

THE IN A HURRY SERIES

Energy *in a Hurry*

Where power comes from and where it's going

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The Whole Thing in One Page

Energy is usually presented as a row of rivals: coal against solar, oil against batteries, nuclear against wind. That picture makes arguments easy and the system invisible. A fuel, turbine or panel is only the first link. Nobody wants crude oil, uranium atoms or sunlight for their own sake. People want warm rooms, moving vehicles, light, steel, food, communications and computation. Energy matters when a source becomes a useful service in the right form, place and moment.

Follow that chain and the subject changes. Primary energy begins in coal, oil, gas, moving water, wind, sunlight, biomass or atomic nuclei. Carriers such as electricity, petrol, hydrogen and hot water move or deliver it. Converters turn it into motion, heat, light or chemical change. Every link loses something. A petrol engine discards most of its fuel energy as heat. A power station loses heat before electricity reaches the grid. A heat pump can reverse the usual arithmetic by moving several units of environmental heat with one unit of electricity.

Two properties explain much of energy history. The first is density. Dense fuels put a large store of usable energy into a small mass and volume. The second is control. Coal, oil and gas can be stored, transported and burned when wanted. They freed industry from the daily flow of wind, water and crops, then supplied furnaces, engines, ships, cars, boilers and power stations built around combustion. Fossil fuels did not merely enter the old system. They created a system suited to their strengths.

The newer sources arrive with different packages. Nuclear fission offers concentrated fuel and steady low-carbon output, with demanding construction, safety and waste obligations. Hydropower can supply energy, storage and rapid response, where rivers and landscapes permit it. Wind and solar need no purchased fuel and can be built quickly, but their output follows weather and daylight. Batteries move electricity across hours. Reservoirs, transmission, flexible demand, thermal stores and fuels can move larger amounts across different distances and timescales. No device

performs every job.

Electricity is becoming the central carrier because it can connect many sources to efficient machines. Motors waste less than combustion engines. Heat pumps move heat rather than manufacture it. Electric processes can replace some direct burning. Yet electricity is not the whole system. Aviation, shipping, high-temperature industry, fertiliser and long-duration storage may still require molecules, direct heat or new processes. The transition is therefore larger than cleaning the grid.

Its difficulty comes from having to build the replacement while the old system keeps running. Energy demand is still growing. Hundreds of millions of people lack electricity, and billions still cook with polluting fuels. Reliability cannot be suspended during construction. Mines, wells, plants, grids, vehicles and buildings last for decades. Costs depend on finance, fuel, networks, land, permitting and who carries risk. The future will be decided less by a single winning technology than by whether all the links arrive together.

Energy is a chain, and a chain delivers only as well as its slowest link.

That is the book.

Why You Should Care

A litre of petrol can move a family car several miles because it contains a concentrated store of chemical energy and the car can release that store quickly. Most of the energy becomes waste heat. The useful fraction still feels miraculous because the liquid can be pumped in minutes, carried for weeks and called upon at any second. Replace the engine with an electric motor and the machine needs much less energy for the same journey, but it now depends on a battery, charger, power system and a place to stop. The service is unchanged. The chain is different.

That small comparison opens the whole subject. Energy arguments often ask which source is cheapest, cleanest or safest. Real systems ask harder questions. Can it deliver at the required hour? Can it provide heat as well as

electricity? Can the network reach the load? Can the equipment be financed? What happens during a windless evening, a drought, a fuel interruption or a damaged transmission line? Can a household afford the machine that would reduce its bill later? A source becomes useful through infrastructure and timing.

Understanding the chain clarifies the scale. In 2025 global energy demand rose by 1.3 per cent, while electricity demand grew by around 3 per cent. Low-emissions sources supplied nearly 60 per cent of the increase in total energy demand. In electricity, fossil fuels still provided more than half of generation and coal remained the largest single source. Two stories are true together: low-emissions supply is growing at remarkable speed, and the inherited system remains enormous.

You should care because energy hides inside prices. A gas shock changes fertiliser, food, glass and heating. Oil prices travel into freight and aviation. Expensive electricity can close an aluminium smelter or make a heat pump unattractive. Cheap midday solar can lower wholesale prices while networks, backup and winter capacity remain costly. The number on a household bill is the compressed result of fuels, machines, markets, taxes, debts, weather and past construction.

Energy also hides inside power. States that control fuels, pipelines, enrichment, minerals, factories or shipping routes gain leverage. Importers gain exposure. A domestic wind farm removes fuel purchases but may depend on imported components and a grid whose transformers take years to procure. Nuclear fuel occupies little volume but requires specialist supply chains and institutions. Security moves rather than disappearing.

Then there is access. In 2024 roughly 655 million people still lacked electricity, most in sub-Saharan Africa. About two billion people relied mainly on polluting fuels or technologies for cooking. For them, the energy transition cannot mean consuming less of a service they never received. It means reliable light, refrigeration, clean cooking, communications, pumping, clinics and industry, supplied without repeating every cost of the fossil path.

The environmental pressure cannot be separated from this expansion. Combustion made modern abundance possible and released greenhouse gases and air pollutants at a scale the atmosphere and human lungs register. The dedicated climate and pollution books own those mechanisms. The energy question is what must change upstream: which sources, carriers, machines and habits can provide the services with lower emissions, and how quickly old equipment can be replaced without creating scarcity or political revolt.

This is why slogans fail. “Build renewables” omits grids, storage, permits and winter supply. “Use nuclear” omits finance, construction capability and waste institutions. “Reduce demand” may mean better motors and insulation, or denying mobility, cooling and industrial growth to people who need more. The missing links decide whether the slogan works.

By the end of this book, you should be able to look at any energy claim and ask what service is being delivered, through which chain, with what losses, at what time, under which constraint, and at whose expense. Those questions will not settle every policy dispute. They will stop you being impressed by answers to the wrong problem.

The Core Ideas

Energy Is a Chain from Source to Service

A tonne of coal in the ground does not heat a room. Sunlight falling on an empty field does not run a train. Uranium sealed inside rock does not light a hospital. An energy source becomes socially useful only after a chain of extraction, capture, conversion, transport, storage and control delivers a service.

The chain begins with primary energy. That is energy found in nature before human conversion: chemical energy in coal, oil, gas and biomass; nuclear energy in uranium; gravitational energy in water held above sea level; kinetic energy in wind and flowing rivers; radiation from the Sun; heat from inside Earth. The categories are useful, though international statistics count

them differently. Combustible fuels are often credited with the heat released when burned, while wind and solar are commonly counted by the electricity they generate. A headline about the share of primary energy can therefore change with the accounting convention even when the physical system has not.

Primary energy is converted into carriers. Electricity is a carrier. So are petrol, diesel, hydrogen, steam, hot water and charged batteries. A carrier is valuable because it can be moved, stored or controlled more conveniently than the original source. Crude oil is refined because engines cannot use it as it leaves a well. Electricity is generated because a motor cannot connect directly to falling water hundreds of kilometres away. Hydrogen must be made from water, natural gas or another feedstock; it is not a free-standing source waiting underground in useful quantities.

The carrier then enters a device. A motor makes motion. A lamp makes light. A furnace makes high-temperature heat. A refrigerator moves heat out of a cold space. A data centre turns electricity into computation and a great deal of heat. What the user values is the final service: kilometres travelled, tonnes of steel, litres of cold milk preserved, rooms held at a tolerable temperature, messages delivered.

This language exposes losses. Suppose one hundred units of chemical energy enter a thermal power station. A large share leaves through the cooling system and exhaust before electricity reaches the grid.

Transmission and distribution lose some more. The motor at the end converts most of what arrives into motion. Another chain can begin with sunlight, become electricity in a solar cell, pass through an inverter and battery, then run the same motor. Comparing the panels with the coal mine misses the chain. The service is the proper endpoint.

It also exposes why local solutions differ. A sunny country may have abundant solar energy and poor evening capacity. A mountainous country may store water behind dams. A cold city may use district heating that captures waste heat from power or industry. A remote clinic may gain more from a small solar system and battery than from waiting for a national grid.

The same service can be assembled from different links.

Energy policy often starts too far upstream. It asks which source should win, then assumes the rest will follow. The better order is to state the service, trace the chain backwards and locate the constraint. Sometimes the scarce item is fuel. Sometimes it is a transmission line, skilled installer, efficient appliance, insulated wall, financing contract or permission to build. The source can be abundant while the service remains scarce.

That is the condition the rest of the book develops. Energy is not delivered when nature offers it. It is delivered when a complete chain makes it useful.

Power Is Energy on a Clock

Energy is an amount. Power is a rate. Confusing them is like confusing litres with litres per minute, or distance with speed.

The joule is the standard unit of energy. The watt is one joule per second. A one-kilowatt heater transfers energy at one thousand joules each second. Run it for one hour and it uses one kilowatt-hour. The kilowatt-hour is an amount of energy, despite containing the word watt. A power station rated at one gigawatt describes how rapidly it can produce electricity at that moment. Its annual output depends on how often and how fully it runs.

That distinction explains why installed capacity is a poor guide to delivered energy. A one-gigawatt nuclear plant operating most of the year can generate far more electricity than a one-gigawatt solar fleet whose output rises with daylight and weather. This does not make the solar fleet defective. It makes the capacities different promises. One describes a maximum under suitable conditions; the other may be scheduled around maintenance and refuelling but can still suffer outages. Capacity factor records average output as a share of maximum over a period. It says nothing by itself about whether the output arrives when most valuable.

Timing changes value because demand moves. A power system may have abundant electricity at noon and face scarcity after sunset. A heat network may need its highest output during a cold spell. A gas system must handle

winter heating peaks that dwarf summer use. A transport fuel must deliver rapidly enough to accelerate a lorry, not merely contain enough energy to complete the journey eventually.

This creates several jobs that the word supply hides. Energy adequacy asks whether enough total energy exists over a season or year. Capacity adequacy asks whether enough equipment can meet the highest credible demand. Flexibility asks whether output or consumption can change quickly. Reserves cover unexpected outages and forecast errors. Networks must carry power to the place it is needed. A system can pass one test and fail another.

Wind and solar make the clock more visible because their available output varies. Forecasting makes much of that variation manageable, and large geographic systems smooth some local changes. Yet a forecast does not control the weather. Other resources must shift around the available output: hydro reservoirs, batteries, gas turbines, nuclear plants capable of some load-following, interconnectors, thermal stores, flexible industry or customers willing to move demand. The correct mix depends on the duration and frequency of the gap.

Storage is power and energy in one device. The power rating says how quickly it can charge or discharge. The energy rating says how long it can continue. A battery able to discharge one gigawatt for two hours cannot cover a five-day shortage by being called large. A reservoir may hold much more energy but exist only where geography permits. Hydrogen or other fuels can store energy for long periods, though making, compressing, moving and reconverting them loses a substantial share.

Price signals often reveal the clock. Wholesale electricity can become cheap or negative when supply exceeds demand, then expensive during a tight evening. Those prices report the marginal condition of a system at a moment, not the permanent value of a source.

Any energy claim therefore needs a time unit. How much energy? How much power? For how long? At what hour and season? A plan answering

only the first question has not kept anything running.

Density and Storage Built the Fossil System

For most of human history, usable energy arrived as a flow. Crops captured a small share of sunlight. People ate the crops and worked. Animals converted feed into pulling power. Wood supplied heat. Wind moved sails and millstones. Falling water turned wheels. These sources could support remarkable societies, but they were tied to land, seasons and local geography.

Coal changed the relationship because it was stored sunlight from ancient ecosystems, concentrated underground across geological time. A mine could release energy accumulated over millions of years faster than a forest could regrow. Steam engines converted that heat into mechanical power independent of a river's location. Factories could concentrate. Pumps could drain deeper mines, which supplied more coal to power more pumps. The loop was physical before it was economic.

Oil added portability. Liquid fuel flows through pipes, into tanks and through injectors. It carries a large amount of energy for its mass and volume, can be stored without continuous conversion, and can release power rapidly inside a compact engine. Those properties made it suited to cars, trucks, aircraft, ships and mobile machinery. Natural gas moved through networks and supplied controllable heat, electricity and chemical feedstocks. The full histories belong to the dedicated coal and oil books. Their shared energy-system lesson is that dense, storable fuels solved several problems at once.

Density appears in several forms. Energy per mass matters in aviation; energy per volume matters for tanks and shipping; power per unit of land matters for infrastructure. Hydrogen contains much energy per kilogram but little per litre unless compressed or liquefied, which requires equipment and energy. Uranium fuel is extraordinarily concentrated, while the plant needed to use it is large and specialised.

Storage made fossil fuels dispatchable in the everyday sense. A pile of coal

or tank of oil is an inventory. Burn more when demand rises, less when it falls, subject to the limits of the machine. Sunlight and wind are flows. Their fuel arrives free but cannot be ordered. This difference is why adding a megawatt of wind or solar changes the need for other system capabilities rather than erasing it one for one.

Yet stored fuel carries its own vulnerabilities. Stocks can run out. Pipelines can be cut. Tankers cross chokepoints. Prices can jump across continents. Extraction depletes deposits and damages landscapes. Combustion creates pollution and greenhouse gases. The qualities that made fossil systems convenient also created dependence on continuous fuel supply and on wastes discharged into shared environments.

Modern low-carbon systems try to separate the useful properties. Wind and solar provide energy without fuel purchases. Grids share output across distance. Batteries and reservoirs shift it through time. Nuclear stores years of fuel in a small volume. Efficient electric machines reduce the amount that must be supplied. Flexible demand changes the service schedule. Synthetic fuels may preserve high density for applications that need it, at the price of conversion losses and greater upstream generation.

This is why transitions tend to add before they subtract. New sources first meet new demand or occupy jobs where their properties fit. The old source remains in the jobs built around its advantages until machines and infrastructure change. Steam power did not instantly remove horses. Oil did not instantly remove coal. Electricity did not replace fuels; it gave them a new route into services.

The fossil system is therefore more than a collection of mines and wells. It is an arrangement of engines, furnaces, ports, pipelines, roads, buildings, finance and habits built around energy that can be stored and released on command. Replacing its emissions means reproducing the service without assuming the old source was the only part doing useful work.

Conversion Losses Shape the Whole Machine

Energy is conserved. Useful energy is not. Every conversion spreads some energy into forms that are harder to use, usually low-temperature heat. The first law of thermodynamics keeps the books balanced. The second law explains why the balance can still be disappointing.

A thermal engine works because heat flows from a hotter place to a colder one. A steam turbine, gas turbine or piston engine takes part of that flow as mechanical work. No heat engine can turn all input heat into work, and real machines remain below the theoretical limit. A coal or nuclear plant therefore rejects large amounts of heat even when well designed. A petrol engine sends energy into exhaust, cooling and friction. The fuel tank may look compact because the waste stream is invisible.

Electricity can be generated by avoiding the heat-engine step. A wind turbine converts moving air into rotation and then electricity. A hydro turbine uses falling water. A solar cell converts photons directly into electrical current. These devices have losses too, but comparing their primary energy with the heat content of fossil fuel can mislead. One chain begins with counted thermal input and discards much of it; another begins with electricity at the generator terminals. When a system moves from combustion to wind, solar or hydro, reported primary-energy demand can fall even if the final service remains the same.

The same effect appears at the user. A combustion engine converts a minority of fuel energy into motion; an electric motor converts a much larger share of electricity. Batteries and power systems have upstream losses, but the electric chain can still require far less energy for the same kilometres. Electrification changes efficiency as well as source.

Heating gives the clearest surprise. A resistance heater converts one unit of electricity into about one unit of heat at the point of use. A heat pump uses electricity to move heat from outside air, ground or water into a building. Under suitable conditions, one unit of electricity can deliver three to five units of heat. It has not created energy. It has collected environmental heat

and raised its temperature. Performance falls under some conditions and depends on design, but the principle changes the size of the upstream system required.

Efficiency also happens before equipment. Insulation reduces the heat service a boiler or pump must deliver. Lighter vehicles require less motion. Recycling aluminium avoids much of the energy needed to refine it from ore. Urban form can shorten journeys. Better controls can stop machines working when the service is not needed. These changes reduce the chain rather than improve one converter.

There is a trap. Technical efficiency lowers the energy required per unit of service, which often lowers cost. People may then buy more of the service. More efficient lighting contributed to a world with far more light. Cheaper travel can increase distance travelled. Economists call this rebound. It rarely erases every gain, but it prevents efficiency from being treated as a guaranteed one-for-one fall in total demand.

Quality matters too. Electricity is high-quality energy because it can become motion, light, heat, sound, chemical change or computation with precise control. Low-temperature waste heat cannot run all those processes. Using electricity to make mild heat through a resistance coil may be physically possible while a heat pump would deliver the service with less upstream energy. Burning high-grade fuel to warm a poorly insulated room may be convenient and wasteful at once.

A serious transition counts useful output, not tonnes of fuel preserved for tradition. It asks how much primary input survives each conversion, whether waste heat can be used, and whether a different machine can eliminate the loss. Some of the cheapest energy supply is the energy a better chain never needs.

Electricity Is the Great Carrier, Not the Whole System

Electricity has no mine. It must be generated from another source or released from storage. Its strength lies in what happens next. It travels through wires, changes voltage, drives motors, powers electronics, makes heat, splits chemicals and can be controlled in fractions of a second. A common carrier lets a hydro dam, nuclear reactor, gas turbine, wind farm, solar panel or battery serve the same lamp or motor.

That interchangeability made the grid one of the decisive energy inventions. A factory no longer needed a steam engine beside every machine. One generator could supply many motors, each switched independently. Power stations grew larger, networks spread and demand from many users was pooled. The engineering details belong to Electricity in a Hurry. The energy-system result is that sources became substitutable at the electrical interface.

Electrification now offers a route away from direct combustion. Cars can use motors. Buildings can use heat pumps and induction. Some industrial processes can use electric furnaces, resistance heating, microwaves, plasma, mechanical vapour recompression or electrochemistry. As electricity supply becomes cleaner, the emissions of these devices can fall without replacing the device again. A petrol car remains tied to liquid fuel for its life; an electric car can receive a cleaner mix as the grid changes.

Electricity also creates coordination problems. It is hard to stockpile in the network itself, so generation, storage and demand must remain balanced. Transmission must connect windy, sunny, watery or nuclear locations to loads. Distribution systems designed for one-way flow may need reinforcement for rooftop solar, heat pumps and vehicle charging. A cheap generator behind a connection queue supplies nothing. More than 2,500 gigawatts of proposed generation, storage and large loads were reported waiting in grid connection queues worldwide in 2026, a measure of ambition stranded behind networks and procedures.

Storage helps at several scales. Batteries respond quickly and shift solar output into the evening, manage short peaks and provide grid services. Pumped hydro moves water uphill and releases it later. Thermal stores hold hot or cold material for buildings and industry. Interconnectors share differences in weather and demand. Flexible loads move charging, pumping, heating or production into favourable hours. None creates net energy. Each makes existing energy more usable.

Some services resist direct electrification for different reasons. Long-haul aircraft care intensely about mass. Ocean shipping needs compact onboard energy. Steel needs high heat and, in many routes, a chemical reducing agent. Fertiliser needs hydrogen as feedstock, not merely as fuel. Cement releases carbon dioxide from the raw material as well as from heat. Seasonal energy gaps can exceed economical battery duration. These jobs may use direct electricity, hydrogen, ammonia, biofuels, synthetic hydrocarbons, carbon capture, nuclear heat or redesigned processes. The correct route depends on the job, not the sector label.

Hydrogen illustrates the boundary. It can fuel chemical processes, store energy or become ammonia and synthetic fuels. Yet most hydrogen must first be produced, and converting electricity into hydrogen and back into electricity discards much of the original energy. Direct electrification is usually more efficient where possible. Hydrogen earns a role where molecules perform a job wires cannot easily do, not because attaching the word green removes the conversion chain.

The future is therefore likely to use more electricity and fewer direct fuel conversions for many services, while retaining a molecular system for selected jobs. That raises electricity demand even as efficiency can reduce total primary energy. It also makes reliability more consequential. A society that moves transport and heating onto the grid gains efficiency and loses some separation between systems. A power failure can then interrupt more services unless resilience improves with electrification.

Electricity is the central joining technology of the transition. Treating it as the whole of energy makes the hard sectors disappear. Treating it as one fuel

among many misses why it can reorganise the rest.

Every Source Arrives as a Package

There is no best energy source in the abstract. There are sources suited to different chains, locations and risks. Each arrives as a package of physical properties, costs, infrastructure, environmental effects and institutional demands.

Coal is storable and suited to high heat and power, but carbon-intensive and polluting. Gas turbines can change output quickly, and gas supplies heat and chemical feedstock, but pipelines, import exposure, methane leakage and combustion emissions matter. Oil dominates transport because liquids are dense and portable. Their detailed histories belong elsewhere; here they show how fuel properties create roles.

Nuclear fission uses little fuel, produces low lifecycle emissions and can run for long periods at high output. It needs exacting safety systems, skilled operators, secure institutions and long-term waste management. Existing plants can be valuable low-carbon assets. New large reactors have often faced high financing costs and construction risk in countries that build them rarely, while programmes with repeated designs and supply chains can perform differently. Small modular reactors may change construction patterns, but claims about future cost remain claims until fleets are built.

Hydropower can provide low-carbon electricity, rapid response and large-scale storage. Reservoirs can shift water through seasons in a way most batteries cannot. The package is inseparable from place. Dams flood land, alter rivers and sediment, block fish, displace communities and become exposed to drought. Many of the best sites are already used, and changing rainfall can alter output.

Wind and solar use flows rather than stocks. Their fuel is free, their operating emissions are low and construction can be modular and fast. Costs have fallen enough to make them the leading source of new capacity in many markets. Output varies, good sites may be distant from demand, and high shares increase the value of networks, flexibility, storage and

complementary firm supply. Manufacturing, land, minerals and end-of-life management do not vanish because the fuel is free.

Biomass looks familiar because it stores solar energy in matter. Its value depends on the feedstock and counterfactual. Waste that would decompose differs from a forest cut for fuel. Regrowth takes time, combustion emits carbon dioxide and air pollutants, and land can compete with food or ecosystems. Calling biomass renewable answers how the stock might be replaced, not whether a particular use is low-emission or sustainable.

Geothermal energy can provide steady heat or power where accessible temperatures and geology cooperate. It may be a local foundation and a global minority. Tidal energy is predictable but site-limited and technically demanding. Carbon capture can reduce emissions from some fossil or industrial processes, but adds equipment, energy use, transport and storage obligations. None of these is helped by being either dismissed as irrelevant or promoted as universal.

Cost comparisons need equal care. Levelised cost of electricity spreads a plant's lifetime capital, operation and fuel costs across expected generation. It is useful for comparing projects under stated assumptions. It does not include every network reinforcement, balancing cost, financing risk, tax, subsidy, environmental damage or value of output at a particular hour. A low-cost solar farm may be an excellent addition and still require spending elsewhere. An expensive peaking plant may run rarely and remain valuable as insurance.

Reliability belongs to the portfolio. A system can combine variable energy, firm capacity, storage, transmission, flexible demand and reserves. Diversity can reduce exposure to one fuel or weather pattern, though too many poorly connected assets do not create reliability by committee. The test is whether the package of packages delivers the service across credible conditions.

Technology debates prefer champions. Systems require combinations judged by the jobs they perform.

The Transition Is a Live Rebuild

The energy transition is often drawn as two coloured areas crossing on a graph. Fossil fuels shrink, clean sources grow, and one line replaces another. The physical task is messier. Mines, wells, refineries, power stations, pipelines, grids, cars, boilers, furnaces and buildings turn over at different speeds. Demand continues while the replacement is built. A transition must add, connect, convert and retire in the correct sequence.

Start with clean electricity because it can serve existing loads and make later electrification useful. In 2025 electricity demand grew by nearly three per cent, adding about 800 terawatt-hours. Solar generation rose by around 600 terawatt-hours, renewable capacity additions reached roughly 800 gigawatts and battery additions exceeded 100 gigawatts. The build is no longer a pilot project.

Nor is it a completed substitution. Fossil fuels still supplied more than half of global electricity in 2025 and a larger share of total energy. Demand rose by 1.3 per cent, and coal remained the largest single electricity source. Rapid clean growth and continued fossil dependence describe the same year because the system is growing while it changes.

The next link is electrification. Replace combustion engines with motors where practical. Replace boilers with heat pumps and direct electric heat where suitable. Expand electric industrial processes. This increases electricity demand while lowering the energy needed per service. It also changes peaks. Millions of cars charging together can burden a network; scheduled charging can absorb surplus output. Electrification works best when devices and grids are planned as one system.

Then build the connective tissue. Transmission reaches strong resources and shares weather across regions. Distribution upgrades serve new loads and local generation. Batteries cover short mismatches; reservoirs, fuels, demand response and firm low-carbon generation cover longer ones. Connection queues show what happens when generation policy outruns network delivery.

Hard sectors change more slowly. Steel plants, cement kilns, chemical complexes, ships and aircraft are expensive and long-lived. Some can electrify; others may need hydrogen, biomass, synthetic fuels, carbon capture or redesigned products. Waiting for a perfect cheap option leaves old assets operating, while scaling the wrong option can lock in another chain.

Materials move the security question. Solar panels, batteries, turbines, reactors and grids require minerals and specialist components. Fossil systems require continuous fuel extraction; many clean technologies concentrate demand in construction. Recycling can reduce future mining but cannot supply a first wave from products not yet built. Diversified supply and responsible mining remain part of the chain.

Finance changes geography. Fuel-free technologies exchange future fuel spending for upfront capital, so borrowing conditions become part of the resource. A sunny or windy country can pay more for the same equipment if debt is expensive, currency risk is high or utilities are weak counterparties. Many lower-income systems also face faster demand growth and thinner grids. Resource quality matters, but the cost of capital can outweigh better weather.

Retirement has to be sequenced with replacement capability. Closing a plant before enough energy, capacity, network and flexibility exist can raise prices or prolong dirtier emergency supply. Keeping every incumbent asset indefinitely defeats the transition. The hard judgement is asset-specific: what service does it provide, when is a cleaner substitute ready, and what investment today would either shorten or extend its useful life?

Access is part of the build. A transition that cleans existing consumption while leaving hundreds of millions without electricity has solved the wrong service problem. Distributed systems, stronger grids, clean cooking, efficient appliances and productive uses of energy must grow together. More energy service and lower environmental damage are compatible only if the chain is designed for both.

The first Core Idea began with a source that becomes useful only through a complete chain. The final consequence is now visible. Fossil fuels shaped carriers, machines, networks and institutions around density and stored control. Replacing their emissions means rebuilding all those links while they remain in use. A solar panel without a grid, a heat pump without an affordable power supply, a battery without generation, a reactor without finance, or a retirement date without replacement capacity is an incomplete chain.

The transition will not be won by naming the future source. It will be won by making the future service arrive.

How It Actually Works

The solar income

For a forager, almost every usable calorie had arrived recently from the Sun. Plants captured a minute share of sunlight. Animals ate plants or other animals. Human muscles converted food into movement. Fire released chemical energy from wood. The chain was short, local and constrained by the rate at which landscapes could renew it.

Agriculture enlarged the capture. Fields concentrated useful plants, animals supplied traction, and settlements organised labour around seasonal flows. Wind filled sails and turned mills. Waterwheels used rivers where terrain permitted. These machines could multiply human effort, but they remained tied to place and weather. A watermill stopped when the stream failed. A sailing ship waited for wind. A growing town competed with furnaces and households for wood from the same surrounding land.

Pre-industrial societies were not energy-poor in every sense. They built cities, moved armies and raised monuments. They were limited by how much current biological production could be appropriated without exhausting soil, forests, animals and people. Energy was woven into land ownership because land collected sunlight. It was woven into class because someone had to supply muscle. The energetic ceiling could be raised through better

crops, wheels, sails, canals and organisation, but the system still lived mostly on annual income.

A horse makes the constraint tangible. It can deliver far more sustained mechanical power than a person, yet it also needs land for feed, time for rest and labour for care. Add more animal power and part of the agricultural surplus must feed the machines with legs. The system scales by claiming more photosynthesis. Fossil energy later seemed to remove that bargain because a mine or well delivered ancient biological output without requiring current fields to grow the fuel.

The underground stock

Britain's turn towards coal began before the steam engine. Wood became costly around growing cities and industries. Coal could be dug, shipped and burned for heat. Its smoke was filthy, but its underground stock was not competing directly with food crops or standing timber. The mine converted geological accumulation into current supply.

Deep mining then created its own constraint: water. Early steam engines were built to pump it out. Thomas Newcomen's atmospheric engine from the early eighteenth century consumed prodigious coal but worked at mines where fuel was cheap. James Watt's later improvements reduced fuel use and helped steam power escape the coalfield. Rotating engines could drive mills, and mobile engines could pull trains and ships. Coal supplied heat to make iron, power to move machinery and a transport system to move more coal.

The important shift was not a single inventor or machine. Society had gained access to a stock that could be released faster than landscapes replenished it. Power became less dependent on the local flow of wind and water. Factories could cluster around labour, markets and transport. Railways made distance cheaper. Steamships made schedules less obedient to weather. Industrial output, mining, steel and urbanisation reinforced one another.

The chain also began feeding itself. Coal powered the ironworks that made

rails, boilers and engines. Railways carried coal to inland users and lowered the cost of moving ore and food. Better pumps and ventilation extended mines. This positive feedback helps explain why energy systems become difficult to reverse. Infrastructure created with one source increases the market for that source, while skills, finance and law gather around the expanding chain.

Coal's rise was uneven and political. Mines demanded dangerous labour. Smoke and soot filled industrial towns. Railways and factories redistributed wealth and power. States acquired tax bases, armaments and logistical reach. The dedicated coal book owns that history. Within the energy system, coal established a pattern that later fuels would repeat: a dense stock supported machines, and the machines made continued access to the stock more valuable.

Liquid motion

Oil had been used for lamps and materials long before it became the main transport fuel. Refining separated crude into useful fractions. Kerosene supplied light. Petrol was initially an awkward by-product until internal combustion engines gave it a market. Diesel engines used heavier fractions efficiently and reliably. A liquid fuel could be pumped, carried and burned inside a compact mobile machine.

The car then produced a chain much larger than the engine. Wells, pipelines, tankers, refineries, filling stations, roads, suburbs, parking, finance and mass manufacturing developed together. Aircraft took the energy-density advantage further because every kilogram carried into the sky has a cost. Oil became hard to replace in transport because transport itself had been redesigned around oil.

Natural gas occupied another route. It could be burned cleanly at the point of use compared with coal, moved through pipes, used in boilers and turbines, and converted into hydrogen and ammonia for fertiliser.

Combined-cycle gas turbines used both a gas turbine's hot exhaust and a steam cycle, raising efficiency. Gas plants could be built faster than many

coal or nuclear plants and could vary output to support changing electricity demand. Dependence moved into pipelines, storage sites, liquefied-gas terminals and import contracts.

The twentieth-century energy system therefore layered fuels rather than completing neat replacements. Coal remained central to electricity and industry. Oil dominated transport. Gas expanded in heat, power and chemicals. Traditional biomass persisted, especially where modern access remained poor. New demand was so large that one source often grew without forcing another to shrink.

One carrier, many sources

Electricity began as a local service. Early stations served nearby lights because low-voltage networks could not move much power far. Alternating current, transformers and high-voltage transmission made larger systems possible. The electrical details belong to the neighbouring book. The systemic change was that energy from coal, water, gas, uranium, wind or sunlight could meet at a common interface.

This separated the location of conversion from the location of use. Large generators could serve cities. Hydroelectric resources could be transmitted from mountains. Industrial motors could replace shafts and belts, allowing factories to arrange machines for production rather than around one mechanical drive. Refrigeration, telecommunications, lifts, appliances and computing followed because electricity is precise, controllable and clean at the point of use.

The grid also pooled risk. A single household no longer needed enough generation for its own highest demand. Many users peak at different times, and many generators fail at different times. Connection allows diversity to reduce the total reserve required. The price is coordination. Supply and demand must remain balanced, lines must stay within limits, and disturbances must be contained before they cascade.

This changed ownership of reliability. A mill beside a stream knew which wheel had stopped. A modern customer sees only a socket. Reliability is

produced elsewhere through spare capacity, maintenance, control rooms, fuel contracts, vegetation management, protection and crews able to restore damaged lines. Much of the system earns its value by waiting. That makes it easy to underfund until a storm, drought or equipment failure reveals what the quiet capacity had been doing.

Electricity's share of final energy rose gradually because existing services were already attached to fuels. A boiler connected to a gas network does not change because a wind farm opens. A petrol car remains in the fleet for years. A blast furnace can last decades. Energy transitions happen through stock turnover, refurbishment and infrastructure, not by changing a national pie chart at midnight.

Rivers and nuclei

Hydroelectricity was the first large low-carbon source to scale in many power systems. A dam converts the gravitational energy of stored water into electricity. Reservoirs can hold energy, respond quickly and support flood control, irrigation and water supply. Those combined purposes can also conflict. Releasing water for electricity may not match agricultural needs. A dam changes a river, sediment, fisheries and communities. Its value cannot be read from electricity output alone.

Nuclear power arrived through a different physical route. Fission splits heavy nuclei and releases heat, which makes steam and drives a turbine. The electrical end resembles a coal plant; the fuel and hazards do not. A small mass of uranium supports large output, fuel costs are a modest share of total generation cost, and operation produces low lifecycle greenhouse-gas emissions. Reactors can run for long periods and provide firm power.

The package demands institutions. The chain includes uranium mining, conversion, enrichment, fuel fabrication, reactor safety, security, spent-fuel handling, decommissioning and long-term waste management. Severe accidents are rare and consequential. Routine air pollution is low. Waste volumes are small relative to fossil wastes but require isolation over long

periods. Proliferation and security are political concerns as well as engineering ones.

Construction performance varies sharply. Countries that preserve designs, skilled teams and supply chains can build differently from countries attempting one project after a long pause. High upfront cost makes interest rates and delays decisive. Existing reactors may produce low-carbon electricity economically even where new construction is difficult. The technology cannot be judged honestly from either its fuel density alone or its worst accident alone.

Fusion joins light nuclei rather than splitting heavy ones. Research machines have reached important plasma and ignition milestones, and ITER is being built as an experimental bridge towards future power plants. No commercial fusion plant was supplying a grid by August 2026. Materials under neutron bombardment, tritium breeding, heat removal, maintenance and cost remain engineering problems. Fusion may matter later; it cannot carry a near-term transition plan.

Manufacturing the flow

Wind turbines and solar panels changed the industrial structure of power. Their energy source is a flow, but their cost is concentrated in manufactured equipment and construction. Once built, they buy no fuel. Mass production, larger markets, improved engineering and supply chains drove sharp cost reductions. Solar modules became standardised products that can be installed on rooftops or in plants measured in gigawatts. Wind turbines grew taller, reached steadier winds and moved offshore.

Their output follows nature. Solar is predictable in its daily pattern and uncertain in cloud detail. Wind can vary across hours, days and regions. A grid can integrate substantial shares by forecasting output, sharing power across distance, varying other plants, shifting demand and using storage. As shares rise, the system's need for flexibility changes in scale and duration. Curtailment may become rational when building extra renewable capacity is cheaper than using every possible unit of output.

Scale creates new geography. The best solar and wind resources are often far from cities. Permitting a generator can take less time than permitting the line that makes it useful. Land may be physically abundant and politically unavailable. Offshore wind avoids some land conflict and adds marine construction, cables and ports. Rooftop solar uses existing surfaces and depends on distribution networks, building ownership and the ability of households to finance equipment. “Potential” narrows at every link.

Batteries expanded because they suit several emerging jobs. Lithium-ion systems can respond almost instantly, smooth short changes, shift midday solar into evening and defer some network upgrades. Their energy duration is finite, and repeated charging loses energy. Pumped storage remains the largest form of grid electricity storage by energy, where geography allows. Thermal storage can be cheaper when the final service is heat or cold. Fuels remain attractive for long-duration storage because tanks and caverns can hold large energy stocks, though converting electricity into fuel and back is inefficient.

Renewables also moved energy security from fuel towards equipment and networks. A solar farm does not need imported gas each morning, but it needs modules, inverters, transformers, land, connection and maintenance. Wind farms need steel, copper, blades, bearings and cables. Batteries need cells, power electronics and minerals. Manufacturing concentration and long equipment lead times can create dependencies as real as fuel trade, though different in frequency and form.

The present machine

The global system in the mid-2020s remains dominated by combustion while its fastest-growing edge is electrical and low-carbon. Oil still supplies transport, coal supplies power and industry, and gas supplies heat, power and chemicals. Hydropower and nuclear remain the largest established low-carbon electricity sources in many systems. Wind and solar account for most new renewable capacity, with solar expanding fastest.

Demand differs by sector. Buildings need heating, cooling, hot water,

cooking, lighting and appliances. Transport needs motion from bicycles to aircraft. Industry needs motors, steam, high-temperature heat, chemical reactions and feedstocks. Electricity generation is a conversion sector: it consumes primary energy to supply a carrier used elsewhere. Calling all these needs electricity demand hides the majority of present fuel use outside the power system.

Heat deserves separate attention because it spans temperatures. Warm water for washing, space heat for a house, steam for food processing and the heat inside a cement kiln are not one service. Low-temperature heat can often come from heat pumps, solar thermal systems, district networks or recovered waste heat. Higher temperatures may need electric furnaces, biomass, hydrogen, gas or redesigned chemistry. Treating every thermal need as a boiler problem preserves combustion by definition.

The system loses large amounts between source and service. Thermal power stations reject heat. Engines reject more. Buildings leak warmth. Industrial processes discard hot gases. Some losses are unavoidable; many can be reduced. This is why a future with more electrical services need not require a proportionate rise in primary energy. Replace a combustion chain with an efficient motor or heat pump and the same service can begin with fewer input joules.

Demand is also unequal. High-income households use energy through large homes, flights, vehicles and consumption embedded in goods. Poor households may use little commercial energy while spending time collecting fuel or enduring heat, smoke and unreliable supply. National averages make these worlds look like one customer. They are not.

Access changes the operating sequence. A village receiving electricity for the first time may begin with lighting and phone charging, then add refrigeration, pumping, workshops and cooling as supply becomes dependable. A connection that fails daily cannot support the same enterprises as one available continuously. Clean cooking needs appliances, fuels or electricity that fit local meals, kitchens, incomes and supply chains. A nominal connection is not yet a service.

Building while running

A practical transition starts by reducing demand that provides no valued service: heat leaking through a roof, friction in an old motor, an empty building cooled all night. It then cleans the electricity supply, because clean electricity can serve current loads and open routes into transport, buildings and industry. Electrification follows where machines are ready and networks can carry the new demand.

The sequence loops rather than marching once. More solar creates value for midday flexible loads and storage. More electric vehicles create demand and a distributed battery fleet, though using it for grid support requires compatible chargers, contracts and customer consent. More heat pumps raise winter electricity peaks in cold regions, strengthening the case for insulation, thermal storage and firm winter capacity. More transmission makes geographically diverse supply more valuable.

Planning must cover bad conditions rather than average years. Drought can reduce hydro. Heat can raise cooling demand and reduce some plant or network performance. Cold, dark and still periods can strain a wind-and-solar-heavy system. Fuel interruptions can disable thermal plants. A reliable portfolio prepares for combinations, including events outside recent experience. Redundancy looks wasteful until the day it is used.

Prices must pay for both energy and readiness. A plant that produces many cheap kilowatt-hours has one value. A flexible resource available during scarcity has another. Networks, reserves and storage provide capabilities that energy-only comparisons can omit. Market rules differ because systems distribute these payments differently, but the physical requirements do not disappear when a tariff hides them.

Retiring fossil assets changes communities and balance sheets. A mine or refinery may anchor local employment and tax revenue. A power station may carry unpaid debt. A household may own a recent boiler or car. Policies that treat every asset as frictionless capital invite resistance. Training, replacement industries, consumer finance and protection from price shocks

are not decorative fairness measures. They affect whether the physical build survives politics.

The destination is not one universal mix. Countries differ in rivers, sun, wind, existing reactors, fuels, industry, demand patterns, institutions and ability to borrow. A hydro-rich system will solve flexibility differently from a dry island. A country adding first access to electricity faces a different task from one replacing an ageing car fleet. The shared direction is a chain with lower emissions, higher efficiency, stronger electricity, cleaner molecules where needed, and enough resilience to remain trusted.

How we know

Energy statistics are measurements wrapped in conventions. Fuel production and trade can be counted directly, but informal biomass use, off-grid supply and useful-energy output are harder to observe. Primary-energy totals differ according to how agencies convert non-combustible electricity into an equivalent input. Comparisons should therefore use one accounting system consistently.

Capacity is not generation, and annual generation is not dependable output at a particular hour. Levelised cost is not a complete system bill. Scenario results are conditional on assumptions about policy, technology, prices, behaviour and growth; they are not predictions wearing decimals.

The historical account rests on machines, fuel records, industrial statistics and scholarship about energy and economic change. Causation remains difficult because energy, institutions, knowledge and capital develop together. Coal did not industrialise every country that possessed it, and no source acts without organisations able to use it.

Current figures in this book were checked against International Energy Agency, International Renewable Energy Agency, World Bank, World Health Organization, United Nations and International Atomic Energy Agency material available on 11 August 2026. Their statistical boundaries do not always match, so apparent differences are reconciled before comparison. The figures date the system. The source-to-service model is

the part intended to last.

What People Get Wrong

"Electricity and energy are the same thing"

The confusion is encouraged by daily life. Electricity bills are called energy bills, power stations are called energy sources, and a socket seems to be where energy comes from.

Electricity is an energy carrier. It must be generated from a primary source or released from storage, then delivered through a network. Much of the world's useful energy still arrives directly as fuels: petrol in vehicles, gas in boilers, coal in furnaces and biomass in cooking. A country can clean its electricity rapidly while retaining high emissions in transport, buildings and industry.

The distinction also prevents double counting. Gas burned in a power station is primary input; the electricity produced is a secondary carrier. Add both as independent supplies and the same energy appears twice. Statistics separate primary, final and useful energy to follow the chain.

Why it matters is strategic. Replacing fossil electricity is one task. Electrifying cars and heat, changing industrial processes and producing low-carbon fuels are others. A clean grid is a platform for transition, not the entire transition. Conversely, efficient electric machines can reduce total fuel use even while electricity demand rises. The carrier changes the size of the system as well as its source.

"The cheapest generator should supply everything"

Levelised cost spreads a generator's expected capital, operating and fuel costs across its lifetime output. Under consistent assumptions, it helps compare projects. Falling wind and solar costs are real, and expensive construction or fuel can make alternatives unattractive.

A power system buys more than annual kilowatt-hours. It needs output at particular times and places, enough capacity during scarcity, reserves for failures, networks, and a plan for long periods of adverse weather or fuel interruption. A generator can be cheap on average and produce when electricity is abundant. Another can be costly per unit and valuable during a few critical hours.

This does not rescue every expensive plant. It changes the comparison. Ask how the next asset alters total fuel spending, networks, emissions, reliability and exposure to risk. The answer varies with the existing mix. The first solar farm in a fuel-importing system may displace costly daytime generation. Later additions may face curtailment unless storage, transmission or flexible demand grows.

The myth persists because a single number offers a winner. Systems assemble portfolios. Cheap energy is valuable, but the cheapest complete system is not necessarily the one containing only the generator with the lowest isolated cost.

"Renewables are free once they are built"

Wind and sunlight have no fuel invoice. That removes exposure to future commodity prices and gives operating costs a different shape from combustion. The phrase free energy turns a real advantage into a false claim.

Panels, turbines, foundations, cables, inverters, substations, land, maintenance, insurance and finance all cost money. Equipment wears. Good sites may lie far from demand. Networks and balancing resources become more valuable as variable output grows. None of this proves renewable power is uneconomic. It proves that zero fuel cost is not zero system cost.

The opposite exaggeration is also wrong. Every source needs infrastructure and protection against failure. Gas needs wells, pipelines and storage. Nuclear needs construction, regulation and waste management. Coal needs mines, transport and pollution controls. Hydropower needs rivers, dams and

social permission.

Ask which costs are fixed upfront, which recur, who finances them, and which risks remain with consumers or taxpayers. Fuel-free generation exchanges continuing commodity exposure for capital and infrastructure. That can be attractive where resources are strong and finance is cheap. It is still an engineered service, not a gift collected without a chain.

"Storage solves variability"

Storage is often drawn as a tank beside a wind turbine or solar farm. Output fills the tank; demand empties it. The diagram is correct and incomplete.

A store has a power rating, energy capacity, response speed, losses, cost and duration. A battery sized for an evening peak contributes little to a week of low wind. A reservoir can hold far more energy but needs suitable geography and water. Thermal storage works well when the final service is heat. Hydrogen can hold seasonal stocks, but production and reconversion lose energy and require infrastructure.

Storage also needs surplus supply. It cannot cover a persistent shortage by circulating the same electricity. The system must meet demand and refill the store after losses. A portfolio may combine overbuilt renewables, transmission, firm generation, demand flexibility and several storage durations.

The myth became persuasive because batteries solve important visible problems. Their fast response and modular construction suit frequency services, short peaks and shifting solar through hours. Specify that success rather than turning it into a universal answer.

Ask what gap is being covered, how much power is needed, how long it lasts, how often it occurs and what happens after the store empties. Storage solves a timing problem of a stated size. Without duration, the claim has no content.

"Nuclear is either harmless or uniquely dangerous"

Nuclear debate often treats risk as an identity test. Supporters point to low routine emissions and strong safety records. Opponents point to Chernobyl, Fukushima, weapons, waste and costs. Each can select a true fact and use it to erase the rest.

Nuclear power has low lifecycle greenhouse-gas emissions and low routine air pollution. Fuel is compact and plants can provide firm output. Severe accidents are rare, can contaminate land and impose large social and economic costs, and have shaped public trust. Modern designs and regulation reduce risk without making failure impossible.

Spent fuel and high-level waste are small in volume compared with fossil wastes, intensely radioactive and in need of secure management across long periods. Containment methods exist. Siting, governance and institutional continuity decide whether they are used well. Proliferation concerns arise from the wider fuel cycle and state behaviour.

Construction risk is separate. A reactor can be safe in operation and financially disastrous if delayed. Another can be expensive to build and valuable once operating. National experience differs because designs, skills and supply chains differ.

A serious comparison places accident, waste, air pollution, climate, security, finance and reliability on the same page. Nuclear is a demanding low-carbon option whose value depends heavily on institutions.

"Efficiency always cuts total energy use"

An efficient machine uses less energy for each unit of service. The mistaken step is to assume total consumption must fall by the same percentage.

When a service becomes cheaper, people may use more of it. Efficient air conditioning can spread to more rooms. Better engines can accompany larger vehicles or longer journeys. Cheap lighting can illuminate more places for more hours. This response is called rebound. In some cases, efficiency

helps a service expand enough that total energy use rises.

Rebound does not make efficiency pointless. Its size varies by service, income and price, and it seldom erases the full technical saving. A better motor still needs less electricity for the same work. Insulation still reduces the heat needed to hold a building at a chosen temperature. Standards can preserve gains while prices or other measures limit wasteful expansion.

Separate efficiency from sufficiency. Efficiency asks how much energy a service requires. Sufficiency asks how much of the service is wanted. A heat pump improves the first question. Floor area and thermostat settings affect the second.

In growing economies, efficiency can allow more people to gain cooling, mobility or industrial output without proportionate energy growth. Total demand may still rise because the service was scarce. The goal is useful service with fewer inputs, followed by an honest choice about scale.

"The transition begins by switching the old system off"

A photograph of a smokestack being demolished makes a clean ending. A functioning transition begins earlier, with the replacement chain.

Close a fossil plant before enough energy, firm capacity, network and flexibility exist, and the result can be shortage, high prices, imports or dirtier generation. Keep every asset operating indefinitely, and emissions continue while new investment struggles to gain space. Sequencing is a real problem, not an excuse for either permanent delay or careless closure.

The replacement includes generators, grids, storage, efficient machines, installers, permits, finance and supply chains. Transport changes when vehicles and charging arrive together. Heating changes when buildings, heat pumps and winter power are ready. Industrial plants need new processes before old furnaces retire. Workers and communities need credible routes beyond incumbent industries.

This is why transitions look contradictory. A country may build renewables

and a gas terminal, extend one reactor and close another. Some choices are sensible bridges, some are hedges, and some are lock-in disguised as prudence. The label cannot decide which.

Judge the sequence by the service. Is the new chain reducing fuel use and emissions over its life? Does temporary backup shrink as replacement capability grows? Are new fossil assets compatible with plausible retirement, conversion or low utilisation? Switching off is an outcome. Building a system that makes the switch survivable is the work.

Use It

Follow the chain to the service

When somebody announces an energy solution, begin at the other end. What service is being promised? Heat at which temperature, motion over what distance, electricity at which hour, or material produced by which reaction?

Then trace backwards. Electric heating needs a building, heating system, distribution network, generation mix and winter capacity. Hydrogen aviation needs production, storage, transport, airport equipment, aircraft and enough upstream electricity. Rooftop solar needs a suitable roof, inverter, finance, connection and a use for surplus output.

This distinguishes a technology from a delivered system and locates the missing link. A country may possess excellent sunlight and lack affordable capital. A city may have grid capacity and buildings that leak heat. A battery factory may open before charging infrastructure creates demand. The strongest source is irrelevant when another link blocks the service.

Use the chain to resist both optimism and dismissal. “It works” may mean one converter has worked in a demonstration. “It cannot work” may mean the present chain was designed for something else. Ask what must change around the device, and whether that change is easier or harder than the device itself.

Separate amount, rate and timing

Any large energy number should trigger three questions. Is it energy or power? Over what period? Does it arrive when wanted?

A battery capacity quoted in gigawatt-hours says how much energy can be stored, not how quickly it can be delivered. A power station's gigawatts say the maximum rate, not annual generation. A country's annual solar output says little about a cold winter evening. A fuel reserve measured in days depends on the demand rate assumed.

A household bill records energy. Connection size and simultaneous loads concern power. Time-of-use prices attach value to the hour. Insulation reduces the rate of heat loss, then the energy needed across a season.

The clock exposes false equivalence. One terawatt-hour of summer surplus cannot automatically replace one terawatt-hour of winter gas. Moving energy across months needs different infrastructure from shifting solar across four hours. Annual balances can hide peaks, while peak numbers can hide how rarely they occur.

Whenever two resources are compared, give them the same clock. Ask how much, how fast, for how long and with what certainty. A claim without those dimensions is advertising dressed as arithmetic.

Compare packages rather than champions

Choose a technology and it is easy to build a case. Nuclear offers dense fuel and firm low-carbon output. Wind and solar offer fuel-free generation and modular construction. Gas offers flexibility and established infrastructure. Hydropower offers energy, response and storage. Efficiency can remove the need for supply.

The case becomes useful when the bill arrives. Add construction time, finance, fuel, networks, land, environmental effects, waste, supply chains, accident risk, weather exposure and value of output. No source escapes its package because advocates prefer one metric.

Ask what the next unit adds to the existing system. A battery may be valuable in a solar-heavy mix and less valuable where prices barely vary. A gas plant may insure against peaks and create fuel exposure. Extending a safe reactor differs from starting a first-of-a-kind project. A transmission line may displace several local assets.

Packages also interact. Wind and hydro can complement each other. Solar and air-conditioning demand may align. Nuclear and district heating can share output. Electric vehicles can add load or flexibility depending on charging. The value lies in the portfolio, not the purity of one component.

When an argument produces a universal winner, check which costs, times or conditions were excluded to make the victory possible.

Find the binding constraint

Energy debates often assume the scarce resource is energy itself. Modern projects are frequently blocked elsewhere.

A renewable project may wait for a grid connection. A nuclear project may lack an experienced supply chain. A heat-pump programme may run short of installers. A transmission line may be delayed by planning and land rights. A household may save money over ten years and be unable to afford the first payment.

The binding constraint is the limit that, if relaxed, lets the system move. Adding a non-binding input can increase congestion. Approving generators without networks lengthens a queue. Subsidising cars without charging narrows adoption. Setting retirement dates without replacement construction raises risk rather than speed.

Constraints migrate. Once panels become cheap, connections and permits matter more. Once networks expand, flexible demand may become scarce. As technology scales, minerals, factories or skills can tighten. Diagnosis must be repeated rather than preserving yesterday's bottleneck as theory.

Ask what is stopping the next useful unit of service today, who controls that constraint, and how long it takes to change. The answer is often less

glamorous than the advertised technology and more decisive.

Ask who pays and who waits

A national energy system can become cheaper in total while some people pay more. That distribution can decide whether the change survives.

Fuel-free generation concentrates cost upfront while benefits arrive through lower fuel exposure over years. A household may need credit for insulation or a heat pump. A worker may lose a mining job before a new factory opens. A community may host lines serving distant cities. Countries with high borrowing costs can pay more for identical equipment.

Timing creates political asymmetry. Construction costs are visible now; avoided fuel imports and price shocks are spread across the future. A closure is concentrated in one town while benefits disperse across millions. People facing immediate losses can rationally oppose a plan that looks efficient in aggregate.

People without dependable electricity or clean cooking should not preserve low consumption so a global average falls. Their service must grow. Efficiency and low-carbon supply matter because they allow growth with fewer fuels and wastes.

Whenever a transition is described as cheapest, ask cheapest for whom, financed at what rate, paid at which date and compared with whose alternative. Cost is a physical and institutional chain. Distribution is one of its links.

The limits

The source-to-service model can become too tidy. Real energy systems are shaped by war, monopoly, labour, culture, geography, regulation and historical accident. A technically efficient chain may be politically impossible. A wasteful chain may persist because its infrastructure is paid off, its firms are powerful or its users trust it.

Metrics also conceal choices. Primary-energy accounting can make

non-combustible sources look different depending on convention. Lifecycle emissions depend on boundaries and assumptions. Levelised costs depend on finance, utilisation and future fuel prices. Energy-return estimates depend on which inputs count. Reliability standards express a judgement about how much risk and expense society accepts. Numbers discipline debate, but they do not remove values.

This book treats climate pressure as a reason the chain must change without repeating climate science. It includes pollution in source packages without cataloguing health effects, summarises coal and oil only far enough to explain their system roles, and uses grids without reteaching electrical engineering.

There is no single global transition timetable. A country replacing a mature fossil system, a country expanding first access and a country rich in hydro or nuclear begin from different positions. The model helps compare their chains. It cannot prescribe one mix without local data and political choices.

The one thing to keep

Keep the service at the end of the chain.

The energy system is easy to mistake for its most visible hardware. A cooling tower becomes nuclear power. A turbine becomes wind energy. A petrol pump becomes transport. The object is one link. Its purpose is to deliver something people use.

Once the service stays visible, several confusions clear. A less wasteful machine can reduce upstream supply without reducing comfort or motion. A cheap generator can be valuable and incomplete. Storage shifts energy but does not make it. A clean source can be stranded behind a missing line. Clean capacity and fossil use can rise together while demand and infrastructure change on different clocks.

Progress is not the number of panels, reactors, batteries or wells. It is reliable light, heat, movement, materials and computation delivered with lower cost, damage and exposure to failure. For people lacking those

services, progress means more. For wasteful systems, it can mean the same life from fewer inputs.

The old energy system became powerful because dense, storable fuels shaped every link around themselves. The next one will succeed when cleaner sources disappear into dependable services so completely that the user notices the warm room, moving train and working clinic rather than the heroic technology behind them.

Follow the service backwards. Build the chain forwards.

Terms

Primary energy. Energy as found in nature before human conversion, including coal, crude oil, gas, uranium, sunlight, wind and moving water. Statistical treatment differs by source, so comparisons need consistent accounting.

Energy carrier. A form used to move or deliver energy from source to user. Electricity, petrol, hydrogen, steam and hot water are carriers made or prepared from primary energy.

Final energy. Energy delivered to the user after conversion and network losses, such as electricity at a meter or petrol at a pump. It precedes the final device that provides the service.

Useful energy. The portion of final energy converted into the desired output, such as motion at wheels or heat retained in a room. The gap from final energy reveals end-use losses.

Energy service. The outcome people value, including warmth, light, mobility, refrigeration, materials and computation. Services allow different sources and technologies to be compared by the same purpose.

Joule. The SI unit of energy. One joule is one newton metre. Everyday and national energy systems use multiples because a joule is small: megajoules, gigajoules, petajoules and exajoules.

Watt. The SI unit of power, equal to one joule per second. Watts measure the rate at which energy is generated, transferred or used, not the total amount over time.

Kilowatt-hour. An energy unit equal to using one kilowatt for one hour, or 3.6 megajoules. Electricity bills use it because it joins appliance power to operating time.

Exajoule. One quintillion joules, written 10^{18} joules. It is large enough for national and global energy balances. Global annual energy use is measured in hundreds of exajoules.

Efficiency. Useful output divided by energy input for a stated boundary. Efficiency cannot exceed one for a converter, though a heat pump's coefficient of performance can exceed one because it moves environmental heat.

Energy intensity. Energy use per unit of economic output, activity or service. Falling intensity can reflect better technology, structural economic change or higher utilisation, so it is not a pure engineering measure.

Energy density. Energy stored per unit of mass or volume. High density matters where weight and space are constrained, especially aviation, shipping, mobile machinery and fuel storage.

Power density. Power obtained per unit of land, area, volume or equipment. It describes spatial concentration, but results depend on the boundary chosen around mines, plants, reservoirs or collection areas.

Capacity. The maximum output rate a generator, network or store can deliver under specified conditions. Capacity is measured in watts and does not state annual generation or duration.

Capacity factor. Actual generation over a period divided by generation at full rated capacity throughout that period. It reflects resource availability, outages, maintenance, demand and market operation.

Dispatchable. Able to change output on instruction within technical limits.

Dispatchability has degrees: start time, ramp rate, minimum output, fuel availability and duration all affect usefulness.

Firm capacity. Capacity expected to be available during system stress at a stated confidence level. Its value depends on the wider portfolio, weather correlations, outages, networks and demand.

Baseload. The minimum level of demand sustained across a period, and historically the plants built to serve it continuously. It is a demand description, not a law requiring one technology.

Peak load. The highest demand reached over a chosen period. Systems must cover credible peaks, but reducing or shifting a brief peak can be cheaper than building supply used rarely.

Load curve. A record of demand through time. Its shape reveals peaks, valleys, ramps and seasons, helping planners match energy, capacity, flexibility and networks to use.

Grid. The connected electricity system of generators, transmission, distribution, storage, control and loads. Its job is to coordinate power across distance and time while remaining secure.

Transmission. High-voltage movement of bulk electricity between generators, regions and major substations. Transmission can share resources and weather, relieve congestion and reduce the need for local backup.

Storage. A process that takes energy at one time and returns it later. Batteries, reservoirs, thermal stores and fuels differ in power, duration, losses, location and cycling capability.

Round-trip efficiency. Energy recovered from storage divided by energy used to charge it. It does not measure duration, response speed, degradation or whether the returned energy arrives at a valuable hour.

Curtailement. Deliberate reduction of available generation because demand, network capacity, system security or market conditions cannot accept it.

Some curtailment can be cheaper than eliminating every surplus.

Levelised cost of electricity. The discounted lifetime cost of a generator divided by expected output. It compares projects under assumptions but omits some network, balancing, timing and risk effects.

System cost. The total cost of delivering reliable energy services, including generation, fuels, networks, reserves, storage, losses, administration and sometimes environmental damage. Its boundary must be stated.

Electrification. Replacing direct fuel use with electricity, such as motors for engines or heat pumps for boilers. It can raise electricity demand while lowering total primary-energy use.

Heat pump. A machine that uses work to move heat from a cooler source to a warmer destination. Its performance depends on temperatures, design, operation and the building or process it serves.

Lifecycle emissions. Greenhouse-gas emissions across construction, fuel supply, operation, maintenance and decommissioning. They allow broader comparison than smokestack emissions, though results depend on technology and assumptions.

Go Deeper

Richard Rhodes, *Energy: A Human History*

Simon & Schuster, 2018. Start here for people, machines and the sequence by which wood, coal, oil, electricity, nuclear power and renewables entered society. Rhodes is strongest when an invention becomes a lived struggle involving mines, engines, businesses and states. The book is selective rather than a complete global balance, and its character-led method gives more space to dramatic innovators than to ordinary energy use. Read it for momentum and historical texture, then use a systems work for the full accounting. Its central gift is showing that energy transitions are made by contested decisions rather than by sources sliding smoothly across a chart.

Vaclav Smil, Energy and Civilization: A History

MIT Press, 2017. Read this for the long view and the discipline of physical scale. Smil follows energy capture, converters, agriculture, transport, industry, war and economic growth from muscle power to fossil civilisation. He is sceptical of fast, frictionless transition stories and relentless about quantities, efficiencies and infrastructure. The book is dense and occasionally austere. It is the best next step when you want to see why replacing a fuel means replacing machines, material stocks and social organisation built across generations. Keep another source nearby for faster-moving technology costs and developments after publication.

David J. C. MacKay, Sustainable Energy: Without the Hot Air

UIT Cambridge, 2009. Read this with a pencil. MacKay compares demand and supply using common units and refuses to let words such as huge settle a numerical question. The examples are centred on Britain and some technology costs have aged, but the method has not: estimate the service, state the area or capacity, keep units consistent and make the plan add up. The full text remains freely available from the author's site. It is an unusually inviting route into quantitative energy reasoning. The enduring lesson is not any single British scenario, but the habit of converting rival claims into comparable rates, areas and totals.

International Energy Agency, World Energy Outlook 2025

IEA, 2025. Use this as a current map rather than a book to read straight through. It assembles global data on fuels, electricity, access, investment, technologies and emissions, then explores conditional futures under current policies, stated policies and a net-zero pathway. The scenarios are not forecasts and should not be blended into one prediction. Read the executive summary, methods and chapters relevant to your region, then compare assumptions. Its great value is seeing the entire chain in one consistent accounting framework. The warning is institutional: its scenario results depend on policy and technology assumptions, so inspect those before quoting a future number.

Notes and Sources

The Whole Thing in One Page

The source-to-service chain. The distinction among primary energy, energy carriers, final energy, useful energy and energy services follows standard energy-balance practice used by the International Energy Agency and other statistical agencies. The central editorial choice is to end the chain at the service rather than at final consumption, because differences in motors, engines, boilers, heat pumps, buildings and industrial processes can change the primary input required for the same result.

Accounting conventions. Primary-energy totals are not neutral readings from nature. Combustible fuels are generally counted by heat content, including energy later lost in thermal conversion. Non-combustible wind, solar and hydro electricity is commonly counted by generated electricity, while some organisations use substitution methods. The manuscript avoids comparing shares drawn from incompatible conventions and explains the issue in Core Idea 1 and How we know. The IEA's *World Energy Outlook 2025* methods and energy balances informed this treatment.

Heat pumps. The International Energy Agency reports that current market

heat pumps can commonly be three to five times as energy-efficient as gas boilers because they move environmental heat rather than creating the entire heat output from the purchased energy. Real performance varies with source and delivery temperatures, climate, system design, controls and installation. The narrative says “under suitable conditions” and does not treat a laboratory coefficient as a universal household result.

Source packages. The high-level comparison of fossil fuels, nuclear, hydropower, wind, solar, storage and efficiency draws on the IEA reports listed below, IRENA's capacity and cost statistics, UNECE lifecycle assessment, IAEA reactor data, and the long-run syntheses by Vaclav Smil and Richard Rhodes. The dedicated neighbouring books retain detailed coal, oil, electricity and climate mechanisms.

Why You Should Care

Current demand and supply. The dated picture is from the IEA's *Global Energy Review 2026*. Global energy demand rose 1.3 per cent in 2025. Electricity demand rose by almost 3 per cent, adding roughly 800 terawatt-hours and growing more than twice as fast as total energy demand. Low-emissions sources supplied nearly 60 per cent of the increase in global energy demand, while fossil fuels still supplied more than half of global electricity and a larger share of total energy. The text presents rapid clean growth and continued fossil dependence together because both are supported by the same balance.

Access. *Tracking SDG 7: The Energy Progress Report 2026*, published jointly by the IEA, IRENA, United Nations Statistics Division, World Bank and World Health Organization, estimates that global electricity access stood at 92 per cent in 2024, leaving about 655 million people without access. Roughly 563 million of them were in sub-Saharan Africa. The same report estimates that about 2.0 billion people relied primarily on polluting fuels and technologies for cooking. These are modelled global estimates rather than a census of every household.

Environmental boundary. This book states that fossil combustion creates

greenhouse-gas and air-pollution pressures but leaves atmospheric physics, impacts, exposure and health effects to *Climate in a Hurry* and *Pollution in a Hurry*. UNECE lifecycle work supports the broad statement that wind, solar, hydro and nuclear generally have far lower lifecycle greenhouse-gas emissions than unabated fossil generation, while ranges depend on technology, supply chain, location and assumptions.

The Core Ideas

Energy Is a Chain from Source to Service

Definitions. The terminology is consistent with IEA energy balances.

Hydrogen is treated as a carrier because useful hydrogen must usually be produced from another energy source or feedstock. Batteries are treated as storage devices rather than primary sources. The book avoids saying energy is “consumed” in the physical sense when the intended meaning is that high-quality energy is converted and dispersed.

Local chains. The examples of off-grid clinics, district heating and solar-plus-storage are explanatory rather than claims that one architecture fits every location. System choice depends on resource quality, demand density, network reach, finance and institutions.

Power Is Energy on a Clock

Units. The joule and watt definitions follow the International System of Units. One watt equals one joule per second; one kilowatt-hour equals 3.6 megajoules. The distinction among capacity, generation, capacity factor and duration is standard in power-system statistics.

Capacity factor and dependable contribution. Capacity factor records average generation relative to maximum possible generation over a chosen period. It does not directly measure output during system stress. Firm or accredited capacity depends on the wider portfolio, correlated weather, forced outages, networks and the reliability standard. The text therefore avoids converting nameplate wind, solar, nuclear or battery capacity directly into equivalent dependable supply.

Storage dimensions. IEA battery analysis and electricity-system work support the separation of power, energy, duration, response and round-trip losses. Most new utility-scale batteries in 2025 still clustered around a few hours of duration, though longer projects were expanding. The discussion does not assign one standard duration to all batteries.

Density and Storage Built the Fossil System

Historical interpretation. Smil's *Energy and Civilization* supplies the long-run comparison among animate power, biomass, water, wind and fossil stocks. Rhodes supplies the character-led history of steam, oil, electricity and nuclear power. The manuscript does not claim that energy alone caused industrialisation. Institutions, capital, knowledge, labour, empire, geography and markets interacted with access to coal and machinery.

Coal and oil boundaries. The text uses coal to explain release from the annual photosynthetic land budget and oil to explain mobile energy density. It does not retell mining, refining, labour, corporate or geopolitical histories reserved for *Coal in a Hurry* and *Oil in a Hurry*.

Hydrogen density. Hydrogen has high energy content per unit mass and low energy per unit volume at ambient conditions. Compression or liquefaction increases usable volumetric density but requires energy, equipment and specialised storage. The narrative uses this only to show that “energy density” needs a stated denominator.

Conversion Losses Shape the Whole Machine

Thermodynamics. The claim that heat engines cannot convert all heat into work follows the second law of thermodynamics. The manuscript stays at conceptual level and does not derive Carnot efficiency. It distinguishes conservation of total energy from degradation of energy's ability to perform useful work.

Electrification efficiency. IEA *Energy Efficiency 2024* and *Energy Efficiency 2025* support the statement that electric motors, electric vehicles and heat pumps can use substantially less energy for the same service than

fossil-based alternatives. The exact saving depends on vehicle, electricity supply, climate, building and operating pattern. The book avoids one universal percentage.

Primary-energy decline under electrification. Part of the apparent fall in primary energy comes from physical efficiency and part from accounting. Replacing a thermal power station with wind or solar removes counted conversion losses under the IEA's direct-equivalent method. Replacing an engine with a motor also reduces real end-use loss. Both effects are described rather than merged.

Rebound. The efficiency misconception follows a broad energy-economics literature on direct and indirect rebound. The text states the robust point: lower energy required per service can lower effective cost and increase use, while rebound varies and rarely justifies abandoning efficiency. No fixed universal rebound percentage is claimed.

Electricity Is the Great Carrier, Not the Whole System

Neighbour boundary. Electrical potential, current, resistance, transformers, AC and DC, frequency, reactive power and protection belong to *Electricity in a Hurry*. This manuscript uses the grid only as an energy carrier and coordination system.

Grid queues. The IEA's *Electricity 2026* reports more than 2,500 gigawatts of renewable generation, storage and large-load projects waiting in grid connection queues worldwide. Queue totals combine different project types and levels of maturity, and some projects will never be built. The figure is used as evidence that networks and procedures can bind, not as a forecast of capacity certain to arrive.

Electrification and hard sectors. The balance among direct electrification, hydrogen, bioenergy, synthetic fuels and carbon capture draws on *World Energy Outlook 2025* and related IEA sector work. The book avoids assigning fixed future market shares because those are scenario-dependent and fast-moving.

Hydrogen losses. Hydrogen is described as potentially valuable where molecules provide storage, feedstock or mobile energy that direct electricity cannot easily provide. The book also states that producing and reconverting hydrogen loses substantial energy. The magnitude depends on production route, compression, transport and end use, so no single round-trip figure is given.

Every Source Arrives as a Package

Lifecycle emissions. UNECE's *Life Cycle Assessment of Electricity Generation Options* was used for the broad ranking and for the warning that construction, fuel supply, operation and decommissioning boundaries matter. The narrative avoids quoting one median as a permanent property of a technology because methane leakage, solar manufacturing, reservoir emissions, uranium supply and plant performance vary.

Renewable costs and capacity. IRENA's *Renewable Power Generation Costs in 2025* and *Renewable Capacity Statistics 2026* support the claims that wind and solar remain highly competitive sources of new generation and that renewables dominate new power capacity. IRENA reports 692 GW of renewable capacity additions in 2025, while the IEA's *Global Energy Review 2026* reports about 800 GW. The difference reflects statistical scope and reporting conventions rather than a physical contradiction. The narrative uses each agency's figure only inside its own accounting frame and does not convert global weighted costs into guaranteed project prices.

Nuclear package. The IEA's *The Path to a New Era for Nuclear Energy* and the IAEA Power Reactor Information System informed reactor fleet, construction and institutional context. Nuclear is described as low-carbon and firm, with severe-accident, waste, security, construction and financing risks. The text does not claim zero risk, zero emissions or a universal cost.

Hydropower and storage. IEA hydropower analysis supports the treatment of reservoirs as sources of generation, flexibility and large-scale storage. Pumped-storage hydropower remains the largest form of electricity storage by energy volume, although batteries are expanding rapidly. Dams' social

and ecological effects are stated because electricity output is only one part of the package.

Biomass. The treatment follows standard lifecycle reasoning: carbon neutrality depends on feedstock, land-use change, regrowth, time horizon, displacement of other uses and the counterfactual fate of residues. Renewable classification alone does not establish low emissions.

Levelised and system cost. Levelised cost is retained as a useful project metric and rejected as a complete portfolio metric. The IEA and OECD Nuclear Energy Agency's *Projected Costs of Generating Electricity 2020* informed the cost categories, while IRENA provides recent renewable project data. The book does not claim that every network or balancing cost belongs uniquely to variable renewables.

The Transition Is a Live Rebuild

2025 energy data. The IEA's *Global Energy Review 2026* supplies the current anchors. Total energy demand rose 1.3 per cent and electricity demand around 3 per cent in 2025. Low-emissions sources supplied nearly 60 per cent of total demand growth. The IEA reports about 800 gigawatts of renewable capacity additions, with solar providing roughly three quarters; solar generation rose by around 600 terawatt-hours. Battery storage additions reached 108 gigawatts, about 40 per cent higher than in 2024. Fossil fuels still supplied more than half of global electricity, with coal at 34 per cent and gas at 21 per cent. Construction began on more than 12 gigawatts of nuclear capacity. These are dated indicators, not permanent rates.

Fossil persistence. The same report records continued growth in total energy demand, fossil fuels supplying more than half of global electricity, coal remaining the largest single electricity source, and energy-related carbon dioxide emissions rising slightly in 2025. The manuscript uses these facts to reject both “nothing is changing” and “substitution is complete”.

Energy intensity. IEA *Energy Efficiency 2025* estimated global efficiency progress at about 1.8 per cent in 2025, an improvement from 2024 but

below the rates in faster transition pathways. *Tracking SDG7 2026* uses the formal SDG energy-intensity measure and reports slower progress for the latest fully observed year. The manuscript avoids combining preliminary 2025 estimates with earlier SDG data as though they were one series.

Critical minerals. The IEA's *Global Critical Minerals Outlook 2026* supports the shift from continuous fuel supply towards construction-intensive mineral and manufacturing chains. The narrative names common materials but avoids deterministic shortage claims. Demand, substitution, recycling, mine development, processing concentration and policy can all change the balance.

Finance. IEA and IRENA work support the claim that capital-intensive, fuel-free projects are highly sensitive to financing cost. The line “cost of capital can outweigh sunlight” is an inference from this structure, not a quoted result. It means that a resource-rich country can face higher delivered cost than a less sunny country able to borrow more cheaply.

Access within transition. The access figures are from *Tracking SDG7 2026*. The normative conclusion is editorial: a global transition that lowers emissions while leaving basic services unavailable has failed the title's source-to-service test.

Operating and historical spine

Pre-industrial energy. Smil documents the dependence of pre-industrial systems on human and animal muscles, biomass, wind and water. The horse example illustrates the land and feed requirement of animate power. It does not imply that every society followed the same path or that land was the sole constraint.

Newcomen and Watt. Newcomen's atmospheric engine entered mine drainage in the early eighteenth century. Watt's improvements, including a separate condenser, reduced fuel consumption and helped broaden steam power's uses. Rhodes and Smil provide the narrative basis. The book avoids the false claim that Watt invented the steam engine or industrialisation alone.

Self-reinforcing coal chain. Coal powering pumps, ironworks and railways that expanded coal supply is a causal synthesis supported by energy history. It is not presented as a closed monocausal loop; labour, finance, patents, transport demand and state institutions also mattered.

Oil and gas. The treatment of refining, internal combustion, transport density, gas turbines and fertiliser is a functional summary. The manuscript does not assign invention to one person, quote early market shares or give a complete petroleum chronology.

Electricity. The shift from local stations to interconnected grids and independent electric motors is supported by Smil, Rhodes and the neighbouring Electricity manuscript. The statement that grids pool risk is a system principle: diverse loads and generators can reduce reserve needs, though correlated events and transmission constraints limit the benefit.

Hydro and nuclear. IEA and IAEA sources support the operational descriptions. The manuscript states that reactor construction performance varies across national programmes and does not infer a universal learning rate. Hydropower's multi-purpose operation and ecological effects are treated as site-specific.

Fusion. The IAEA's *World Fusion Outlook 2025* and ITER's official description support the distinction between current experiments and future power plants. The National Ignition Facility's scientific ignition compared fusion output with laser energy delivered to the target, not with the whole facility's electricity use. The manuscript therefore records the research milestone without treating fusion as commercial generation. Tritium breeding, neutron-resistant materials, heat extraction, maintainability and plant economics remain open engineering tasks.

Wind, solar and batteries. IEA *Global Energy Review 2026*, *Electricity 2026* and IRENA 2026 reports provide the current scale. The discussion of modular manufacturing and cost decline is broad; it does not claim every component follows the same learning curve or that recent cost declines must continue unchanged.

Pumped storage. The IEA's 2025 hydropower commentary and its 2021 market report support the statement that pumped storage remains the largest electricity-storage form by energy volume. Battery additions are described in power terms because current global reporting is more robust there than for comparable stored-energy duration.

Heat by temperature. The separation of low-temperature building heat, industrial steam and high-temperature process heat prevents “heat” from becoming one undifferentiated demand. Technology suitability depends on required temperature, process integration, electricity price and retrofit constraints.

Access ladder. The progression from lighting and charging to productive loads is a common pattern, not a guaranteed sequence. Reliability, affordability and appliance ownership determine whether a nominal connection becomes economically useful. Clean-cooking adoption must fit local cooking practices and supply reliability, as stressed in *Tracking SDG7 2026*.

Reliability. The adverse-condition examples are illustrative. Planning standards vary, and no portfolio is immune to compound events. The text deliberately avoids prescribing one reserve margin or one definition of “firm” across systems.

What People Get Wrong

Electricity versus energy. The correction follows energy-balance definitions. It matters because power-sector decarbonisation, end-use electrification and fuel production are different links.

Cheapest generator. LCOE is not dismissed. The correction is that system value depends on timing, location and portfolio effects. IEA, IRENA and IEA-NEA cost work informed the treatment.

Renewables after construction. The no-fuel advantage is retained. Capital, finance, networks, maintenance, land and equipment replacement are included without attributing all system cost to renewables.

Storage. IEA storage analysis supports the distinction among seconds, hours, days and seasons. The text avoids saying lithium-ion batteries cannot become longer-duration or that hydrogen must be used seasonally.

Nuclear risk. The correction separates routine health and emissions, severe accidents, waste, proliferation, construction and finance. IAEA and IEA sources informed the institutional framing. No cross-technology mortality ranking is given because estimates depend heavily on historical boundary and method.

Efficiency and rebound. The rebound treatment is qualitative. It rejects both zero rebound and the claim that rebound makes efficiency futile.

Sequencing. The final misconception applies the source-to-service chain. The questions about bridge assets, lock-in and retirement are evaluative lenses, not claims that every new gas project is either required or unjustified.

Use It

The five lenses are deductions from the book's model rather than independent research findings. They are designed to change how the reader evaluates projects and policy: begin with service, specify time, compare packages, identify the binding constraint and examine distribution. The limits section warns that physical accounting cannot settle politics, values or local choice.

Terms

Definitions are consistent with IEA usage, the SI system and standard power-system terminology. “Baseload” is defined as a demand level and a historical plant role rather than a technical requirement that one class of generator run continuously. “System cost” is flagged as boundary-dependent because studies include different networks, externalities, taxes and market transfers.

Go Deeper

Bibliographic details were checked against the publishers, the University of Cambridge repository and the IEA report page. MacKay's work was first published in 2008, with the widely circulated UIT Cambridge edition dated 2009; this manuscript cites the 2009 edition used for the recommendation. The IEA scenarios are described according to the report's own distinction among Current Policies, Stated Policies and Net Zero Emissions by 2050.

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