2011, a magnitude-9 earthquake and a tsunami about 15 meters high flooded the backup generators at Fukushima Daiichi in Japan, and three reactors melted down. More than 150,000 people were evacuated, and while no one died of radiation sickness, more than 2,000 deaths, mostly of elderly evacuees, were later attributed to the evacuation itself. The Japanese parliament's inquiry called the disaster 'profoundly man-made,' because the seawall was built for a smaller wave, backup power sat in basements, and the regulator had been captured by the industry it oversaw.

Japan shut all its reactors and spent about $30 billion a year on extra imported fuel in the years that followed, while Germany decided in 2011 to close its whole fleet, which it finished in 2023, and deepened its dependence on Russian gas. A nuclear accident's cost is counted in the fossil fuels burned instead, and in the politics.

10c. The Cost Problem

Project	Country	Capacity	Cost	Cost per kW	Schedule	Lesson
Vogtle 3 and 4	US (Georgia)	2.2 GW	Over $30 billion (first estimate $14 billion)	~$14,000	Begun 2009; finished 2023-24, seven years late	First-of-a-kind AP1000s in an industry out of practice; the second unit went faster
Hinkley Point C	Britain	3.3 GW	£35 billion in 2015 prices (first estimate £18 billion)	Over $15,000	Begun 2017; first unit not before 2030	EPR complexity; a rebuilt supply chain
Sizewell C	Britain	3.2 GW	£38 billion in 2024 prices	~$15,000	Approved July 2025; complete by 2039	Financed partly by consumers during construction

Project	Country	Capacity	Cost	Cost per kW	Schedule	Lesson
Flamanville 3	France	1.6 GW	€13 billion on the count of EDF, the state utility; about €24 billion with financing, on the state auditor's	$9,000-16,000	Begun 2007; full power December 2025	The EPR's first-of-a-kind ordeal
Barakah 1-4	UAE	5.6 GW	About $24 billion financed	~$4,500	Begun 2012; finished 2024	Korea's APR-1400 built close to schedule
Hualong One units	China	1.2 GW each	About ¥17,000 per kW	~$2,500-3,500	5-6 years	Serial construction and state finance
Dukovany 5 and 6	Czechia	About 2 GW (APR1000)	407 billion Czech crowns (about $18.6 billion)	~$9,000	Construction from 2029; power by 2036	Korea's first European order; an EU state-aid inquiry
VVER-1200 exports (Akkuyu, El Dabaa)	Turkey, Egypt	4.8 GW each	$20-30 billion each	~$5,000	10 years and more; Akkuyu 1 not yet fueled (October 2026)	Rosatom's state-financed model

World Nuclear Association country profiles (2026); EDF; the UK National Audit Office (May 2026); France's Cour des comptes (2025). Costs per kW approximate.

The West forgot how to build reactors, and the East did not. The AP1000s at Vogtle cost more than twice their estimate and finished seven years late, and the European EPRs at Olkiluoto, Flamanville, and Hinkley Point ran years late and several times over budget. Korea built Barakah's four reactors in the UAE close to schedule at about $4,500 per kilowatt, and China builds Hualong Ones in five to six years. The difference is serial construction: one standard design built again and again by a workforce and supply chain that never stopped.

At Western costs, new nuclear power costs about $175-255 per MWh on Lazard's July 2026 estimates, and at Korean or Chinese costs about $50-80. Existing reactors, whose capital is paid, produce power for about $30-40, which is why extending a reactor's life is the cheapest clean firm power available, and why the revival started there.

10d. The Revival

Date	Event	Significance
2022	A federal credit for existing reactors; California reverses Diablo Canyon's closure	The first policy reversals
2023-24	Vogtle 3 and 4 enter service	The first new US reactors in thirty years
September 2024	Microsoft signs a 20-year deal for Constellation to restart Three Mile Island Unit 1, renamed Crane	The tech giants become nuclear's customers
May 2025	Four executive orders: 400 GW by 2050, ten large reactors under construction by 2030, 18-month licensing deadlines, three test reactors critical by July 4, 2026	The most pro-nuclear US policy since the 1970s
June-July 2025	Meta signs for Clinton's output (1.1 GW) for 20 years; Amazon for 1.92 GW from Susquehanna through 2042; the World Bank ends its nuclear ban; the budget law keeps nuclear's tax credits	Nuclear the bipartisan survivor

Date	Event	Significance
October 2025	A US government partnership with Westinghouse for $80 billion of AP1000s; Google and NextEra agree to restart Duane Arnold by 2029	Large reactors back on the agenda
November 2025-August 2026	Test reactors at Los Alamos, Idaho, and elsewhere reach criticality, starting with Valar Atomics	The executive order's goal of three met
January-April 2026	Meta signs for 2.2 GW from Vistra's Perry and Davis-Besse plants; the Nuclear Regulatory Commission (NRC) issues TerraPower's construction permit and a new licensing rule for advanced reactors; Kashiwazaki-Kariwa 6 returns	Contracts and licenses
June-October 2026	Up to $17.5 billion of conditional federal loans for AP1000 equipment; a US-Korea framework for six AP1000s and two APR1400s; Google buys about 890 MW of uprates; Palisades' restart slips	Money committed, sites not yet named

World Nuclear Association, *Nuclear Power in the USA* (updated October 7, 2026); company announcements.

Nuclear's second life began with data centers. In September 2024 Microsoft agreed to buy the output of Three Mile Island's Unit 1, closed in 2019 as uneconomic, for twenty years once Constellation restarts it, at a price that was not disclosed but that analysts at Jefferies estimated at $110-115 per MWh. The signal was a customer that needs firm clean power around the clock and can pay for it, and Amazon, Google, and Meta followed with restarts, uprates, and contracts for new designs.

Restarts have proved slower than announced: Palisades in Michigan, closed in 2022, won approval to restart in 2025, but a fuel assembly tipped over during fuel loading on August 30, 2026, and as of early October no new date had been set. Crane is due in the second half of 2027, though delivering its full output depends on transmission upgrades due in 2030.

10e. Can the West Build Again?

The case for, as the industry and the administration make it. Vogtle's second unit was built faster than its first, proof that the learning curve is real once a crew builds the same design twice. The policy is now in place, with the May 2025 orders, a faster licensing rule, the Westinghouse partnership, and billions in conditional federal loans, and so are the buyers, as technology companies pay premium prices for firm clean power. Korea and China show what a standard design built in series can cost.

The case against, as skeptics such as the authors of the *World Nuclear Industry Status Report* make it. Every large Western project of the past twenty years ran years late and billions over budget. As of October 2026 no new pair of AP1000s has a firm site or a construction start, so the executive order's goal of ten large reactors under construction by 2030 has no project yet on site. The supply chain and the skilled workforce rebuild slowly, while solar plus batteries delivers energy more cheaply and arrives in a year or two.

The evidence between them. Both sides accept the Western cost record and the Asian one, and they differ on whether policy and money can recreate serial building in the United States. The loans, permits, and contracts of 2025-26 are necessary conditions, and none has yet produced a construction start for a large reactor.

The course's reading. The West can build again only by building the same design repeatedly, so the test is a first order of several units on named sites. Until then, restarts and uprates are the nuclear the decade will get.

Module 10 Key Points

Nuclear: The Fleet and the Revival

• About 413 reactors produced a record 2,702 TWh in 2025, about 9% of the world's electricity.

• Chernobyl and Fukushima each halted reactor building for years; Fukushima's evacuation caused more than 2,000 deaths.

• Vogtle cost more than $30 billion, over double its estimate, while Korea built Barakah at about $4,500 per kW.

• Existing reactors make power for about $30-40/MWh, so restarts and uprates lead the revival.

• China has about 38 reactors under construction, roughly half the world's total; the US has no large ones.

• The case for a Western revival rests on serial building; as of October 2026, no new AP1000 pair has a firm site.

Module 10 Quiz

Check Your Understanding

1. Why did Vogtle cost so much more per kilowatt than Barakah?

A) American reactors are larger and need thicker containment
B) The UAE subsidized Barakah and left part of its cost off the books
C) First-of-a-kind building by a rusty industry
D) Georgia's labor rules slowed the work by years and doubled wages

2. Why is extending an existing reactor's life the cheapest clean firm power?

A) Uranium is free
B) Its capital is paid, and it runs at a high capacity factor
C) Old reactors need no repairs
D) Federal subsidies cover the full running cost of every plant over forty years old

3. What happened to the Palisades restart in August 2026?

A) It succeeded
B) Regulators revoked its license after a court challenge by Michigan's attorney general
C) It reached full power in September and now supplies a Microsoft data center
D) A fuel-loading problem delayed it

4. Which country is building the most reactors?

A) Russia
B) The United States, with ten AP1000s under way since 2025
C) China, with about 38
D) India, with twenty units since the private-sector law of December 2025

5. On the module's reading, what will decide whether the West can build reactors again?

A) Building the same design repeatedly, as Korea and China do
B) Smaller reactors only
C) A carbon tax
D) A new federal agency that would own and operate every reactor built after 2030

Module 11 — Nuclear: Small Modular Reactors, the Fuel Cycle, and Fusion

The Next Reactors and the Fuel Behind Them

Recommended Reading / Reference

Reference: NRC and Canadian Nuclear Safety Commission licensing records; World Nuclear Association pages on enrichment, uranium production, and fusion (September-October 2026); Cameco's uranium price series; the Fusion Industry Association's 2026 report; the 2024 baseline of ITER, the international fusion project in France

11a. Small Modular Reactors

Design	Developer	Type	Size	Status, October 2026	First power (target)	Customer or site
BWRX-300	GE Vernova Hitachi	Light-water, boiling	300 MW	Darlington, Ontario: licensed April 2025, first nuclear concrete June 2026. The Tennessee Valley Authority's (TVA's) Clinch River: US construction permit September 2026	2030 (Ontario)	Ontario Power Generation (four units, C$20.9 billion); TVA
US460	NuScale	Light-water, pressurized	77 MW modules	Uprated design approved May 2025; Utah project cancelled 2023; Romanian project's conditional decision (2026) in doubt	2030s	RoPower (Romania); data-center developers
Rolls-Royce SMR	Rolls-Royce	Light-water	470 MW	Chosen for Britain (2025) and Wylfa named as site; three-unit contract April 2026; chosen by Vattenfall for Sweden (June 2026)	Mid-2030s	Great British Energy – Nuclear; Vattenfall; ČEZ
Xe-100	X-energy	High-temperature gas-cooled	80 MW modules	Dow's Long Mott, Texas: environmental review done May 2026, permit decision expected 2027	Around 2030	Dow; Amazon
Hermes / KP-FHR	Kairos Power	Cooled by fluoride salt	Test units; 75 MW commercial	Hermes 1 test reactor building at Oak Ridge (finish expected 2028); Hermes 2 begun April 2026	About 2030	Google (up to 500 MW by 2035); TVA
Natrium	TerraPower	Sodium-cooled fast reactor with molten-salt storage	345 MW (500 MW peak)	Construction permit March 4, 2026; building at Kemmerer, Wyoming	2030-31	PacifiCorp; Meta
Aurora	Oklo	Sodium-cooled fast microreactor	75 MW	Ground broken at Idaho National Laboratory (September 2025); a test reactor critical in August 2026	Late 2027-28	Data centers; Meta's Ohio campus

Design	Developer	Type	Size	Status, October 2026	First power (target)	Customer or site
Linglong One (ACP100)	CNNC (China)	Light-water	125 MW	Under construction on Hainan since 2021; commissioning expected in 2026	2026	The first commercial land-based SMR
RITM-200	Rosatom	Light-water	55 MW per unit	A floating plant in the Arctic since 2020; a land plant in Yakutia planned	About 2030	Russia's Arctic

NRC; Canadian Nuclear Safety Commission; World Nuclear Association (September-October 2026); company statements.

Small modular reactors (SMRs) are units of up to about 300 MW meant to be built largely in factories and shipped, against the 1,000-1,600 MW giants built on site. They are the industry's bet that serial manufacturing can do for nuclear what it did for gas turbines and solar panels.

As of October 2026, none generates power in the West. Ontario's BWRX-300, the most advanced, poured its first nuclear concrete in June 2026 and targets 2030, and in September 2026 the Tennessee Valley Authority (TVA) won the first US construction permit for the same design, after TerraPower's Natrium in Wyoming received its permit in March. NuScale's first project died on cost in 2023, after its expected price rose to $89 per MWh even with subsidies, and China's Linglong One is expected to become the world's first commercial land-based SMR in 2026.

The economics are unproven: first units cost more per kilowatt than large reactors, and the factory cost curve needs dozens of orders that do not yet exist, so the technology companies' willingness to pay premium prices for firm clean power is the industry's main demand signal. The honest expectation is a handful of Western SMRs around 2030 and a verdict on their costs in the mid-2030s.

11b. The Fuel Cycle

Step	What happens	Who dominates	Concentration risk
Mining	Ore mined or dissolved in place; about 60,000 tonnes of uranium a year	Kazakhstan about 40% (Kazatomprom), then Canada (Cameco), Namibia, Australia, Uzbekistan, Russia	Kazakh output moves through Russia or across the Caspian
Conversion	Ore concentrate (yellowcake) turned into uranium hexafluoride gas	Russia, Canada, France (Orano), China, the US (ConverDyn)	Russia's share
Enrichment	Uranium-235 raised from 0.7% to 3-5% for reactors, or up to 20% (HALEU) for advanced designs, in centrifuges	Rosatom about 43% of world capacity (2025); Urenco, Orano, China; Centrus, the only US-owned enricher, small	A US ban on Russian enriched uranium, with waivers ending January 1, 2028
Fuel fabrication	Pellets and assemblies for a specific reactor design	Westinghouse, Framatome, Global Nuclear Fuel, TVEL (Russia), China	Westinghouse now fuels Soviet-designed reactors in Ukraine, Bulgaria, and Czechia
In the reactor	Fuel produces power for 4-6 years	—	—
Spent fuel	Pools, then dry casks at the plant	Every operator	US: about 95,000 tonnes and no permanent repository; Finland's Onkalo awaits its license

Step	What happens	Who dominates	Concentration risk
Reprocessing	Plutonium and uranium recovered for reuse (France, Russia, Japan)	Orano (La Hague), Rosatom, Japan's Rokkasho (decades late)	Proliferation concerns; the US does not reprocess

HALEU = high-assay low-enriched uranium. World Nuclear Association (September-October 2026).

The fuel cycle is nuclear's supply chain and its geopolitics. Uranium itself is plentiful: its spot price was $89.63 a pound at the end of September 2026, against $25-34 in 2020, on Cameco's figures, and Kazakhstan mined about 40% of the world's supply in 2025. The steps between the mine and the reactor are concentrated, and Rosatom, Russia's state nuclear company, holds about 43% of the world's enrichment capacity and has been the main supplier of HALEU, the higher-enriched fuel most advanced designs need.

The United States banned imports of Russian enriched uranium in 2024, with waivers that end on January 1, 2028. Centrus has produced more than 1,900 kilograms of HALEU and holds a federal contract worth up to $1.07 billion to expand. Urenco is enlarging its New Mexico plant and Orano plans a new one at Oak Ridge for 2032, but the rebuild runs about a decade behind the reactor revival it must supply.

Waste is the other unsolved step: the United States holds about 95,000 tonnes of spent fuel in pools and casks at its plants, with no permanent repository. Finland's Onkalo, the world's first deep geological repository, won a favorable safety assessment from its regulator in August 2026, and the government's license decision is pending.

11c. Fusion

Fusion joins light atoms at temperatures of about 100 million degrees, the reaction that powers the sun, and it has been thirty years away for seventy years, but the 2020s changed the pace. The National Ignition Facility in California achieved ignition in December 2022, getting more energy from the fuel than its lasers delivered, though not more than the facility drew from the grid, and it has since repeated the feat, with a record 8.6 megajoules in April 2025.

ITER, the 35-nation reactor in France, now plans to begin research operations in 2034 and to burn deuterium and tritium in 2039. Private firms have raised about $14.2 billion in all, $4.5 billion of it in the year to July 2026, on the Fusion Industry Association's count. Commonwealth Fusion Systems plans to run its SPARC machine in 2027 and to build a 400 MW plant in Virginia in the early 2030s, with Google agreeing to buy half its output. Helion began building a plant in Washington state in July 2025 for Microsoft, aiming to start it in 2028, and China outspends everyone.

The honest status: a private demonstration of net energy is plausible before 2030, a commercial plant selling power is a question for 2035-45, and fusion's contribution to the energy system of 2026-35 is essentially zero.

Module 11 Key Points

Nuclear: Small Modular Reactors, the Fuel Cycle, and Fusion

• No small modular reactor generates in the West yet; Ontario's first BWRX-300 poured nuclear concrete in June 2026 and targets 2030.

• TVA won the first US construction permit for a BWRX-300 in September 2026; TerraPower's Natrium got its permit in March.

• Rosatom holds about 43% of world enrichment capacity, and US waivers for Russian enriched uranium end in January 2028.

• Uranium sold at about $90 a pound in September 2026, against $25-34 in 2020; Kazakhstan mines about 40%.

• The US holds about 95,000 tonnes of spent fuel and no repository; Finland's Onkalo awaits its operating license.

• Private fusion firms have raised about $14 billion, but commercial fusion power is a question for 2035-45.

Module 11 Quiz

Check Your Understanding

1. Where did Western small modular reactors stand in October 2026?

A) Ten were running in Texas
B) None was generating; Ontario's first BWRX-300 had begun nuclear construction and targets 2030
C) NuScale's first plant in Utah opened in 2025
D) All projects were cancelled after the 2025 law

2. What is the fuel cycle's largest concentration risk?

A) Uranium mining, where Australia holds half of world output and sets the price
B) Reprocessing, which every reactor needs before its fuel can be reused
C) Fuel fabrication, done by a single French company for every Western reactor
D) Enrichment, where Rosatom holds about 43%

3. What was the status of Finland's Onkalo repository in October 2026?

A) Its regulator approved the safety case; the license decision is pending
B) It was cancelled in 2025
C) It has stored fuel since 2020
D) It began taking spent fuel from across Europe in 2025, under an EU agreement

4. Roughly what was the uranium spot price at the end of September 2026?

A) About $30 a pound, its 2020 level
B) About $90 a pound
C) About $200 a pound, a record set during the war
D) About $60 a pound, near its 2025 low

5. What is fusion's realistic contribution to the 2026-35 energy system, on the module's reading?

A) About 10% of electricity
B) Enough to replace coal in China
C) Essentially none: a demonstration of net energy is plausible, power for the grid is not
D) Most of the new firm power for data centers

Module 12 — Solar

The Cheapest Electricity in History, and Its Limits

Recommended Reading / Reference

Reference: IRENA, *Renewable Power Generation Costs in 2025* (July 2026); SolarPower Europe, *Global Market Outlook 2026-2030* (June 2026); the IEA Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global PV Markets 2026*; the Solar Energy Industries Association (SEIA) and Wood Mackenzie, *US Solar Market Insight*; InfoLink module price series; Ember

12a. The Cost Curve

Year	Module price ($/W)	Utility-scale system cost ($/W)	Average cost of electricity ($/MWh)	Added that year (GW)	Installed (GW)	Context
1976	~100	—	—	<0.001	~0	Satellites and calculators
2000	~5	~10	—	0.3	1	Germany's feed-in tariff begins
2008	~4	~7	—	6	15	Spain's boom; a polysilicon shortage
2010	~2	~4.50	~420	17	40	China's manufacturing scale begins
2013	~0.70	~2.50	~190	40	140	The first consolidation; trade tariffs
2016	~0.40	~1.50	~110	75	300	Record-low auctions in the Gulf and Chile
2020	~0.20	~1.00	~57	140	760	The cheapest new power in most markets
2023	~0.13	~0.90	~44	440	1,600	China's polysilicon glut
2025	~0.10 (China-made); $0.27-0.46 in the US	China ~0.50; US ~1.10-1.20	44	~600-700	~2,900-3,000	The record year
2026 (forecast)	~0.11 outside China (September 30)	—	—	~610-650, the first fall in two decades	Passed 3,000 early in the year	China's consolidation; US tariffs

IRENA's global weighted averages for new utility-scale solar (2010 onward); SolarPower Europe, IEA PVPS, BNEF, InfoLink, and the National Laboratory of the Rockies (NLR), formerly the National Renewable Energy Laboratory. Early figures approximate. US module prices after the 2026 tariffs.

A solar module cost about $100 a watt in 1976 and about $0.10 in 2025, a thousandfold fall, because the cost has dropped about 20% with each doubling of cumulative production, a learning rate that has held for five decades. The result is the cheapest electricity in history: IRENA puts the global average cost of power from new utility-scale solar at $44 per MWh in 2025, unchanged from 2024, below new gas, coal, and nuclear nearly everywhere the sun shines.

The world installed roughly 600-700 GW of solar in 2025, about 1.8 GW a day, and the global fleet passed 3,000 GW early in 2026. Solar passed wind in generation in 2025 and drew almost level with nuclear, at 8.7% of the world's electricity against 8.9%, and in the first half of 2026 it supplied 10.2%. Yet forecasters expect installations to fall in 2026 for the first time in about two decades, to 612-649 GW, mostly because China's installations drop after its pricing reform.

12b. Additions by Country

Country	Added in 2025	Installed, end-2025	Share of electricity, 2025	Note
China	315 GW (AC, official); 370-415 GW (DC) on other counts	About 1,200 GW (AC)	11%	A rush before the June 2025 pricing reform; a 14-24% fall forecast for 2026
United States	43.2 GW (DC), down 14%	279 GW (DC)	9%	The federal credit's deadlines; tariffs; 65.5 GW of module assembly capacity
European Union	65.1 GW, the first fall since 2016	406 GW	13%	Rooftops slowing; midday negative prices
India	37.9 GW	—	9%	A target of 500 GW of non-fossil capacity by 2030
Germany	16.4 GW	117 GW	18%	Rooftops and the Energiewende
Brazil	12-14 GW	—	12%	Distributed solar's boom
Pakistan	About 17 GW of imported panels a year (2024-25)	—	Unmeasured	Households escaping a failing grid (Module 19)
Saudi Arabia	About 7 GW, four times 2024	—	Small	Auctions at record-low prices
Africa	18.8 GW of Chinese panels imported, up 48%	—	Small	Rooftops and mini-grids ahead of official statistics
World	~600-700 GW	~2,900-3,000 GW	8.7%	Passed wind; nearly level with nuclear

China: National Energy Administration; US: SEIA and Wood Mackenzie; EU: SolarPower Europe; India: Ministry of New and Renewable Energy; Germany: Bundesnetzagentur; Pakistan and Africa: Ember and Renewables First; shares: Ember. AC and DC figures differ by roughly a fifth.

12c. The Chinese Supply Chain

China made about 80% of the world's solar modules in 2025 and holds about 85% of the supply chain's factory capacity, including about 95% of wafer capacity, on the IEA's figures. The chain was built with state finance, cheap coal power in Xinjiang and Inner Mongolia, and a decade of overcapacity that drove module prices below the cost of making them, bankrupting most Western producers and many Chinese ones.

By 2025 the overcapacity had become a government problem, and Beijing moved against what it calls 'involution,' ruinous price competition. In December 2025 the largest polysilicon makers formed a company to buy and retire up to a third of the industry's capacity, and new rules banned offers below full cost. China scrapped export tax rebates on wafers, cells, and modules from April 2026, yet its solar exports hit a record 68 GW in March, as the energy crisis sent buyers looking for panels.

Other countries have tried to build alternatives, and the United States imposed tariffs on Chinese and Southeast Asian panels, then a new duty on polysilicon and its products, announced in August 2026 and effective in December, with minimum import prices for cells and modules. American factories could

assemble 65.5 GW of modules a year by the end of 2025, but could make only about 3 GW of cells, so the cells and wafers inside American panels still come mostly from Asia. India mandates domestic manufacturing, and the EU has a forced-labor rule aimed at Xinjiang polysilicon.

12d. The Economics, Worked, and the Limits

Worked example — A 100 MW Solar Farm in Texas and in Xinjiang

In Texas the farm costs about $1.10 a watt installed with tariffed modules, or $110 million, and at a 25% capacity factor it produces about 219,000 MWh a year. Assuming a 30-year life, output that degrades 0.5% a year, operating costs of $10 per kW a year, and a 7% cost of capital, its levelized cost of electricity (LCOE), the average cost per MWh over its life, is about $48. A project that began construction before July 4, 2026 keeps the 30% federal tax credit, which cuts that to about $36. It sells into ERCOT at the price prevailing when it produces, and since every other solar farm produces at the same time, its captured price is well below the market average; suppose $30. So it needs the credit, a power-purchase agreement (PPA) of $40-50 with a corporate buyer, or a battery to shift output into the evening. In Xinjiang the same farm costs about $0.45 a watt with untariffed modules and cheaper labor, and at a 20% capacity factor it produces power for about $28/MWh without subsidy. But in China's northwest a meaningful share of solar output is curtailed because the grid cannot carry it east, which is why China builds ultra-high-voltage lines.

The limits of solar are the same in both places: it produces only when the sun shines, its value falls as its share rises, and the grid and storage that move its output, not the panel, are now the main cost.

Module 12 Key Points

Solar

• Module prices fell from about $100 a watt in 1976 to about $0.10 in 2025, a thousandfold drop.

• The world installed about 600-700 GW of solar in 2025, but forecasters expect the first fall in two decades in 2026.

• China installed 315 GW (AC) in 2025, about half the world's total, and made about 80% of its modules.

• Solar supplied 8.7% of world electricity in 2025, passing wind, and 10.2% in the first half of 2026.

• A Texas solar farm costs about $48/MWh unsubsidized but captures far less, so it needs a contract, a credit, or a battery.

Module 12 Quiz

Check Your Understanding

1. How much has the price of a solar module fallen since 1976?

A) Tenfold
B) About halfway, to $50 a watt, because silicon prices doubled in the 2020s
C) About a hundredfold, to about a dollar a watt, where it has stayed since 2010
D) About a thousandfold, to about $0.10 a watt

2. What do forecasters expect for world solar installations in 2026?

A) The first fall in about two decades
B) Another record, about 900 GW, led by India and the US
C) A doubling, as Europe replaces Qatari gas with solar farms
D) Flat installations, because module prices doubled under the 2026 tariffs

3. What share of the world's solar modules did China make in 2025?

A) About 20%
B) About half
C) About 80%, with even higher shares of wafers and polysilicon
D) About 35%, behind Southeast Asia

4. In the worked example, why does the Texas farm need a contract, a credit, or a battery?

A) Texas taxes solar
B) Its panels fail in heat
C) ERCOT bars solar farms from selling into the wholesale market without a utility partner
D) It sells when everyone's solar is selling, so its captured price is low

5. What share of world electricity did solar supply in the first half of 2026?

A) About 2%
B) About 10.2%
C) About a quarter, more than coal
D) About 40%, after the war cut gas supplies

Module 13 — Wind

Onshore's Maturity and Offshore's Troubles

Recommended Reading / Reference

Reference: Global Wind Energy Council, *Global Wind Report 2026* (April 2026) and *Global Offshore Wind Report 2026* (June 2026); GWEC's 2026 supply-side report; IRENA, *Renewable Power Generation Costs in 2025*; the Bureau of Ocean Energy Management and court records on US offshore projects

13a. Capacity and Economics

Country	Installed, end-2025 (GW)	Added in 2025 (GW)	Offshore (GW)	Share of electricity, 2025	Note
China	~640	120.5	~45-50, the largest fleet	11%	About 73% of the world's additions
United States	~160	6.9	Under 1 operating	10%	Offshore halted, then partly restored by courts
Germany	~75	5.7	~9.5	27%	An August 2025 offshore auction drew no bids
India	~54	6.3	0	5%	Growing
Britain	~32	1-2	~16, the second-largest fleet	~30%	Contracts for difference; the 2026 auction
Spain, Brazil, France, Sweden, Canada, Turkey	15-35 each	1-4 each	Small	10-25%	Brazil's northeast; Spain's plains
Denmark, Netherlands, Belgium	5-12 each	Under 1-2 each	3-5 each	25-55%	The North Sea build-out
World	1,299	165, a record (up 40%)	92	8.5%	Onshore 93% of capacity

GWEC, *Global Wind Report 2026*; National Energy Administration (China); Ember for shares. Country totals other than China's additions approximate.

Wind supplied about 8.5% of the world's electricity in 2025 from about 1,300 GW of turbines, 93% of them on land, after the world added a record 165 GW that year, up 40%, of which China added 120.5 GW, about 73%.

Onshore wind is a mature, cheap technology, and IRENA puts the global average cost of power from new onshore wind at $33 per MWh in 2025, the lowest of any new source it tracks. A modern turbine of 5-7 MW on a tall tower runs at capacity factors of 35-45% in good sites such as the American Plains, Brazil's northeast, or Inner Mongolia. Its constraints are siting, since local opposition has slowed it across Europe and the United States, transmission, since the best wind is far from cities, and the same value cannibalization that solar faces. Because the wind often blows at night and in winter, grids want both.

13b. The Offshore Crisis

Date	Event	Cost
2020-21	Offshore auctions clear at record lows in Britain, and developers bid without subsidy in the Netherlands and Germany	The industry assumes costs will keep falling
2022-23	Inflation, interest rates, and supply costs rise; Ørsted, Equinor, BP, and Shell cancel or write down US and British projects; Britain's 2023 auction draws no offshore bids	Billions written off; US state contracts renegotiated at higher prices
2024	Britain's auction succeeds at higher prices; a blade fails at Vineyard Wind; the first US projects generate	Recovery at higher prices
January 2025	A presidential memorandum halts new US offshore leasing and permits	The American pipeline frozen
2025	Empire Wind stopped in April and restored in May; Revolution Wind stopped in August and allowed by a court in September; Ørsted raises about $9 billion of new equity; Germany's August auction draws no bids	The industry's worst year
July 2025	The US budget law ends wind's tax credits for projects not under construction by July 4, 2026 or in service by the end of 2027	Onshore squeezed too
December 2025-January 2026	Interior suspends the leases of all five US projects under construction, citing national security; courts let Revolution and Vineyard Wind resume	Construction by injunction
2026	Vineyard Wind 1 finishes construction in March; Britain's auction awards Berwick Bank B a contract at £89.49 per MWh (2024 prices); Washington plans to buy back leases for four more projects	China and Europe build; the US finishes what it started

Court and agency records as reported; GWEC; company statements.

Offshore wind was the transition's showcase, with turbines of 15 MW and more on towers taller than skyscrapers and auction prices that fell every year, and it broke in 2022-23, when inflation, interest rates, and supply-chain costs rose against fixed-price contracts signed at the lows. The industry leader, Ørsted, wrote down billions and in 2025 raised about $9 billion of new equity, while Shell, BP, and Equinor retreated and Britain's 2023 auction drew no offshore bids.

Then the United States stopped. A January 2025 memorandum halted new leasing and permits, projects under construction were halted and restored by turns, and the July 2025 budget law ended the tax credits for later projects. In December 2025 the Interior Department suspended the leases of all five projects under construction on national-security grounds, and courts let construction resume in January 2026. Vineyard Wind 1 finished construction in March 2026, though many of its turbines were idle in May, and the handful of projects already building will be the American fleet for years.

Europe redesigned its auctions with inflation indexing and higher prices; Britain's January 2026 round awarded Berwick Bank B a contract at £89.49 per MWh in 2024 money, while China, on state finance and its own turbines, owns the largest offshore fleet. The lesson applies across the transition: fixed-price contracts written on the assumption of falling costs break when the cost curve turns, and policy can stop an industry in a year.

13c. Turbines and Manufacturers

A turbine's output rises with the area its blades sweep, the square of the rotor's diameter, and with the cube of the wind's speed. Offshore winds are stronger and steadier, so offshore turbines have grown to 15-26 MW, with rotors more than 250 meters (820 feet) across, and the largest prototype on record, Dongfang Electric's 26 MW machine, went up in September 2025.

Chinese makers now dominate the market: in 2025 Goldwind installed 29.7 GW, Envision 21.8, Windey 19.8, Mingyang 18.6, and SANY 15.1, mostly in China, where Chinese firms hold almost the whole market. Outside mainland China, Vestas led with 12.9 GW, followed by Nordex, GE Vernova, and Siemens Gamesa, and Vestas and GE Vernova together hold about 93% of the American market. The EU opened an inquiry into Chinese turbine subsidies in 2024, Western makers lean on service revenue and protected markets, and the rare-earth magnets in many turbine generators are a Chinese chokepoint (Module 21).

Module 13 Key Points

Wind

• Wind supplied 8.5% of world electricity in 2025 from about 1,300 GW, after a record 165 GW was added.

• China added 120.5 GW of wind in 2025, about 73% of the world's total.

• New onshore wind cost about $33/MWh on IRENA's 2025 global average, the cheapest new source it tracks.

• Offshore wind broke in 2022-23 when costs outran fixed-price contracts; Ørsted needed about $9 billion of new equity in 2025.

• Washington suspended the leases of five offshore projects under construction in December 2025; courts let construction resume.

Module 13 Quiz

Check Your Understanding

1. Why do grids want both wind and solar?

A) They share transmission lines, so they cost less to connect together
B) Wind often blows at night and in winter
C) Regulators require both under the renewable portfolio standards in every state
D) They have the same capacity factor, so they can be planned as one source

2. What broke offshore wind in 2022-23?

A) A ban on new leases
B) Turbine blades failed
C) Chinese turbines undercut every Western bidder in that year's North Sea auctions
D) Inflation and interest rates outran fixed-price contracts

3. What did Washington do to the five offshore wind projects under construction in December 2025?

A) Suspended their leases on national-security grounds, until courts let work resume in January
B) Paid them to finish early
C) Granted them new tax credits
D) Bought them for the Navy

4. Why are offshore turbines so much larger than onshore ones?

A) Rules require it
B) Steel is cheaper at ports, so larger towers cost nothing extra to build and ship
C) Output rises with rotor area and wind speed cubed
D) Larger blades are easier to ship by sea than by road, so there is no practical limit

5. Which turbine maker installed the most capacity outside mainland China in 2025?

A) Goldwind
B) Vestas, with about 12.9 GW
C) Siemens Gamesa, after its 2023 quality crisis ended
D) GE Vernova

Module 14 — Hydro, Geothermal, and Bioenergy

The Older Renewables and the Newest One

Recommended Reading / Reference

Reference: International Hydropower Association, *World Hydropower Outlook*; IRENA, *Renewable Capacity Statistics 2026* and *Renewable Power Generation Costs in 2025*; Ember, *European Electricity Review 2026*; the EU's ReFuelEU Aviation regulation; the UK government's 2025 agreement with Drax

14a. Hydropower

	Figure	Note
World capacity	About 1,470 GW at the end of 2025, including just over 200 GW of pumped storage	The largest renewable source of electricity: about 14%, or 4,480 TWh, in 2025
Largest fleets	China (over 400 GW including pumped storage), Brazil (~110), Canada (~85), the US (~80), Russia (~55), India (~50)	Brazil, Norway, Canada, Ethiopia, and Zambia get most of their power from it
The newest giant	China's Medog project on the Yarlung Tsangpo in Tibet: 60 GW, about 300 TWh a year, over ¥1 trillion; begun July 2025	Downstream India and Bangladesh object
Drought episodes	Brazil (2001, 2021), Sichuan (2022), the 2023 global fall, Zambia and Ecuador (2024), EU output down 12% (2025), Europe's drought of June-August 2026	The renewable most exposed to the climate it helps protect
New building	28 GW added in 2025, a record 11.6 GW of it pumped storage; China is building more than 300 GW, 218 GW of it pumped storage	Large new dams are contested outside China, Africa, and the Himalaya
Cost	New hydro averaged $62 per MWh in 2025 (IRENA)	Sediment, methane, displacement, and downstream conflict

IRENA; International Hydropower Association, *World Hydropower Outlook 2026* (June 2026); Ember; Energy Institute. Fleet sizes approximate.

Hydropower is the largest renewable source of electricity, about 14% of the world's supply in 2025, and because it is dispatchable and cheap once built, it is the backbone of Brazil's, Canada's, and Norway's grids and much of Africa's and Latin America's.

Its problem is that its fuel is rain, and droughts have cut output in Brazil, in China's Sichuan province, in southern Africa, and in Ecuador. EU hydro output fell 12% in 2025, and Europe's drought of June-August 2026 drove the Rhine to record lows and nearly forced Hungary's Paks nuclear plant to shut for lack of Danube cooling water. Growth has shifted from new rivers to pumped storage, which pumps water uphill when power is cheap and releases it when power is dear (Module 15), except in China, which began the 60 GW Medog dam in Tibet in July 2025, the largest hydro project ever attempted.

14b. Geothermal: Volcanic Fields and Enhanced Wells

	Conventional geothermal	Enhanced geothermal (EGS)	Next generation (closed-loop, 'superhot')
How it works	Wells tap naturally hot, permeable rock and its water or steam, in volcanic regions	Shale drilling and fracturing open hot dry rock, and water is circulated through it	Closed pipes exchange heat with the rock (Eavor), or drills reach rock above 400°C (Quaise)
Where	Iceland, Kenya, Indonesia, the Philippines, California, Italy, New Zealand, Turkey	Anywhere with hot rock 2-4 km down: most of the western US and much of the world	Anywhere, if the drilling works
Scale	About 16 GW worldwide; under 1% of electricity	Fervo's Cape Station in Utah, planned at 100 MW first and 500 MW in all	Demonstrations; Eavor's first German plant
Cost	New geothermal averaged $89 per MWh in 2025 (IRENA)	Higher today; falling with drilling experience	Unknown
Character	Firm and clean, with capacity factors above 90%	Firm and clean; the oil field's skills applied	The prize: firm clean power anywhere

IRENA; company disclosures. Capacity figures approximate.

Conventional geothermal, drilling into naturally hot, wet rock in volcanic regions, is a mature industry of about 16 GW that supplies around 40% of Kenya's power and a large share of Iceland's, but it is limited to places where the earth offers it. Enhanced geothermal changes the map by applying the shale industry's horizontal drilling and fracturing to hot dry rock, which exists almost everywhere at depth.

Fervo Energy's Cape Station in Utah, planned at 100 MW in its first phase and 500 MW in all, is the first attempt at commercial scale, and it raised $462 million in December 2025. The July 2025 US budget law preserved geothermal's tax credits while ending wind's and solar's, a sign of its unusual support across the American political divide, since it is firm, drilled by oil-field crews, and, in its enhanced form, an American invention. Closed-loop systems and drilling into 'superhot' rock would make it available anywhere, and both remain demonstrations.

14c. Biofuels

Bioenergy is the largest renewable in total energy use, mostly because about two billion people still cook with wood, dung, and charcoal (Module 19), and modern biofuels tie food to fuel. About a third of the US corn crop becomes ethanol under the federal renewable fuel standard, at an energy return not far above one, while Brazil turns about half its sugarcane into ethanol at a much better return, and biodiesel and renewable diesel now take about half of American soybean oil.

Sustainable aviation fuel, made from waste oils, crops, or synthetic processes, is the growth market. The EU requires 2% of jet fuel to be sustainable from 2025, 6% from 2030, and 70% by 2050, Britain has a similar mandate, and such fuel costs roughly two to five times as much as fossil jet fuel.

14d. Burning Wood for Power

Biomass power burns wood pellets in converted coal plants, the largest of which is Britain's Drax, burning millions of tonnes of pellets a year, mostly from North American forests. In February 2025 the British government extended its subsidy from 2027 to 2031, on condition that the plant run no more than 27% of the time, well below its recent output.

The case for, as Drax and the governments that subsidize it make it. International accounting counts the carbon where trees are cut, in the land sector, so counting it again at the stack would double-count it. Managed forests regrow, many pellets come from sawmill residues and thinnings, and biomass offers dispatchable low-carbon power that, fitted with carbon capture, could even remove CO2 from the air.

The case against, as many forest scientists and environmental groups make it. Burning wood releases more CO2 per MWh at the stack than burning coal, and the regrowth that recaptures it takes decades, a 'carbon debt' paid back long after the climate needs the cuts, while whole trees, not only residues, end up in pellets.

The evidence between them. Both sides accept the stack emissions and the accounting rules and differ on the feedstock and the time horizon, since residues pay back quickly and whole trees slowly, and capture on biomass plants has not yet been shown at scale.

The course's reading. Biomass power without carbon capture is a weak climate bet, which Britain's tighter subsidy now reflects; with capture it is an unproven removal technology.

Module 14 Key Points

Hydro, Geothermal, and Bioenergy

• Hydropower supplied about 14% of world electricity in 2025, but drought cut EU hydro output 12% that year.

• China began the 60 GW Medog dam in Tibet in July 2025, the largest hydro project ever attempted.

• Enhanced geothermal applies shale drilling to hot dry rock; Fervo's Utah project is planned at 500 MW.

• About a third of the US corn crop becomes ethanol, at an energy return not far above one.

• The EU requires 6% sustainable aviation fuel by 2030 and 70% by 2050, at two to five times jet fuel's price.

• Wood burned for power emits more CO2 per MWh than coal at the stack; Drax's subsidy now runs to 2031 at reduced output.

Module 14 Quiz

Check Your Understanding

1. What is hydropower's structural weakness?

A) It is costly
B) It cannot be dispatched at the evening peak, because its reservoirs must stay full
C) China has banned new dams, ending growth in the largest market for a decade
D) Its fuel is rain, which droughts cut

2. What does enhanced geothermal change?

A) Its cost, to zero
B) The need for wells
C) Where geothermal can be built, by applying shale-style drilling to hot dry rock almost anywhere
D) Its output, which no longer varies with the season or the weather

3. Roughly what share of the US corn crop goes to ethanol?

A) About a third
B) About 5%, mostly for export to Brazil
C) About 80%, which is why food prices rose in 2022
D) Almost none; US ethanol comes from sugarcane

4. What does the EU's aviation-fuel rule require for 2030?

A) All flights within Europe to use hydrogen-powered aircraft
B) 6% sustainable fuel
C) A 50% blend of e-fuels in every tank at every airport
D) A ban on new jet engines that cannot burn pure biofuel

5. Why is biomass power's carbon accounting contested?

A) Wood is costly
B) Pellets are taxed twice
C) It is counted as carbon-neutral, yet a forest takes decades to regrow
D) It is counted twice, once in the forest where the trees grow and again at the power station's stack

Module 15 — Storage

The Technology That Lets Variable Power Be Used When It Is Needed

Recommended Reading / Reference

Reference: BloombergNEF, *Energy Storage Market Outlook 1H 2026* (May 2026); the IEA's *Global Energy Review 2026* and *Global EV Outlook 2026*; Ember on China's and California's batteries (2026); SEIA and Benchmark, *Energy Storage Market Outlook*; IRENA, *Renewable Power Generation Costs in 2025*

15a. The 2025 Record

Market	Added in 2025	Note
World	112 GW and 307 GWh, up 48% (BNEF); 108 GW (IEA)	Forecast for 2026: 158 GW and 459 GWh (BNEF)
China	About 54% of the world's additions	Installations up 84%; a lithium-ion fleet of 140 GW at end-2025, more than the rest of the world's 132 GW (Ember)
United States	57.6 GWh, up 30%	About 16% of world additions; 43.6 GW installed at end-2025 and about 52 GW by mid-2026 (EIA); California and Texas lead
European Union	About 27 GWh	Germany and Italy lead; home batteries a large share

GW measures how fast a battery can deliver power; GWh measures how much energy it holds. A 1 GW, 4 GWh battery runs for four hours at full output.

Storage is the fastest-growing power technology, and BloombergNEF counts 112 GW and 307 GWh of batteries added worldwide in 2025, up 48% in a year, with China installing about half. Nearly all of it is lithium iron phosphate (LFP) chemistry in shipping-container units that hold about four hours of output.

The reason is cost: battery pack prices fell 8% in 2025, LFP packs cost more than 40% less than the nickel-based packs used in many cars, and Chinese packs cost about 30% less than North American ones (IEA, citing BNEF). IRENA puts the average installed cost of a four-hour battery at about $140 per kWh in 2025.

The merit order of Module 9 explains why storage matters: a battery buys midday solar at $20 per MWh or less and sells it into the evening peak at $70-500, the arithmetic that displaces the gas peaker. In California, solar plus batteries met more than a quarter of demand between 7 and 9 p.m. in the first half of 2026, up from 6.8% three years earlier.

15b. The Duration Ladder

Technology	Duration	Round-trip efficiency	Installed cost ($/kWh)	Status, 2026	Role
Lithium-ion (LFP), 1-2 hours	1-2 hr	90-95%	$200-450	Mature	Frequency regulation, reserves, short peaks
Lithium-ion (LFP), 4 hours	4 hr	85-90%	About $120-250 (world average about $140)	The standard	The evening peak; capacity payments
Lithium-ion, 8 hours	8 hr	85-90%	$110-200	Rising in high-solar grids	Overnight shifting
Sodium-ion	2-4 hr	85-90%	Falling	Grid projects in China	Cheap, cold-tolerant storage
Pumped hydro	8-24 hr	70-85%	$50-150	About 200 GW; over 90% of stored energy worldwide	The incumbent; needs mountains
Flow batteries (vanadium, iron)	4-12 hr	65-75%	$200-500	GWh-scale in China	Long cycle life
Iron-air (Form Energy)	About 100 hr	40-50%	Target $20-50	First utility projects	Multi-day reserve
Thermal (bricks, salt, sand)	8-100+ hr	40-60% as power; 90%+ as heat	$20-60	Commercial for industrial heat	Heat for industry
Compressed air	8-24 hr	55-65%	$100-200	A few large plants	Caverns
Hydrogen (seasonal)	Seasons	30-40%	Low per kWh, high per kW	Pilots	The only seasonal option; inefficient

Cost ranges approximate, from IRENA, BNEF, and developers; the installed cost per kWh covers the storage system, not the cost of the power it stores.

15c. The Economics and the Long-Duration Gap

A four-hour battery at about $200 per kWh installed, a typical American cost, cycled daily for fifteen years, adds roughly $80-100 to the cost of each MWh it stores and returns, and at IRENA's global average of $140 per kWh it adds about $60-70. That beats a gas peaker, whose power costs about $144-276 per MWh on Lazard's July 2026 estimates, which is why the peaker is losing.

The economics fail at long durations, because the same battery cycled once a week spreads its capital over a seventh as many discharges, so each MWh costs several hundred dollars. A grid with 60-80% wind and solar needs something else for a windless winter week, and the candidates, iron-air, flow batteries, thermal storage, compressed air, and hydrogen, are early commercial technologies with growing project lists and a graveyard of failed predecessors.

The IEA's reading is that durations are lengthening from four hours toward eight rather than leaping to days, and that until the early 2030s gas plants that run less often will fill the long gaps. Long-duration storage remains the transition's most consequential unsolved engineering problem.

15d. The Revenue Stack and the Risks

A grid battery earns money in four ways: it buys low and sells high across the day, it is paid for being available at the peak, it sells fast services that keep frequency steady, and it can defer the need for new transmission. The fast-service markets were the first that batteries dominated, and they saturated, so prices for those services fell, while in Texas batteries earn much of their money in a few dozen scarcity hours a year, so revenues swing widely and are shrinking as batteries multiply.

Fires wrote the safety codes: battery fires in Korea (2018-19), Arizona (2019), and at Moss Landing in California, which burned in January 2025 and again in September 2026, drove the shift to LFP chemistry and to separated outdoor containers. Local opposition after Moss Landing has made siting the main American obstacle, while Chinese integrators supply most of the world's systems and Tesla's Megapack is the main alternative.

Module 15 Key Points

Storage

• Batteries added a record 112 GW and 307 GWh in 2025, up 48%, with China about half (BNEF).

• China's battery fleet reached 140 GW at the end of 2025, more than the rest of the world combined.

• A four-hour battery cost about $140/kWh installed in 2025 on IRENA's average, cheap enough to displace gas peakers.

• Cycled weekly, the same battery costs several hundred dollars per MWh; the long-duration gap remains unsolved.

• Solar plus batteries met more than a quarter of California's 7-9 p.m. demand in the first half of 2026.

Module 15 Quiz

Check Your Understanding

1. How much battery storage was added worldwide in 2025, on BNEF's count?

A) About 10 GW
B) About 1,000 GW
C) About 30 GWh, mostly in Europe
D) A record 112 GW and 307 GWh, up 48%, about half of it in China

2. Why can a four-hour battery displace a gas peaker?

A) It delivers peak power at a lower cost, with no fuel
B) Peakers are banned
C) Batteries store power for weeks, covering whole seasons when the wind is calm
D) Federal rules give batteries first call in every capacity auction in every market

3. Why can lithium batteries not fill the long-duration gap?

A) They are flammable
B) Their efficiency is too low to be useful over a week of calm
C) Cycled weekly, their capital is spread too thin
D) They cannot hold a charge for more than an hour in winter, when it is needed most

4. What still holds most of the world's stored energy?

A) Pumped hydro, about 200 GW of it
B) Hydrogen
C) Lithium batteries
D) Flow batteries in China, which passed pumped hydro in 2024

5. Where does the IEA see storage durations heading?

A) To 100 hours by 2027
B) From four hours toward eight, with gas filling longer gaps until the 2030s
C) Shorter, toward two hours
D) Fixed at four hours by market rules

Module 16 — Hydrogen and the Molecules

Hydrogen, Ammonia, E-Fuels, and Carbon Capture, Against Their Numbers

Recommended Reading / Reference

Reference: IEA, *Global Hydrogen Review 2026* (June 2026); BloombergNEF hydrogen cost estimates; Global CCS Institute, *Global Status of CCS 2025* (October 2025); the IEA's *World Energy Investment 2026*; company filings (Air Products, Occidental, Stegra)

16a. The Colors and the Costs

Type	How it is made	Cost ($ per kg)	Emissions (kg CO2 per kg of hydrogen)	Share of production	Note
Grey	Steam reforming of natural gas	About $1-2.35 (higher where gas is dear)	9-10	About 65% of 2025 supply	Refineries and ammonia
Black or brown	Coal gasification	$1.5-2.5	18-20	Most of the rest, chiefly in China	Chinese fertilizer and chemicals
Blue	Grey plus carbon capture	$1.5-3	1-4	Small but growing	The US 45Q credit; Gulf projects
Green	Electrolysis on renewable power	About $3.74-11.70	Near zero	Low-emissions hydrogen about 1 Mt in all, under 1%	Electrolyzer capacity doubled to over 4 GW in 2025, three-quarters of the additions in China
Pink	Electrolysis on nuclear power	$4-6	Near zero	Pilots	Draws on nuclear's credits
Turquoise	Methane split by heat, leaving solid carbon	$2-4 (target)	Near zero directly	Pilots	Monolith in Nebraska
White or natural	Hydrogen found underground	Unknown	Near zero	Exploration	Unproven

IEA, *Global Hydrogen Review 2026*; costs from BloombergNEF (January 2025).

Hydrogen is not an energy source but a carrier that must be made from something else, then stored, and then burned or reacted. The world used just over 100 million tonnes in 2025, up almost 3%, according to the IEA, almost all of it in oil refining, ammonia fertilizer, and chemicals, and about 65% was made from natural gas and most of the rest from coal.

The 2020s' hope was 'green' hydrogen, made by splitting water with renewable electricity, which would replace grey hydrogen in its existing uses and then fuel steel mills, trucks, ships, and long-duration storage. The reality, in the IEA's 2026 review, is that low-emissions hydrogen of all kinds came to about 1 million tonnes in 2025, still under 1% of production.

The pipeline is shrinking: projects announced for 2030 fell to 27 million tonnes a year, from 37 a year earlier, and those operating or past a final investment decision add up to 4.3 million. New investment decisions fell below 0.8 million tonnes in 2025, the first decline, because the cost gap has not closed, with green hydrogen at roughly $4-12 a kilogram against grey's $1-2.35.

The July 2025 US budget law requires projects to begin construction before 2028 to claim the federal hydrogen credit, and on June 30, 2026, Air Products cancelled its Louisiana Clean Energy Complex and an

Arizona green-hydrogen project, taking charges of up to $2.9 billion. The flagship survivor, NEOM Green Hydrogen in Saudi Arabia, with more than 2 GW of electrolyzers, was about 90% complete in 2026, and its first ammonia is now expected in 2027. Blue hydrogen, grey with carbon capture, is the pragmatic middle course that the US capture credit and Gulf producers are pursuing.

16b. Where Hydrogen Makes Sense

An honest map of hydrogen's uses runs from certain to implausible. Certain: replacing grey hydrogen in refineries and fertilizer, about 100 million tonnes of demand that already exists, and making steel by reducing iron ore with hydrogen instead of coal. The steel case is proving hard, as Sweden's Stegra, building the first large green-steel plant, needed a €1.4 billion rescue in June 2026 and said in September that it needs more capital.

Plausible: long-haul shipping on ammonia or methanol, aviation on synthetic fuels, and seasonal storage in salt caverns, each at two to five times the cost of what it replaces. Implausible: cars, where batteries won, home heating, where heat pumps are about three times as efficient, and the 'hydrogen economy' of the 2020 roadmaps.

The rule of thumb follows from the physics: use electricity directly wherever possible, as in cars, heat, and most industry, use hydrogen where electricity cannot do the job, as in chemistry, steel, and perhaps ships and planes, and turn hydrogen back into electricity only as a last resort.

16c. Ammonia and E-Fuels

Ammonia, hydrogen bound to nitrogen, is one of the world's most produced chemicals, mostly for fertilizer, and because it is easier to ship and store than hydrogen it is the leading candidate for shipping fuel and for carrying hydrogen from Australia, Chile, and the Gulf to Japan and Korea. The first ocean-going ship designed to run on ammonia, the gas carrier *Antwerpen*, was delivered in June 2026.

E-fuels are synthetic gasoline, diesel, jet fuel, and methanol made from green hydrogen and captured CO2, the only path to cutting aviation emissions at scale, at three to six times the cost of fossil fuel. Porsche's partner HIF still runs only a pilot plant in Chile, and its first commercial plant has slipped to 2029, while Europe's aviation mandate requires synthetic fuels to reach 1.2% of jet fuel in 2030 and 35% in 2050. Both ammonia and e-fuels depend on green hydrogen becoming cheap, which it has not.

16d. Carbon Capture

	Figure	Note
Operating capacity	About 64 million tonnes of CO2 a year at 77 facilities, under 0.2% of energy emissions	Mostly at gas processing and ethanol plants, where the CO2 is already concentrated
Under construction	47 facilities, about 44 Mt a year	History says only a fraction of announced projects is built
Cost	$15-40 a tonne at gas processing and ethanol plants; $60-120 at power, cement, and steel plants; $500-1,900 for first-of-a-kind direct air capture	The US 45Q credit pays $85 a tonne for storage and $180 for direct air capture

	Figure	Note
Flagships	Norway's Northern Lights (first injection August 2025, 1.5 Mt a year); Occidental's Stratos direct-air plant in Texas (delayed; operations expected in 2027); Canada's Boundary Dam (underperformed); Shell's Quest	A mixed record
Uses of captured CO2	Enhanced oil recovery (most), storage in saline rock, e-fuels	Using captured CO2 to pump more oil is the industry's contradiction; since July 2025 it earns the same US credit as storage
Verdict	Necessary for cement, steel, and residual emissions; not a substitute for replacing fossil fuels	Net-zero models assume gigatonnes; the world captures megatonnes

Global CCS Institute, *Global Status of CCS 2025*; IEA, *World Energy Investment 2026*; company statements. A 2026 edition of the Institute's report is due on October 20, 2026.

Module 16 Key Points

Hydrogen and the Molecules

• Hydrogen is a carrier made from other energy; the world used just over 100 Mt in 2025, about 65% of it made from gas.

• Low-emissions hydrogen was about 1 Mt in 2025, and the 2030 project pipeline shrank from 37 to 27 Mt.

• Green hydrogen costs roughly $4-12 a kilogram against grey's $1-2.35, so most projects stall without subsidy.

• Hydrogen makes sense in refineries, fertilizer, and steel, plausibly in ships and planes, and rarely in cars or home heating.

• Carbon capture runs at about 64 Mt a year, under 0.2% of energy CO2, while net-zero models assume gigatonnes.

Module 16 Quiz

Check Your Understanding

1. Why is hydrogen called a carrier rather than a source?

A) It is too rare to mine in the earth's crust, unlike natural gas or coal
B) It burns too cleanly to count in the national energy statistics
C) It is a liquid at room temperature and must be stored under pressure
D) It must be made from other energy

2. What happened to the low-emissions hydrogen projects announced for 2030?

A) The pipeline doubled
B) All were built
C) The pipeline grew to 100 Mt as the 2026 gas crisis made green hydrogen competitive
D) The pipeline shrank to 27 Mt, from 37 a year earlier

3. Where does hydrogen make the most sense, on the module's map?

A) Cars
B) Home heating and passenger cars, where it replaces gas and gasoline directly
C) Refineries, fertilizer, and steel
D) Everywhere electricity reaches, since hydrogen is cheaper to move than power

4. What happened to Air Products' Louisiana hydrogen complex in June 2026?

A) The company cancelled it
B) It opened as the largest blue-hydrogen plant on the Gulf Coast
C) It was sold to Saudi Aramco and converted to make ammonia for export
D) It was taken over under the Defense Production Act to supply the Navy

5. How does carbon capture's delivery compare with its role in net-zero models?

A) Capture exceeds the models
B) Models assume gigatonnes a year; about 64 Mt of capture operates
C) The two match closely
D) Capture is banned in the EU

Module 17 — Demand: Who Uses Energy and How

The Consumption Side by Sector, Country, and Use

Recommended Reading / Reference

Reference: IEA, *Global Energy Review 2026* (April 2026), *Global EV Outlook 2026* (May 2026), *Heat Pump Monitor 2026* (July 2026), and *Energy Efficiency 2025*; the Energy Institute's *Statistical Review of World Energy 2026*; EIA reporting on US car sales and electricity demand

17a. By Sector

Sector	Share of world final energy	Main fuels	Share met by electricity	Trend	Hard cases
Industry	About 38%	Coal, gas, electricity, oil	About a quarter	Rising in Asia; flat in the West	Steel (coal), cement (heat and limestone), chemicals (gas and oil as feedstock)
Transport	About 27%	Oil (over 90%)	A few percent, rising with electric vehicles (EVs) and rail	Electric cars displacing about 1.7 mb/d of oil by 2025	Aviation, shipping, long-haul trucks
Buildings (homes and offices)	About 30%	Electricity, gas, biomass, oil	About a third	Cooling rising in hot, growing countries; flat in the rich world	Heating in cold climates; cooking with biomass
Agriculture and other	About 5%	Diesel, electricity	About a fifth	Flat	Irrigation pumping
Electricity, across sectors	21% of final energy (2025)	—	—	Up about 3% a year; the fastest-growing carrier	The transition's core

Sector shares approximate, from the IEA's energy balances; electricity share and EV oil displacement from the IEA (2026).

17b. By Country and Person

Country or region	Energy per person (gigajoules a year)	Electricity per person (kWh a year)	Driver	Trend
United States	~280	~13,000	Large homes, cars, and industry	Electricity demand rising, about 2-2.6% in 2025
Canada, Norway, Gulf states	200-350	15,000-25,000	Cold winters, or cheap energy and cooling	Flat
Japan, France, Germany	~110-150	~6,000-8,500	Efficient industry; smaller homes	Falling about 1% a year
China	~115	~7,500, above the EU average	Industry, about half of all use	Electricity demand up about 5% in 2025
Brazil, Mexico, Turkey	~50-65	~2,500-3,500	Growing middle classes	Rising
India	~27	~1,400	Cooling, industry, a growing middle class	Rising fast

Country or region	Energy per person (gigajoules a year)	Electricity per person (kWh a year)	Driver	Trend
Indonesia, Vietnam, Philippines	~25-40	~1,300-3,000	Manufacturing and cooling	Rising fast
Sub-Saharan Africa (excluding South Africa)	Far below the world average	~150-200	Biomass; the access gap (Module 19)	Rising slowly from a small base
World	~73	~3,900		Energy up 1.3% and electricity about 3% in 2025

Approximate, derived from Energy Institute energy totals, Ember generation data, and UN population estimates; per-person electricity counts generation, not final use.

The world uses about 73 gigajoules of energy per person a year on the Energy Institute's count, while an American uses about 280, a Chinese about 115, and an Indian about 27, so an American uses roughly ten times as much as an Indian. Demand growth is now concentrated in the developing world, in China, India, Southeast Asia, the Middle East, and Africa, where incomes, cooling, and industry are rising, while the rich world's energy use has been flat or falling for twenty years, thanks to efficiency and to industry moving abroad.

The exception is American electricity: US demand rose about 2-2.6% in 2025, and the IEA attributes about half of the increase to data centers (Module 18). China, the largest consumer, uses about half its energy in industry, and its electricity use per person has passed the EU's.

17c. Efficiency and Electrification

Efficiency is the transition's quiet half: energy intensity, the energy used per unit of economic output, improved about 1.8% worldwide in 2025, up from about 1% in 2024, against a target of 4% a year agreed at the 2023 UN climate summit. Light-emitting diodes (LEDs) replace incandescent bulbs, heat pumps replace boilers, and electric cars replace engines, and an EV uses about a quarter of the energy of a gasoline car per mile.

Electrification is efficiency's lever, since an electric motor, heat pump, or induction cooker needs a third to a quarter of the primary energy of the combustion device it replaces. So a world that electrifies transport and heat needs far less primary energy even as it needs far more electricity, which is why electricity demand grows faster than energy demand.

The 2025-26 markers point in several directions: more than 20 million electric cars were sold in 2025, a quarter of new cars worldwide and about 55% in China, and the IEA estimates they avoided about 1.7 mb/d of oil use. In the United States, sales fell 45% year on year in the fourth quarter of 2025, after the federal credit ended on September 30. Global heat-pump sales slipped 2% in 2025, rising 11% in Europe and falling 13% in the United States, where heat pumps still outsold fossil-fuel heating systems.

Cooling is the opposite force: about 200 million air conditioners were shipped in 2024, a quarter more than five years earlier. Cooling uses about a tenth of the world's electricity but drives nearly a third of peak demand, and since 2015 it has accounted for 14% of the growth in electricity demand, on the IEA's figures.

17d. The Hard Cases

Some uses resist electrification, and steel is the first: it needs coke from coal to strip oxygen from iron ore. Its alternatives are electric arc furnaces that melt scrap, already about 30% of output, iron reduced with hydrogen, and electrolysis of molten iron ore, still a pilot, and none is close to replacing about 1.9 billion tonnes of steel a year.

Cement releases CO2 from limestone whatever fuel heats the kiln, which makes it carbon capture's most defensible use, and chemicals use oil and gas as raw materials, not only as fuel. Aviation needs energy density that batteries lack, since jet fuel holds about 12,000 watt-hours per kilogram against about 300 for the best batteries, and shipping is turning to LNG, methanol, and ammonia. Long-haul trucking is a contest between batteries and hydrogen that batteries are winning in China and that no one has yet won in the West. These sectors are where the fuels of Module 16 make their case, and where the transition will be slowest.

Module 17 Key Points

Demand: Who Uses Energy and How

• Industry uses about 38% of world final energy, buildings about 30%, and transport about 27%; electricity is 21% of the total.

• An American uses about ten times as much energy as an Indian; demand growth is concentrated in Asia and the Middle East.

• Electric cars were a quarter of new car sales in 2025, over 20 million, and avoided about 1.7 mb/d of oil.

• US electric-car sales fell 45% year on year in the fourth quarter of 2025, after the federal credit ended in September.

• Cooling uses about a tenth of the world's electricity but drives nearly a third of peak demand.

Module 17 Quiz

Check Your Understanding

1. Where is energy demand growing fastest?

A) In Europe
B) Only in the United States, on the data-center build-out, while every other region falls
C) Everywhere equally, in rich and poor countries alike, at about 2% a year
D) In the developing world, led by Asia

2. Why does electricity demand grow faster than energy demand overall?

A) Electricity is always cheaper
B) Coal plants are reopening
C) Electrification shifts uses onto electricity, and electric machines waste less energy
D) Population grows fastest in cities

3. How many electric cars were sold worldwide in 2025, and what share of new cars?

A) About 2 million
B) Over 20 million, about a quarter of new cars
C) About 5 million, 6%
D) About 60 million, three-quarters of new cars, after China banned petrol sales

4. What happened to US electric-car sales after the federal credit ended on September 30, 2025?

A) They fell 45% year on year in the fourth quarter
B) They rose as buyers rushed to beat new tariffs on imported cars
C) They held steady because automakers cut prices to match the lost credit
D) They doubled after states replaced the federal credit with rebates of their own

5. Why is cement a natural candidate for carbon capture?

A) Its kilns are small
B) Its chemistry releases CO2 from limestone whatever fuel the kiln burns
C) Cement is cheap
D) It uses little energy

Module 18 — Data Centers and the AI Load

The Decade's Largest New Source of Electricity Demand

Recommended Reading / Reference

Reference: Lawrence Berkeley National Laboratory, *2024 United States Data Center Energy Usage Report* (December 2024); the IEA's *Energy and AI* (April 2025) and *Key Questions on Energy and AI* (April 2026); the IEA's *World Energy Investment 2026*; EIA reporting on ERCOT and the Dominion zone (2026)

18a. The Forecasts

Source	US data centers	Share of US electricity	Horizon	Global
Lawrence Berkeley National Laboratory (December 2024)	176 TWh in 2023, rising to 325-580 TWh in 2028	4.4%, rising to 6.7-12%	2028	—
IEA, *Energy and AI* (April 2025)	About 45% of the world's data-center use in 2024; up about 240 TWh by 2030	—	2030	415 TWh (2024), rising to about 945 TWh (2030)
IEA, *Key Questions on Energy and AI* (April 2026)	—	—	2030	485 TWh in 2025, up 17%; about 950 TWh in 2030, about 3% of world electricity
Requests to connect	ERCOT: more than 230 GW of large-load requests by January 2026, 160 GW of them data centers	—	2030s	Ireland: data centers about a fifth of metered electricity
Capital spending	Over $400 billion in 2025; about $715 billion planned for 2026 (Alphabet, Amazon, Meta, Microsoft, Oracle, and newer cloud firms)	—	2026	Mostly AI chips and data centers
The course's range	300-600 TWh by 2030	About 6-12%	2030	The width is the uncertainty

Requests to connect include duplicate and speculative applications; capital spending is the IEA's tally from company guidance and S&P Global.

Data centers used about 485 TWh of electricity worldwide in 2025, up 17% in a year, with AI-focused data centers' use up 50%, and the IEA expects about 950 TWh by 2030. The United States accounts for nearly half of the total, and Lawrence Berkeley National Laboratory found US data centers used 4.4% of the country's electricity in 2023 and projected 6.7-12% by 2028.

The load is concentrated: northern Virginia, in Dominion Energy's territory, holds the world's densest cluster, and the Dominion zone's winter peak was 45% above its 2019 level in 2025-26. Texas received more than 230 GW of requests to connect large loads by January 2026, more than twice its record peak demand of 91 GW, and in 2026 it paused new data-center connections while the grid operator audited the requests.

The case for a very large load, as utilities, chip makers, and the technology companies make it. The money is real: the largest firms spent over $400 billion in 2025 and plan about $715 billion in 2026, and the electricity use of AI data centers rose 50% in 2025. In the United States data centers drove about half of 2025's growth in demand, and connection requests keep arriving.

The case for a smaller load, as efficiency researchers and some grid analysts make it. Each generation of chips does more work per watt, and the queues are full of duplicate and speculative requests,

filed in several places for the same campus. AI's revenues may not justify the spending, turbines and transformers limit how fast campuses can be powered, and forecasts in 2007 of a data-center power explosion were wrong for fifteen years, as efficiency kept demand flat.

The evidence between them. Demand is already rising measurably, globally and in the United States, but Texas's requests alone exceed the state's entire peak, and Texas paused connections rather than attempting to serve them.

The course's reading. The load is real and growing fast, but the queues overstate it, so the middle of the 6-12% range for 2030 is the sensible planning case, and capital spending, which leads demand by two to three years, is the indicator to watch.

18b. The Bottlenecks and the Deals

Constraint	Status (2025-26)	Response
Grid connection	Large loads wait years in many US regions; Texas paused new data-center connections in 2026	Building next to power plants; generating on site
Gas turbines	Orders reached 130 GW in 2025, a 25-year high; new orders can take about five years to deliver	Technology companies bought nearly all of the $28 billion of turbines ordered for on-site power in 2025
Firm clean power	Nuclear restarts and contracts (Crane, Clinton, Duane Arnold, Susquehanna, Perry, Davis-Besse), uprates, geothermal, small-reactor contracts	Nuclear's revival (Module 10); premium prices accepted
Grid equipment	Transformer and switchgear prices nearly doubled in five years	Stockpiling; imports
Water	Evaporative cooling uses millions of liters a day at large sites; local disputes	Closed-loop and direct-to-chip cooling
Other customers' bills	PJM's capacity prices at the cap (Module 9)	States write large-load tariffs so data centers pay for their own grid costs
Off the grid	On-site gas, fuel cells, and batteries	The 'energy park' that bypasses the grid

IEA, *World Energy Investment 2026* and *Key Questions on Energy and AI*; EIA; company announcements.

The grid cannot connect the load on the schedule the technology companies want, so they are buying and building their own power, signing nuclear contracts at premium prices, ordering gas turbines years ahead, and building generation on site. The IEA estimates that 15-27 GW of on-site gas plants may power data centers by 2030, mostly in the United States.

The result is the paradox of the decade: the companies most committed to clean power are driving a large gas build-out, because gas is the firm power available soonest, while also paying for nuclear's revival, because it is the only firm clean power on offer at scale.

18c. Who Pays for a Gigawatt, Worked

Worked example — Who Pays for a Gigawatt

A 1 GW data-center campus in Virginia runs at 90% load, using about 7,900 GWh a year, as much as some 700,000 homes, and to serve it the utility needs about 1.2 GW of new firm capacity, allowing for reserves, plus transmission. Option one: the utility builds a 1.2 GW combined-cycle gas plant at the $2,000-2,500 per kW that industry estimates now put on new gas plants, or $2.4-3 billion, plus perhaps $500 million of lines. Recovered from customers over thirty years at a regulated return of about 10%, that costs roughly $350-400 million a year, and spread across all customers under traditional ratemaking it adds several percent to every bill, for a load that serves one customer. Option two: a large-load tariff, under which the data center signs a long contract to pay for most of its reserved capacity whether it uses the power or not, and posts collateral, a model several states adopted in 2025-26. Option three: the campus builds its own gas plant and batteries behind the meter, which is faster and keeps it out of rate cases, but leaves other customers paying the grid's fixed costs without its help. The underlying arithmetic: an AI campus costs about $40,000-50,000 per kW of capacity to build and equip (IEA), so even expensive power is under a tenth of its cost. Data centers can pay almost any price for electricity and households cannot, so the political fight is over who pays, and the technology companies choose option three where regulators allow it.

Module 18 Key Points

Data Centers and the AI Load

- Data centers used 485 TWh worldwide in 2025, up 17%, and the IEA expects about 950 TWh by 2030.
- The largest technology firms plan about $715 billion of capital spending in 2026, up 75%, mostly on AI.
- Texas received more than 230 GW of large-load requests by January 2026, more than twice its record peak.
- An AI campus costs about $40,000-50,000 per kW to build, so electricity is under a tenth of its cost.
- The load is real, but the queues overstate it; the middle of a 6-12% US share by 2030 is the planning case.

Module 18 Quiz

Check Your Understanding

1. How much electricity did data centers use worldwide in 2025, on the IEA's count?

A) About 485 TWh, up 17%
B) About 50 TWh
C) About 4,850 TWh
D) About 1,500 TWh, more than India's whole consumption

2. Why do the module's skeptics think the AI load may be smaller than forecast?

A) Data centers are moving to orbit, where solar runs around the clock
B) Federal law caps data-center electricity at 5% of each state's use
C) AI models now run on phones, so the large campuses already built will empty by 2027
D) Chips get more efficient, and queues double-count

3. Why are the companies most committed to clean power driving a gas build-out?

A) Gas is free
B) Their clean-energy pledges expired in 2025 and their boards did not renew them
C) Gas is the firm power available soonest
D) Regulators require every data center to be backed by a gas plant on the same site

4. In the worked example, why did states write large-load tariffs?

A) To ban data centers
B) Under traditional ratemaking, the cost of serving one giant campus would fall on every customer
C) To subsidize the chips
D) To lower turbine prices

5. Roughly what share of an AI data center's cost is electricity?

A) About half, which is why campuses chase cheap power above everything else
B) About a third, roughly the same as the chips and the buildings
C) Under a tenth
D) Nearly all of it, since the chips are leased and the buildings are cheap

Module 19 — Energy Access and the Developing World

The People Who Use Too Little

Recommended Reading / Reference

Reference: IEA, IRENA, UN Statistics Division, World Bank, and WHO, *Tracking SDG 7: The Energy Progress Report 2026* (June 2026); the WHO fact sheet on household air pollution (December 2025); Ember and Renewables First on Pakistan's solar boom (June 2026); Ember on African solar imports (August 2026); Mission 300 fact sheet (June 2026)

19a. The Gap

Region	Without electricity, 2024	Access rate	Without clean cooking	Note
Sub-Saharan Africa	563 million, 86% of the world's total	55%	About 970 million rely on polluting fuels; 22% have clean cooking	Nigeria (87 million without power), the Democratic Republic of the Congo (85 million), Ethiopia (57 million)
Rest of the world	About 92 million	Over 95% in most regions	More than a billion, mostly in Asia	Myanmar, Haiti, and war zones such as Yemen, Syria, and Sudan; India near-universal since 2019
World	655 million, down about 11 million from 2023	92%	About 2.0 billion (range 1.8-2.4 billion)	The IEA, counting differently, puts the unconnected at 730 million

Tracking SDG 7: The Energy Progress Report 2026; IEA (October 2025). Regional detail outside Africa approximate.

About 655 million people had no electricity in 2024, according to the agencies that track the UN's goal of universal access, and 86% of them lived in Sub-Saharan Africa, though the IEA, counting differently, puts the figure at 730 million. About 2 billion people cook with wood, dung, charcoal, or kerosene, and the World Health Organization estimates that household smoke from such fires killed about 2.9 million people in 2021, many of them women and young children.

Progress was real, since about 1.2 billion people lacked power in 2010 and India connected nearly every household by 2019, but it has since stalled. Sub-Saharan Africa's population has grown about as fast as its connections, so the goal of universal access by 2030 is out of reach. Beyond the unconnected are the under-served, hundreds of millions whose connection fails for hours or days and who run diesel generators at 30-50 cents per kWh, two to three times what an American household pays for grid power.

19b. Africa's Grid Gap and the Distributed Answer

Sub-Saharan Africa has more than a billion people and less generating capacity than Germany, much of it in South Africa, whose utility Eskom spent the early 2020s rationing power. The continent has the world's best solar resource and, until recently, little solar, and Nigeria has both the largest number of people without power of any country, 87 million, and one of the largest fleets of backup generators on earth.

The grid answer of transmission lines, large plants, and national utilities is slow, costly, and dependent on finance that aid cuts have reduced. The distributed answer is arriving faster, combining solar home systems, village mini-grids, and pay-as-you-go solar sold through mobile-money accounts by firms such as M-KOPA,

Sun King, and d.light. Africa imported 18.8 GW of Chinese solar panels in 2025, up 48%, and 23 GW in the year to June 2026, much of it on rooftops that official statistics do not yet count.

The World Bank and the African Development Bank's Mission 300 aims to connect 300 million Africans by 2030, by grid and off-grid. By April 2026 it had connected more than 50 million people in 40 countries, and 30 countries had launched national energy plans, or 'compacts,' under it by mid-June.

19c. Pakistan's Unplanned Revolution

Pakistan shows what cheap Chinese panels do to a failing grid. Power prices had risen steeply under tariff increases tied to IMF programs, and scheduled blackouts were routine, so households, farms, and businesses imported about 17 GW of Chinese panels in 2024 and a similar amount in 2025, with no policy, subsidy, or utility involvement.

The results, as Ember and the Pakistani think tank Renewables First counted them in June 2026, are stark: about 27 GW of distributed solar went up between fiscal 2023 and fiscal 2025. Total electricity use rose 21% while generation on the grid fell 3%, farms' demand from the grid fell 38%, and the country avoided more than $12 billion of fuel imports by February 2026.

For the utilities it is a spiral: their best customers leave, the fixed 'capacity payments' owed to power plants that now run less are spread over fewer sales, tariffs rise, and more customers leave. Pakistan's energy transition happened from the bottom up in about three years, because panels were cheaper than the grid, and no official forecast predicted it.

19d. Finance and the Aid Cuts

The barrier is capital: Africa will receive about $110 billion of energy investment in 2026, about 3% of the world's $3.4 trillion, for nearly a fifth of the world's people (IEA). A solar project in Nigeria pays 15-20% a year for its capital against 5-7% in Germany, which roughly doubles the price of its electricity. The aid that once narrowed that gap is shrinking, since the United States ended its Power Africa program in February 2025 as it dismantled its aid agency, European donors moved budgets to defense, and Chinese overseas lending has fallen far from its 2016 peak.

The growth now comes from Gulf investors such as Masdar and ACWA Power, from distributed-solar companies, and from the development banks' Mission 300. The honest outlook is that the access gap will close through cheap panels and mobile-money finance faster than through any grid program, and that the 2030 goal will be missed by hundreds of millions of people.

Module 19 Key Points

Energy Access and the Developing World

• About 655 million people lacked electricity in 2024, 86% of them in Sub-Saharan Africa.

• About 2 billion people cook with polluting fuels; household smoke killed about 2.9 million people in 2021 (WHO).

• Africa imported 18.8 GW of Chinese solar panels in 2025, up 48%, ahead of what official statistics record.

• Pakistan's rooftop boom cut grid generation 3% while total electricity use rose 21% over three fiscal years.

• Africa receives about 3% of the world's energy investment, and its high cost of capital roughly doubles power prices.

Module 19 Quiz

Check Your Understanding

1. How many people lacked electricity in 2024, on the count of the agencies that track the UN's access goal?

A) About 655 million
B) About 1 billion
C) About 2 billion, the same as those without clean cooking
D) About 1.2 billion, unchanged since 2010 despite India's connections

2. What is notable about Africa's solar imports in 2025-26?

A) They fell
B) They stopped after a Chinese export ban
C) They came mostly from Europe and the United States under the Mission 300 program
D) They jumped 48% in 2025, ahead of what official statistics record

3. What happened to Pakistan's grid as households installed solar?

A) It expanded
B) Blackouts ended, and utilities' revenues rose as solar homes sold power back
C) It was privatized, with Chinese lenders buying the utilities' debts to cover the losses
D) Grid generation fell as demand rose

4. Why does a solar project in Nigeria produce dearer electricity than one in Germany?

A) Less sunshine
B) Its capital costs 15-20% a year against 5-7%, which roughly doubles the price
C) Higher panel prices
D) Its workers earn more

5. How does the module expect the access gap to close?

A) Through coal
B) Through nuclear plants
C) Through cheap panels and mobile-money finance, faster than grids
D) Through national grids financed by Chinese policy banks under the Belt and Road

Module 20 — Policy: The US Reversal, Europe, and China

The Rules That Decide What Gets Built

Recommended Reading / Reference

Reference: Public Law 119-21 (July 4, 2025) and Treasury's August 2025 guidance; the EPA's final rule on the endangerment finding (February 2026); the EU's Russian gas regulation (in force January 26, 2026) and its carbon border adjustment rules; the Draghi report on European competitiveness (2024); China's 2035 climate pledge (September 2025) and 15th Five-Year Plan (March 2026); the IEA's *Renewables 2025*

20a. The United States

Policy	Before (Inflation Reduction Act, 2022)	After (the July 2025 law and 2025-26 actions)	Effect
Wind and solar tax credits	Credits for any clean technology through 2032, then phasing out	Projects must begin construction by July 4, 2026 or enter service by the end of 2027; Treasury tightened the test for starting construction (August 2025); limits on Chinese content	A 2025-26 rush, then a cliff
Electric-vehicle credits	$7,500 new, $4,000 used, through 2032	Ended for vehicles bought after September 30, 2025	US EV sales down 45% year on year in the fourth quarter of 2025
Nuclear, geothermal, storage, hydro	Credits through 2032	Kept largely intact; Chinese-content limits on storage	These keep building
Hydrogen (45V)	Up to $3 per kg for projects begun before 2033	Projects must begin construction before January 1, 2028	Projects cancelled (Module 16)
Carbon capture (45Q)	$85 a tonne stored; $180 for direct air capture; less for use	Kept; using CO2, including for oil recovery, now earns the same as storing it	Capture keeps its subsidy
Home energy credits	Through 2032	Ended December 31, 2025	Fewer heat pumps and rooftop systems
Offshore wind	Leasing and permits	Halted (January 2025); five projects' leases suspended (December 2025), work restored by courts	The pipeline frozen (Module 13)
Coal and gas plants	Emissions rules; retirements	Plants ordered kept open; the 2024 mercury-rule tightening repealed (February 2026); carbon standards partly repealed (September 2026); LNG export approvals resumed	Retirements delayed; a gas build-out
Vehicle and climate rules	Tightening standards	The 2009 endangerment finding and all vehicle greenhouse-gas standards repealed (February 2026); California's waiver revoked (June 2025); fuel-economy penalties ended	Slower EV adoption
Methane fee	Charged from 2024	The EPA's rule voided by Congress (March 2025); the fee postponed ten years	—

Policy	Before (Inflation Reduction Act, 2022)	After (the July 2025 law and 2025-26 actions)	Effect
Tariffs	Section 301 duties on Chinese solar, batteries, and EVs	Steel and aluminum at 50% (restructured April 2026); emergency-powers tariffs struck down by the Supreme Court (February 20, 2026); duties on Southeast Asian, Indian, Indonesian, and Laotian panels; a polysilicon tariff from December 2026	Higher project costs; more domestic assembly

Public Law 119-21; Treasury; EPA; the IEA's *Renewables 2025* and *Global EV Outlook 2026*; court records.

In a single year the United States reversed its energy policy, cutting short the 2022 Inflation Reduction Act (IRA), the largest climate law in the country's history, which had offered tax credits to every clean technology through 2032. The July 4, 2025 budget law, Public Law 119-21, ended most of the credits for wind, solar, electric vehicles, and hydrogen early, while keeping those for nuclear, geothermal, storage, and carbon capture.

Executive actions went further, halting offshore wind, ordering coal plants kept open, and rolling back vehicle and methane rules. In February 2026 the EPA repealed its 2009 finding that greenhouse gases endanger public health, the legal basis for federal climate rules on vehicles, in pursuit of what the administration calls 'energy dominance.'

The effects are visible: developers rushed to start wind and solar projects before the July 2026 deadline, though US solar installations still fell 14% in 2025. Electric-car sales fell 45% year on year in the fourth quarter of 2025 and most hydrogen projects were abandoned, while nuclear and geothermal survived and gas is being built for data centers. US fossil CO2 emissions rose about 2-2.5% in 2025, as higher gas prices and rising demand brought coal back into the power mix.

20b. The Argument Over the Reversal

The case for, as the administration and the law's supporters make it. The IRA's credits were open-ended, and independent estimates of their cost rose from the $370-400 billion first scored to more than $1 trillion. Wind and solar are mature and do not need subsidy, much of their supply chain is Chinese, and the grid needs firm power for reliability and for data centers. Consumers should not pay for cars they do not choose, and abundant American oil and gas give the country leverage, as its record exports in the 2026 crisis showed.

The case against, as most energy economists, the clean-energy industry, and Democratic critics make it. Cutting the cheapest new sources of power while demand rises pushes electricity prices up, raises emissions, sends investment abroad, and cedes the industries of the future to China, while policy whiplash raises the cost of capital for every long-lived energy project.

The evidence between them. American household electricity prices rose about 5% in 2025 and the EIA expects about 5% more in 2026, but data centers, grid spending, and gas prices drive much of that rise, so the law's share is disputed. Emissions rose in 2025, while oil and gas output and LNG exports set records and Henry Hub gas stayed near $3 even in the 2026 crisis.

The course's reading. The reversal shifted American energy investment toward gas, nuclear, and grids rather than shrinking it, with its costs showing up first in power bills and emissions and its gains in the federal budget and in firm supply. The largest cost may be the whiplash itself, because investors now price in the next reversal.

20c. Europe

Policy	Content	Status (October 2026)
Emissions Trading System (ETS)	A carbon price on power, industry, aviation, and (from 2024) shipping	The world's largest carbon market; a second system for buildings and road fuel (ETS2) delayed to 2028
Carbon Border Adjustment Mechanism (CBAM)	A carbon tariff on imported steel, aluminum, cement, fertilizer, hydrogen, and electricity	Definitive from January 2026, the world's first carbon tariff; trade disputes with India, China, and the US
Climate targets	A 55% cut from 1990 by 2030; a 90% cut by 2040	The 2040 target agreed provisionally on December 9, 2025, with a limited role for international credits
Renewables	42.5% of energy by 2030 (binding)	Wind and solar (30%) passed fossil fuels (29%) in EU power in 2025
Russian gas	A phased ban (Module 5)	In force January 26, 2026; complete by November 1, 2027 at the latest
Nuclear	A choice for each member state	France, Sweden, Belgium, Poland, and Czechia building or extending; Germany out
The retreat	Farm rules loosened; industrial price relief; the Clean Industrial Deal (2025); a December 2025 proposal to loosen the 2035 ban on new combustion-engine cars	Competitiveness weighed against ambition

European Commission and Council; Ember, *European Electricity Review 2026*.

Europe kept its framework and softened its edges. Its Emissions Trading System puts a price on carbon across power, industry, aviation, and shipping, and its Carbon Border Adjustment Mechanism, definitive from January 2026, is the world's first carbon tariff, charging importers for the carbon in their goods.

The retreat is in the details: the second trading system, for buildings and road fuel, has slipped to 2028, the 2035 ban on new combustion-engine cars faces a proposal to loosen it, farm rules were rolled back, and industry got price relief. The driver was the Draghi report of 2024, which found that European companies paid two to three times American prices for electricity and four to five times for gas. In power, Europe is on track, since wind and solar overtook fossil fuels in 2025, but elsewhere it is behind.

20d. Germany's Energiewende

Germany's 'energy turn' is the transition's most studied case, and its feed-in tariffs, guaranteed prices for renewable power from 2000, built the world's first mass market for solar and wind. After Fukushima, Germany decided in 2011 to close its reactors and shut the last three in April 2023, with Russian gas meant to be the bridge, until 2022 broke it.

The results cut both ways. Renewables supplied close to 60% of German power in 2025 and coal fell to about a fifth, but subsidies ran to hundreds of billions of euros, households pay about 40 euro cents per kWh, and heavy industry has cut output. Germany's power-sector emissions fell more slowly than they would have if the reactors had stayed open, and the lesson most analysts draw is that renewables without firm clean power, backed by a single gas supplier, produced an expensive and exposed system.

20e. China

Policy	Content	Status (2026)
The 2035 pledge (September 2025)	Cut net greenhouse-gas emissions 7-10% from their peak by 2035; non-fossil fuels over 30% of energy; 3,600 GW of wind and solar	The first absolute cut China has pledged; criticized as unambitious
The 15th Five-Year Plan (March 2026)	'Actively and prudently' achieve carbon peaking; control both carbon totals and intensity; electricity about 35% of final energy by 2030; nuclear 110 GW by 2030	Coal permits slowed to 45 GW in 2025
The 2025 power-market reform	New wind and solar sell through market-based contracts instead of fixed tariffs from June 2025	A rush before June; a slowdown after
National carbon market	Power since 2021; steel, cement, and aluminum added in 2025	Prices well under $15 a tonne
Industrial policy	Dominant in solar, batteries, EVs, wind turbines, and their supply chains; export controls on key technologies	Supplier and lever (Module 21)
Energy security	Imports 73% of its oil and over a third of its gas; coal as domestic insurance; large stockpiles	The 2026 crisis cut its Gulf imports
Emissions	Energy CO2 down about 0.5% in 2025 (IEA)	A peak may have come in 2024

Government of China; Ember, *China Energy Transition Review 2026*; IEA; CREA.

China's policy is driven by industry and security more than by climate, and it has produced more clean energy than any climate law. China added about 315 GW of solar on the official count and about 120 GW of wind in 2025, sells over half of the world's electric cars, runs the largest nuclear program, and makes the equipment everyone else buys. It also permits coal plants as a backstop, and its 2035 pledge of a 7-10% cut from peak struck most of the world as unambitious.

China's energy CO2 fell about 0.5% in 2025, on the IEA's count, and may have peaked in 2024, earlier than its 2030 pledge, because clean power now covers most demand growth. The 2026 crisis, with most of its oil imported and much of that from the Gulf, reinforced the security logic of electrifying transport and building solar. The global picture: the United States retreating, Europe holding with exceptions, China building everything, and the developing world buying Chinese panels regardless.

Module 20 Key Points

Policy: The US Reversal, Europe, and China

• The July 2025 US law ends wind and solar credits for projects not started by July 4, 2026 or running by end-2027.

• The EPA repealed its 2009 endangerment finding in February 2026, removing the basis for federal vehicle climate rules.

• US fossil CO2 rose about 2-2.5% in 2025 as coal generation rose; the reversal shifted investment toward gas and nuclear.

• The EU's carbon border tariff became definitive in January 2026, the world's first, while ETS2 slipped to 2028.

• Germany's Energiewende brought renewables near 60% of its power at a high price; it closed its last reactors in 2023.

• China's 2035 pledge is a 7-10% cut from peak; its energy CO2 fell about 0.5% in 2025, on the IEA's count.

Module 20 Quiz

Check Your Understanding

1. What does the July 2025 US law require for a wind or solar project to keep its tax credit?

A) Starting by July 4, 2026, or running by end-2027
B) Meeting a domestic-content test, with the credits otherwise unchanged through 2032
C) Using only American-made turbines and panels, with no Chinese parts at any stage
D) Pairing every project with a battery large enough to cover four hours of its output

2. What did the EPA's final rule of February 2026 do?

A) Banned new coal plants
B) Repealed the 2009 finding that greenhouse gases endanger health, and the vehicle rules built on it
C) Set a national carbon tax
D) Restored California's waiver

3. On the module's reading, what may be the largest cost of the US reversal?

A) Higher gas prices
B) Fewer LNG exports to Europe
C) The loss of all federal support for nuclear power, which the law repealed along with wind's
D) The whiplash itself: investors now price in the next reversal

4. What is the EU's Carbon Border Adjustment Mechanism?

A) A subsidy paid to European steelmakers for every tonne of CO2 they avoid
B) A cap on the price of carbon permits during energy crises, set by the Commission
C) A carbon tariff on imports
D) A tax on European consumers' energy bills that funds the bloc's grid investment

5. What did China pledge for 2035 in September 2025?

A) A 7-10% cut from peak emissions
B) Net zero
C) A 50% cut from 2005 levels, matching the European Union's pace
D) No new coal plants after 2030 and an end to coal power by 2040

Module 21 — The Geopolitics of Energy

Energy as Power Between States

Recommended Reading / Reference

Book: Daniel Yergin, *The New Map: Energy, Climate, and the Clash of Nations*

Reference: EIA, *World Oil Transit Chokepoints*; IEA *Oil Market Report* (2025-26); IEA, *Global Critical Minerals Outlook 2026* (July 2026); US Treasury sanctions records; Lloyd's List and Kpler on Gulf and Red Sea shipping

21a. The Chokepoints

Passage	What passes	Keeper	2026 status
Strait of Hormuz	About 20 mb/d of oil and products (a fifth of world use) and a fifth of LNG before the war	Iran and Oman on its shores	Closed, then crippled, since March; about 10 mb/d crossing on darkened ships in September; record attacks in early October; Iran says it stays closed until its conditions are met
Strait of Malacca	Most of China's, Japan's, and Korea's oil imports	Singapore, Malaysia, Indonesia	Open; China's 'Malacca dilemma'
Bab el-Mandeb and Suez	Red Sea traffic, including Saudi crude rerouted through Yanbu	Yemen's Houthis (in practice) and Egypt	Attacks paused in October 2025; about 31 ships a day in May 2026, against about 75 before the crisis; a Houthi blockade of Saudi Arabia declared July 20, 2026
Turkish Straits	Black Sea oil and grain	Turkey (Montreux Convention)	Open to trade
Danish Straits and the Baltic	Russia's Baltic oil exports, much of it on the shadow fleet	Denmark and the Baltic states	Shadow-fleet tankers boarded by several European navies, 2025-26
Panama Canal	US grain, LNG, and container trade	Panama	An El Niño drought cut transits to 32-34 a day from September 2026
Pipelines	Saudi East-West line (rated 5 mb/d, up to 7); UAE's Habshan-Fujairah; Russia-China lines; Ukraine's transit (ended January 2025); Nord Stream (sabotaged 2022)	Transit states	The East-West line shut by Houthi strikes on September 10-11, 2026, and partly restarted
Cables and grids	Baltic power and data cables; Ukraine's grid	Coastal states; grid operators	Cables cut by dragged anchors (2024-25); Ukraine's grid under attack since 2022

EIA; IEA; Kpler; Lloyd's List; news reports.

Energy geopolitics is a geography of chokepoints and pipelines, and in 2026 several were contested at once. Hormuz carried about a fifth of the world's oil and LNG before the war, and its closure showed what the world had feared for fifty years. Oil prices doubled, Gulf producers without bypass pipelines lost their exports, importers drew down their stockpiles, and South Asia's fertilizer plants and power stations went short of gas (Module 4).

The other passages were squeezed in the same year: the Houthis declared a blockade of Saudi Arabia in July and struck the East-West pipeline, the Saudi bypass, in September, drought cut traffic through the Panama Canal, and European navies boarded Russia's shadow-fleet tankers in the Baltic. Every importer relearned Europe's lesson of 2022, that a single supplier or a single route is a single point of failure.

21b. The Energy Powers

Actor	Position	Instruments	2025-26
Russia	The largest gas reserves; 10.5 mb/d of oil and liquids in 2025	Pipelines redirected to China and Turkey; a shadow fleet of over 1,300 tankers; LNG; Rosatom's reactor and fuel exports	US sanctions on Rosneft and Lukoil (October 2025); export revenue down to about half its pre-invasion level by December 2025; a temporary US easing in March 2026 amid the crisis
The Gulf	Most of the world's spare oil capacity and a fifth of LNG before the war; sovereign funds of about $4.7 trillion	OPEC+ quotas; bypass pipelines; investment abroad	Exports trapped; the UAE left OPEC; the Saudi bypass under Houthi fire; Qatar's LNG halted
China	The largest importer of oil (73% import-dependent), gas, and coal; the largest producer of coal, solar, wind, EVs, and batteries	Stockpiles, pipelines, its navy, and dominance of clean supply chains, with export controls	Gulf imports cut; its sweeping October 2025 export controls suspended under the truce, extended to January 10, 2027
United States	The largest producer of oil and gas and the largest LNG exporter	Sanctions, LNG, the Navy, tariffs, 'energy dominance'	Record net petroleum exports of 5.9 mb/d in May 2026; a naval blockade of Iran's ports and oil exports
Europe	The importer that lost its main supplier	Diversification; the Russian-gas ban; the carbon border tariff; renewables	Squeezed by the LNG shortage; storage about 73% full before winter
India	The third-largest oil importer (86% import-dependent); the largest buyer of Russian crude	Refining; trade deals; solar targets	A 50% US tariff over Russian oil (August 2025), cut to 18% in February 2026 after refiners agreed to limit purchases

EIA; IEA; Energy Institute; Ukrainian government count of shadow-fleet vessels (February 2026); public sovereign-fund estimates.

21c. Sanctions and Their Evasion

Sanctions are the West's energy weapon, and their record is mixed. Against Russia, the EU's embargo, the Group of Seven's price cap, and the blacklisting of ships cut Russia's European sales to almost nothing and lowered its revenue per barrel, and in September 2025 the EU switched to a cap that tracks market prices, starting at $47.60 a barrel. They did not cut its volume, because a shadow fleet of over 1,300 tankers, counted by Ukraine's government in February 2026, carries Russian crude to India, China, and Turkey.

The heaviest blow came on October 22, 2025, when the United States sanctioned Rosneft and Lukoil, Russia's two largest oil companies. Indian and Chinese state buyers pulled back, and by December 2025 Russia's oil export revenue was about $11 billion a month, half its pre-invasion level, on the IEA's figures. The 2026 crisis then worked the other way, as prices spiked and on March 13, 2026, with the strait closed, the United States temporarily eased its restrictions on buying Russian oil.

Against Iran, sanctions since 2018 confined its exports mostly to China through the same dark fleet, and UN sanctions returned in September 2025, but the 2026 war and the American naval blockade did what sanctions had not. In Venezuela, a decade of sanctions and mismanagement cut output, and after US forces captured Nicolás Maduro on January 3, 2026, Washington eased oil sanctions within the month and recognized the interim government in March. The newest phase presses buyers rather than sellers, through tariffs on India and sanctions on Chinese independent refiners.

21d. The Minerals Behind the Transition

The transition's geopolitics are the geopolitics of processing: the IEA's July 2026 outlook finds that for key energy minerals, the leading refining country held about 72% of world capacity on average in 2025. China dominates graphite and rare-earth refining and makes about 94% of the world's sintered rare-earth magnets, which go into EV motors and many wind turbines, though its share of rare-earth refining has eased, from over 90% in 2023 to about 85% in 2025. Indonesia, mostly with Chinese-owned plants, now leads nickel refining.

China has used its position, licensing graphite exports in 2023 and restricting rare earths in April 2025, which halted some Western auto and defense production lines for weeks. It added curbs on battery-cathode and lithium-processing technology in July 2025 and a sweeping regime in October 2025, and after the October 30, 2025 meeting between Presidents Trump and Xi it suspended the October rules for a year. In September 2026 the two governments extended the truce, and the suspension with it, from November 10, 2026 to January 10, 2027.

The Western response, which includes limits on Chinese content in tax credits, Europe's Critical Raw Materials Act, a Pentagon stake in the American rare-earth miner MP Materials, and mineral deals with Ukraine and others, reduces the dependence only at the margin. The oil age's chokepoints were straits and the transition's are refineries, and in 2026 both kinds were in play.

Module 21 Key Points

The Geopolitics of Energy

• About a fifth of the world's oil and LNG passed Hormuz before 2026; its closure trapped Iraqi, Kuwaiti, and Qatari exports.

• In 2026 Hormuz, the Red Sea, and Panama were squeezed at once; the Houthis declared a blockade of Saudi Arabia in July.

• Sanctions cut Russia's revenue more than its volumes; by December 2025 its oil export revenue was about half the pre-invasion level.

• China imports 73% of its oil yet dominates clean supply chains, making about 94% of the world's sintered rare-earth magnets.

• China's sweeping October 2025 export controls are suspended under its truce with Washington, now extended to January 10, 2027.

Module 21 Quiz

Check Your Understanding

1. How much oil passed through the Strait of Hormuz before the 2026 war?

A) About 2 mb/d
B) About 20 mb/d of crude and products, a fifth of world use, plus a fifth of LNG
C) About half of world oil
D) About 5 mb/d, mostly Iranian

2. What did the Houthis declare on July 20, 2026?

A) A naval blockade of Saudi Arabia
B) A ceasefire with Israel and the United States, ending attacks on Red Sea shipping
C) The reopening of Bab el-Mandeb to all Western shipping under UN supervision
D) Their support for the June memorandum between Washington and Tehran

3. What have sanctions done to Russia's oil exports, on the module's account?

A) Ended them
B) Doubled them, as India and China paid full market prices for every cargo
C) Cut revenue per barrel more than volume
D) Stopped them reaching Asia entirely after the Rosneft and Lukoil sanctions of 2025

4. What share of the world's sintered rare-earth magnets does China make?

A) About 50%
B) About a fifth
C) About 30%, behind Japan and Germany, which lead in magnets
D) About 94% (2024)

5. What happened to China's sweeping October 2025 export controls?

A) They were repealed
B) They were suspended under the truce with Washington, now extended to January 10, 2027
C) They expanded to oil
D) They were never enforced

Module 22 — Emissions, Climate, and the Transition's Economics

Where Emissions Stand, and What the Transition Costs

Recommended Reading / Reference

Reference: The Global Carbon Project's *Global Carbon Budget 2025* (November 2025; final paper May 2026); the IEA's *Global Energy Review 2026*, *World Energy Investment 2026*, and *World Energy Outlook 2025*; IRENA, *Renewable Power Generation Costs in 2025*; Lazard, *Levelized Cost of Energy+* (July 2026); the Met Office's HadCRUT5 temperature record

22a. Emissions

Country or source	Fossil CO2, 2025 (Gt)	Share	Per person (tonnes)	2025 change	Note
China	~12.2	32%	~8.6	+0.4% (GCP); energy CO2 −0.5% (IEA)	May have peaked in 2024
United States	~5.0	13%	~14.6	+1.9-2.5%	Coal generation rose
India	~3.0	8%	~2.1	+1.1-1.4%	Coal power dipped in 2025
European Union	~2.3	6%	~5.1	About flat	Power emissions falling; industry weak
Japan	~1	~2.5%	~8	−2.2%	Reactors restarting
International aviation and shipping	~1.2	~3%	—	Rising	Outside national totals
World	38.1 (fossil); 42.2 with land use	100%	~4.6	+1.0-1.1% (GCP); energy CO2 +0.4% to 38.4 Gt (IEA)	A record, but the slowest rise since 2021 on the IEA's count

Global Carbon Project, *Global Carbon Budget 2025* and its May 2026 revision (levels derived from published shares); IEA, *Global Energy Review 2026*. The two count slightly different things, so their totals differ.

Energy-related CO2 emissions reached a record of about 38.4 gigatonnes in 2025, up 0.4%, the slowest rise since 2021, according to the IEA, while the Global Carbon Project counts 38.1 gigatonnes of fossil CO2, and 42.2 including land use. China's emissions edged down on the IEA's count, while those of the United States rose about 2% as coal generation rose, India's rose modestly, and the EU's were about flat.

The atmosphere keeps the score: CO2 averaged about 427 parts per million at Mauna Loa in 2025 and peaked at about 432 ppm in May 2026, against about 280 before industrialization. On the HadCRUT5 record kept by Britain's Met Office, 2025 was about 1.41°C (2.5°F) warmer than the late-nineteenth-century average, and the IEA counts it the third-warmest year on record. Human-caused warming, as distinct from natural swings, reached about 1.36°C in 2024.

The Global Carbon Project estimates that about 170 gigatonnes of CO2 remained at the start of 2026 for an even chance of holding warming to 1.5°C, about four years of current emissions. The IEA's 2025 outlook projects almost 3°C of warming by 2100 under today's policies and about 2.5°C if governments meet their stated plans, and it calls an overshoot of 1.5°C inevitable. In 2026 the war's destruction of oil demand cut emissions more than most policies, while the gas shortage pushed coal use to a record.

22b. The Cost of Electricity by Source

Source	Cost of new power ($/MWh)	Capacity factor	Firm?	What the figure misses
Utility solar	IRENA world average 44 (2025); Lazard US range 40-98	20-25%	No	Its value falls as its share rises; integration and land
Onshore wind	IRENA 33; Lazard 37-99	35-45%	No	Transmission from remote sites
Offshore wind	IRENA 78; Lazard 105-167	45-55%	No	The 2022-25 cost rise
Solar plus four-hour storage	Lazard 61-156	—	Partly (evenings)	Multi-day gaps
Combined-cycle gas	Lazard 51-129	50-60%	Yes	Fuel-price risk, carbon, and 2026's turbine prices
Gas peaker	Lazard 144-276	5-15%	Yes	It is built to be available, not to run
New coal	Lazard 72-177	50-70%	Yes	Carbon and local pollution
Existing coal	About 30-50 (running cost)	—	Yes	Age; plants ordered kept open in the US
New nuclear	Lazard 175-255 (Western); about 50-80 at Korean or Chinese costs	~90%	Yes	First-of-a-kind risk and financing
Existing nuclear, life-extended	About 30-40	85-90%	Yes	The cheapest clean firm power
Geothermal	IRENA 89; Lazard 67-111	90%+	Yes	Location and drilling risk
New hydro	IRENA 62	40-60%	Mostly	Rain
Green hydrogen burned for power	About 200-400	—	Yes	Round-trip losses of 60-70%

IRENA, *Renewable Power Generation Costs in 2025* (global weighted averages); Lazard, *Levelized Cost of Energy+* (July 2026, version 19; unsubsidized US ranges). Levelized cost excludes integration, transmission, and firming, which is why firm and variable sources are not directly comparable.

Onshore wind and solar are the cheapest electricity ever built: new onshore wind averaged $33 per MWh worldwide in 2025 and new utility solar $44, on IRENA's figures, below new gas, coal, and nuclear nearly everywhere. But the levelized cost that shows this misses what makes a system work, the storage, backup, and transmission that turn a variable source into a reliable supply, and those costs rise as the variable share grows.

A grid that gets a fifth of its power from wind and solar barely notices them, but at half it needs storage, interconnection, and backup plants that run less often, and at 80% it needs the long-duration storage that does not yet exist at scale (Module 15). Firm sources are what data centers are buying, at different prices: existing nuclear at about $30-40, gas exposed to fuel prices, and new nuclear at $50-255 depending on who builds it. The honest comparison is between systems, not sources.

22c. The Capital Arithmetic

The IEA expects world energy investment to reach about $3.4 trillion in 2026, up 5%, with about $2.2 trillion going to clean energy, meaning grids, renewables, nuclear, storage, efficiency, and electric vehicles, and about $1.2 trillion to fossil fuels, a ratio of almost two to one. Grid spending is about $550 billion, up about a fifth, while solar draws about $365 billion and batteries and nuclear each more than $80 billion.

The war has also lifted fossil spending in places: gas investment is at a decade high of about $330 billion, and coal's, at about $180 billion, is the highest since 2012, while oil investment fell below $500 billion for a third straight year.

The gap that matters is where the money goes, which is to cheap, quick technologies such as solar, batteries, and EVs, in rich countries and China. Too little goes to grids, firm power, and poor countries, and Africa gets about 3% of the world's energy investment. Higher interest rates since 2022 hurt capital-heavy clean projects, such as offshore wind and nuclear, more than fuel-heavy ones such as gas plants, and the windfalls of the 2026 price spike flowed to oil and gas producers.

22d. Addition or Transition?

The case for a transition, as the IEA, Ember, and clean-energy analysts make it. Solar and batteries keep getting cheaper on learning curves that have held for decades, and China's emissions appear to have peaked while its economy grew. Electric cars are a quarter of new car sales, low-carbon sources make 43% of the world's electricity, and on Ember's count renewables passed coal in 2025. Technologies spread along an S-shaped curve, slow and then fast, and these are on the steep part.

The case that the world is only adding, as Vaclav Smil, Jean-Baptiste Fressoz, and other skeptics make it. Fossil fuels still supply 86% of the world's energy and CO2 emissions set a record in 2025, while every new source in history has been added to the old ones (Module 2). Steel, cement, aviation, shipping, and chemicals have no scalable substitute yet, the developing world's growth runs on coal and oil, and the security turn of 2022-26 has made governments value domestic firm energy over imported clean technology.

The evidence between them. Both sides describe real data: in 2025, low-emission sources met about 60% of the growth in demand, on the IEA's count, but total energy demand still rose 1.3%, and fossil fuel use and emissions rose with it. In 2026 the war cut oil demand sharply while pushing coal to a record.

The course's reading. The electric core now grows fast enough to cap fossil fuels in power in China and the West, but not yet to shrink fossil energy worldwide, and whether it does so this decade turns on China's coal and the developing world's growth. By making imported fuel dear, the 2026 crisis may speed electrification in importing countries even as it raised coal use this year.

Module 22 Key Points

Emissions, Climate, and the Transition's Economics

- Energy CO_2 reached a record 38.4 Gt in 2025, up 0.4%, the slowest rise since 2021 on the IEA's count.
- CO_2 averaged about 427 ppm in 2025, and the year was about 1.41°C warmer than the late-nineteenth-century average.
- About 170 Gt of CO_2 remains for 1.5°C, about four years of current emissions (Global Carbon Project).
- New onshore wind averaged $33/MWh and solar $44 in 2025 (IRENA), but such costs leave out firming and grids.
- Energy investment will reach about $3.4 trillion in 2026: $2.2 trillion clean and $1.2 trillion fossil (IEA).
- Both sides of the transition debate read real data; the open question is whether fossil use falls in absolute terms.

Module 22 Quiz

Check Your Understanding

1. What happened to energy-related CO2 emissions in 2025, on the IEA's count?

A) They fell for the first time outside a recession, led by China and India
B) They rose about 5%, the fastest since the rebound from the pandemic in 2021
C) They were unchanged, because the war cut oil use as much as coal rose
D) A record 38.4 Gt, up 0.4%

2. How large is the remaining carbon budget for 1.5°C, on the Global Carbon Project's estimate?

A) About 170 Gt, roughly four years of emissions
B) About 1,000 Gt
C) About 500 Gt, 13 years
D) Already spent: it ran out in 2015, the year of the Paris Agreement

3. What does the levelized cost of electricity (LCOE) leave out when comparing solar with gas?

A) Fuel
B) Capital costs, which are paid by governments in most countries and so excluded
C) Firming, storage, and grid costs
D) Land costs, which exceed the panels' cost at most solar farms

4. How did energy investment split between clean and fossil sources in the IEA's 2026 estimate?

A) About $2.2 trillion clean to $1.2 trillion fossil, almost two to one
B) Equal, at $1.7 trillion each
C) Ten to one, favoring clean energy
D) Two to one in favor of fossil fuels

5. On the module's reading, what decides whether the world shrinks its fossil fuel use this decade?

A) The price of a solar panel, which must fall below $0.05 a watt in every market
B) A global carbon tax, which the UN's 2025 climate summit failed to agree
C) Fusion power's first commercial plants, now due in the early 2030s
D) China's coal and the developing world

Module 23 — Where Things Stand, and What to Watch

The Argument, the Contradictions, and What Moves Next

Recommended Reading / Reference

Reference: The EIA's *Short-Term Energy Outlook* and the IEA's *Oil Market Report*, both monthly, which will show first whether the crisis eases; the Energy Institute's *Statistical Review of World Energy* (each June), which will show whether the fossil shell has begun to shrink

23a. The Argument

The course's argument fits on a page. The world runs on fuels burned directly, oil, gas, coal, and biomass, around an electric core that grows about 3% a year and is now 43% low-carbon (Modules 1 and 22), and the core is where the transition is happening. Solar is being added at roughly 600-700 GW a year and batteries at more than 300 GWh, nuclear is reviving, and electric cars are a quarter of new sales.

The shell is at record volume: the world used about 104 mb/d of oil before the war and a record 8.84 billion tonnes of coal in 2025, and CO2 emissions set a record that year. Forecasters agree on the direction, a growing core and a shrinking fossil share, but disagree on the speed, and on whether the shell's absolute volume falls this decade (Module 22).

The decade's organizing fact is that energy policy turned from climate to security in 2022, and 2026 confirmed the turn. Europe's break with Russia made domestic supply the priority (Module 5), and the Hormuz crisis made every importer want a second route and a deeper stockpile (Module 4). The AI load made firm power the scarce good (Module 18), and China's export controls made the transition's supply chains a chokepoint like the straits (Module 21). The United States, Europe, and China arrive at the same technologies for different reasons: firm, domestic, and fast.

23b. The Contradictions

Read across the modules, the course's evidence leaves five tensions that no single module states.

- **The cheapest power is not the most valuable.** Onshore wind and solar make the cheapest megawatt-hours ever built (Modules 12, 13, and 22), but their value falls as their share rises (Module 9), and the scarce good is firm power (Modules 15 and 18). The cheapest source creates the costliest problem, storage and backup.
- **Security argues for both fuels and electrons.** The 2026 crisis made imported fuel dear, so Asia burned record coal and America pumped record oil (Modules 4 and 7), while the same crisis strengthened the case for domestic solar, storage, and electrification in every importing country (Modules 19 and 20).
- **The clean-energy companies are building the gas boom.** The firms most committed to clean power are driving the largest gas build-out in decades, because gas is the firm power available soonest, while also paying for nuclear's revival (Modules 10 and 18).
- **The transition trades one chokepoint for another.** Moving from oil to electricity swaps dependence on Gulf straits for dependence on Chinese refineries and factories (Modules 12 and 21), since the cheap panels that power the transition come from the country whose export controls halted Western factories in

2025.

• **The fastest transitions are happening where policy is weakest.** Pakistan's and Africa's rooftop solar outran every official plan (Module 19), while the United States, with the most capital, reversed its policy (Module 20).

23c. The Turning Points

Turning point	The assumption that failed	What followed
The 1973 embargo	That the cartel would not act	The IEA, strategic reserves, and a decade of efficiency (Module 2)
Chernobyl, 1986	That the reactor could not fail	Two decades without Western reactor orders (Module 10)
The shale revolution, 2008-20	That tight rock could not be produced	The US became the largest oil and gas producer (Module 3)
The price war, 2014-16	That shale could not cut its costs	OPEC joined Russia in OPEC+ (Module 4)
Fukushima, 2011	That the wave would be smaller than the wall	Japan's fuel-import bill; Germany's nuclear exit (Module 10)
The Energiewende	That Russian gas was a safe bridge	An expensive and exposed system (Module 20)
Texas, 2021	That the deep cold would not come	Winterization and the fastest battery build in the US (Module 8)
Europe, 2022	That mutual dependence meant safety	A law ending Russian gas by 2027 (Module 5)
Iberia, 2025	That voltage would take care of itself	New rules for voltage control (Module 8)
Hormuz, 2026	That the strait would stay open	Record stock releases, bypasses, and a fall in oil demand (Module 4)

Read together, the turning points share a pattern: each was the failure of an assumption about supply. The system's resilience came from diversity, such as shale's swing supply, Norway's pipelines, Japan's restarts, Texas's batteries, and Saudi Arabia's bypass pipeline, and its failures came from concentration. Each case ended with more of whatever had been missing, whether nuclear, LNG terminals, winterization, storage, or routes, and the transition's design question is whether it builds that diversity in before the next failed assumption or after.

23d. What to Watch

What	When	Why it matters
Hormuz: transits, tanker attacks, Iran's terms, and the US blockade	From October 2026	About 4.5 mb/d is expected to stay shut in and spare capacity is near zero, so the EIA's $105 for the fourth quarter and $84 for 2027 depend on the strait (Module 4)
OPEC+'s ministerial meeting	November 29, 2026	The first test of whether quotas mean anything without the UAE, and of what Saudi Arabia does when its barrels can move again (Module 4)
Europe's winter: storage near 73% against an 87% norm; Qatar's force majeure through November	Winter 2026-27	The 2022 test repeated with less margin, with coal and demand cuts as the fallback (Modules 5 and 6)
The IEA's *World Energy Outlook 2026*	November 2026	Whether the war moves the projected peak in oil demand, and whether 'security' now outranks 'climate' in its scenarios
China's export controls on rare earths and battery technology, suspended under the truce extended in September	January 10, 2027	Whether the transition's chokepoint tightens again just as the West tries to build factories (Module 21)

What	When	Why it matters
The US credit cliff: wind and solar projects begun before July 4, 2026, racing the end-2027 deadline	2026-27	The size of the drop in US installations in 2027-28 shows what the reversal cost (Module 20)
PJM's suspended 6.8 GW backstop purchase and its next capacity auction	Early 2027	Who pays for new firm power for data centers: the campuses or every customer (Modules 9 and 18)
Technology companies' capital spending against their AI revenue	Quarterly	Spending leads the AI load by two to three years; a cut would deflate the forecasts first (Module 18)
A first AP1000 order on a named site; the Palisades and Crane restarts; Darlington's first SMR	2026-30	Whether the West rebuilds serial construction or settles for restarts (Modules 10 and 11)
China's coal generation after the LNG shock, and its new coal permits	Monthly; annual	Whether China's apparent emissions peak survives the 2026 coal rebound (Modules 7 and 22)
World solar installations in 2026	Early 2027	Whether the first annual fall in two decades is a pause in China or a plateau (Module 12)

Dates as announced by the organizations concerned, as of October 11, 2026.

23e. The Last Word

Most of this course's figures will date within months, and prices within days, but what will not date is the arithmetic used to read them: energy against power, capacity against capacity factor, the marginal plant that sets the price, and the levelized cost that misses the system. A reader who keeps that arithmetic can read the next decade's headlines without this course.

The harder test is the one 2026 set, when in a single year a strait closed, solar was built at near-record pace, nuclear revived, data centers set off a gas rush, coal headed for a record, and oil demand headed for its largest fall since the pandemic. The transition is real and slower than its advocates say, and the fossil system is durable and more fragile than its defenders say. Which of those matters more by 2030 depends on whether diversity is built in before the next failed assumption.

Module 23 Key Points

Where Things Stand, and What to Watch

• An electric core growing about 3% a year, 43% of it low-carbon, sits inside a fossil shell still at record volume.

• Energy policy turned from climate to security in 2022, and the 2026 Hormuz crisis confirmed the turn.

• The cheapest power is not the most valuable: wind and solar are cheapest, but firm power is what grows scarce.

• Every turning point, from 1973 to Hormuz, broke an assumption about supply; diversity survived and concentration failed.

• Watch Hormuz, OPEC+ on November 29, Europe's winter with storage near 73%, and China's export controls in November.

Module 23 Quiz

Check Your Understanding

1. What is the 'electric core and fossil shell' in the course's argument?

A) A reactor design
B) Electricity growing about 3% a year inside fuels still at record volume
C) Two grids, one AC and one DC
D) A plan by the IEA to replace all fuels burned directly with electricity by 2035, agreed at the UN

2. What does the course call the decade's organizing fact in energy policy?

A) Cheap oil
B) The Paris Agreement's targets, which every large emitter has written into national law
C) The turn from climate to security
D) Falling demand in rich countries, which utilities did not foresee after the pandemic

3. What pattern runs through the course's turning points, from 1973 to Hormuz?

A) Each broke an assumption about supply
B) Weather
C) Regulators caused each crisis through their delays and their rules on prices
D) Markets solved each without government help, once prices had risen far enough

4. Which contradiction does the course draw from data-center demand?

A) Data centers use less power each year as chips improve, so the forecasts are all wrong
B) Utilities refuse to serve the campuses, so the load moves abroad to cheaper grids
C) The cheapest power, solar, now runs the largest campuses around the clock
D) Clean-energy leaders are building gas

5. Which of these is on the module's watch list for November 29, 2026?

A) The first fusion power sale
B) OPEC+'s ministerial meeting, where the group sets quotas without the UAE
C) The end of Qatar's LNG
D) A new EU gas ban

Answer Sheet

Answers to every module's Check Your Understanding quiz.

Module	Answers
Module 1 Quiz	1. D 2. B 3. A 4. C 5. A
Module 2 Quiz	1. B 2. D 3. C 4. A 5. C
Module 3 Quiz	1. B 2. D 3. D 4. A 5. B
Module 4 Quiz	1. C 2. C 3. A 4. D 5. B
Module 5 Quiz	1. A 2. C 3. B 4. D 5. D
Module 6 Quiz	1. C 2. B 3. A 4. A 5. D
Module 7 Quiz	1. B 2. C 3. D 4. B 5. A
Module 8 Quiz	1. C 2. A 3. C 4. B 5. D
Module 9 Quiz	1. D 2. B 3. C 4. A 5. A
Module 10 Quiz	1. C 2. B 3. D 4. C 5. A
Module 11 Quiz	1. B 2. D 3. A 4. B 5. C
Module 12 Quiz	1. D 2. A 3. C 4. D 5. B
Module 13 Quiz	1. B 2. D 3. A 4. C 5. B
Module 14 Quiz	1. D 2. C 3. A 4. B 5. C
Module 15 Quiz	1. D 2. A 3. C 4. A 5. B
Module 16 Quiz	1. D 2. D 3. C 4. A 5. B
Module 17 Quiz	1. D 2. C 3. B 4. A 5. B
Module 18 Quiz	1. A 2. D 3. C 4. B 5. C
Module 19 Quiz	1. A 2. D 3. D 4. B 5. C
Module 20 Quiz	1. A 2. B 3. D 4. C 5. A
Module 21 Quiz	1. B 2. A 3. C 4. D 5. B
Module 22 Quiz	1. D 2. A 3. C 4. A 5. D
Module 23 Quiz	1. B 2. C 3. A 4. D 5. B