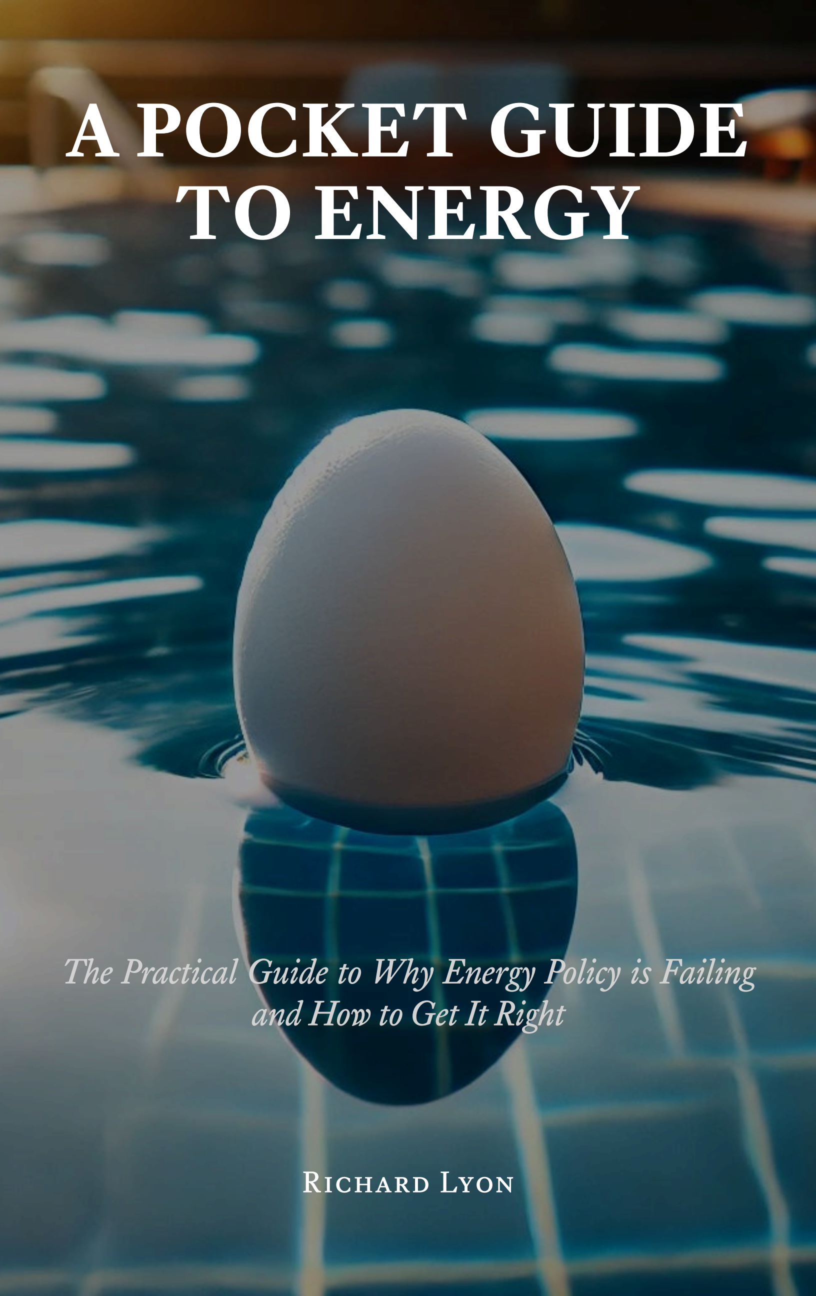

A POCKET GUIDE TO ENERGY

The Practical Guide to Why Energy Policy is Failing and How to Get It Right

Richard Lyon

A Pocket Guide to Energy: The Practical Guide to Why Energy Policy is Failing and How to Get It Right

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Prologue

Fortunately, there aren't many risks in our lives that can kill large numbers of people, and most of them sound like Hollywood movie plots: tsunamis, escaped viruses, asteroids, volcanoes. That sort of thing.

So it's ironic that one of the biggest risks we now face comes from an area of life we thought we'd thoroughly mastered — one that, for over a hundred years, has delivered rising prosperity, increasing lifespans, and the elimination of famine from the developed world: our energy system.

For reasons that would fill another book, a relatively small number of people have taken control of energy policy and are going about the business of dismantling the energy system our lives depend on. They're doing so with confidence, with public money, and with almost no understanding of the physics involved.

You don't believe me? Here's an example. Roughly half the world's population — four thousand million people — depend for life on food grown with fossil fuel based fertilisers. There aren't any significant stockpiles of either food or fertiliser. So if we were to take 'Just Stop Oil' at its word and just stop oil, then within a decade, hundreds of millions of people would starve to death. Yet that is precisely the direction in which the energy policies of advanced industrial countries like the United Kingdom now point.

The effect, for those with eyes to see, is rather like looking out of the window of your aircraft and noticing someone methodically sawing through the wing. You want to turn to the people around you and say: "Can you see what's happening? We have to stop this."

And that is why I wrote this book.

I wrote it because too many people can't yet see the saw. Worse, quite a few have been persuaded that sawing through the wing is a good idea — that if we dismantle the energy system, the weather will finally do as it's told.

There are many excellent books about energy systems. They run to hundreds of pages, they're written for specialists, and they sit unread on shelves while the policy rolls on. What's missing is something shorter and sharper — a friendly guide that gives you the minimum set of facts you need, with references so you can check every claim yourself, written by someone who understands the physics and wants to explain it clearly. That's what this book tries to be. And why am I the person to write it? Let me tell you a little about my journey.

My career was what my father called "unconventional." I didn't plan it. It just happened. But it accidentally produced an unusual combination of knowledge that turns out to be exactly what this subject needs. My first degree was in Electrical Engineering. After serving in the Royal Air Force, I took another degree in Petroleum Engineering. Armed with that, I joined a large oil and gas company and spent two decades managing the production and operation of oil and gas projects around the world.

Large oil companies have a habit of throwing unexpected things at you. One day I was writing briefings for Senior People at Headquarters. "Now see here, Lyon. We keep getting these questions at shareholder meetings about something called 'Peak Oil.' Give me the bullets. I'll fire the gun. Write me a memo." I started writing the memo. One thing led to another, and I ended up with a Masters degree in Energy Economics and a good understanding of the relationship between the energy system and the financial system. (Spoiler: we get it backwards.)

So there I was. Electrical engineering had given me maths, physics, chemistry, and power systems. Petroleum engineering had shown me what it takes to keep the energy flowing. Energy economics had shown me the central error: the assumption that low-density energy can simply replace high-density energy because the price is right.

Draw a Venn diagram of those three, and right in the centre was the biggest threat of our lifetimes: the policy of dismantling our energy system before anything remotely adequate exists to replace it. I read the proposals and couldn't believe them. Then I looked at who was writing them: people with no training in physics, no chemistry, no engineering, no understanding of power systems, no experience of producing energy, and no grasp of the economics of finite resource extraction. They didn't know what they didn't know — and they didn't know that they didn't know it. Fish don't know what water is. These people didn't know what energy is.

There wasn't any point arguing with the policymakers. The place to have the conversation was with you — the person on whom this policy is being inflicted. You're perfectly capable of understanding the physics and the consequences if someone takes the trouble to explain them clearly.

You may not be fully aware yet of your dependence on the energy system and the significance of what they are doing to you. That's understandable — until now, it's worked so well that you've never had to think about it. But the people now dismantling it are counting on that unfamiliarity. This book's my attempt to end it.

I've taken a lot of care to make it short. You can read it in three cups of tea and half a packet of biscuits. But when you're done, you'll understand more about energy than most of the people making energy policy. That's not a boast. It's an indictment of the people making energy policy. And you'll be able to say "I can see what's happening. We have to stop this" to the people with the saw.

Thank you for reading. I'll see you on the other side.

Richard Lyon
Edinburgh, Scotland

Introduction

This is a little book about a big subject. It is written for the general reader who suspects that the public conversation about energy has drifted some distance from physical reality, and who would like a concise, honest account of where things stand.

All governments have an energy policy. But energy policy is not one among many. Energy is the master resource, the precondition for every other activity that an industrial civilisation undertakes. The food on your table, the roof over your head, the hospital that treats you, the phone in your hand, even (as we shall see) the £10 note in your wallet — all of these are, at bottom, transformed energy, or a claim on a future quantity of it. When we get energy wrong, we get everything wrong.

Governments have always understood this, at least implicitly. Every major energy transition[†] in history — wood to coal, coal to oil, oil to nuclear — was driven by the discovery of a denser, more concentrated source. The one now proposed is different. It asks us to reverse the direction.

And yet the mainstream debate about how to do this is strikingly poor. It is dominated by competing narratives — techno-optimist, degrowth, green-growth, fossil-loyalist — each of which selects the facts that flatter its conclusions and ignores the rest. The result is that well-meaning people, including many in government, are making consequential decisions on the basis of claims that are not consistent with basic physics.

This book attempts something different. Rather than asking "what narratives do I prefer", it starts from the physics — the non-negotiable laws that govern how energy is captured, converted, stored, and dissipated — to ask "what narratives are possible". If a policy or a technology cannot satisfy those laws, it does not matter how elegant the spreadsheet or how passionate the advocacy: it will fail. Physical reality does not care about your feelings, your votes, or your investment portfolio.

The argument is organised in seven parts. Part I asks the simplest question: what are the physical rules that every energy source must obey? The answer — what this book calls the thermodynamic floor — turns out to explain most of what is wrong with current energy policy. Part II asks what all this energy is actually *for*, and why the four industrial foundations of modern life — steel, cement, ammonia, and plastics — cannot simply be electrified away. Part III asks what is happening to the fossil fuels themselves — the depleting inheritance that no energy policy acknowledges. Part IV turns to the proposed solution and shows why it won't work: the storage problem, the mineral hunger, and the replacement costs that its advocates prefer not to discuss. Part V tests the three escape hatches most commonly offered — efficiency, hydrogen, and green growth — and finds that none of them works. Part VI follows the money, asking what happens to a financial system built on the assumption of perpetual growth when the energy to fuel that growth is forced to contract. Part VII is about what comes next: why nuclear power is the only technology consistent with the physics, and a seven-point blueprint for an energy policy grounded in reality rather than wishful thinking.

Each chapter is deliberately brief. The aim is not encyclopaedic coverage but clarity of argument. A Glossary and References are provided for those who wish to dig deeper; what matters here is the shape of the problem, not every last decimal place. Where a technical term appears for the first time, it is marked with a dagger† to indicate that a definition can be found in the Glossary.

A word on tone. This book is not neutral, and it does not pretend to be. It takes the position that honesty about physical constraints is not pessimism but the necessary starting point for any serious response. If that strikes you as gloomy, consider the alternative: continuing to promise the public outcomes that the laws of physics will not deliver, and discovering the gap between promise and reality only when it is too late to adapt.

An energy transition is coming. The question is whether it is one that is forced upon us by depletion and wishful thinking, or one that we have chosen and shaped. This book is written in the hope that it is not yet too late for the latter.

Part I

The Physics of Energy

"Ye cannae change the laws of physics, Captain!" — Montgomery Scott. Chief Engineer, USS Enterprise

OK. I get it. Physics. Yuck. But here's the thing. Energy is not particularly difficult to understand, at least at the level required to understand energy policy. But nor does it lend itself particularly well to guesswork.

For example: there's far more heat energy in a swimming pool than there is in a pan of boiling water.[1] You can boil an egg in a pan of boiling water, but you can't boil an egg in a swimming pool. You might guess that, if you increase the amount of pool energy, you might eventually boil your egg. If you doubled the size of the swimming pool, you'd double the amount of energy available to boil your egg. But you'd still have a cold, raw egg.

To understand energy with proper intuition, you need to understand the physics of energy. Luckily, there are only three concepts and one critical distinction

[1]It takes an enormous amount of energy to keep 2,500 cubic metres of water liquid rather than frozen. That energy is real — the water's just not very hot.

that you need to learn to understand 90% of energy policy: energy gradient†, energy density†, power density†, and the difference between a fuel† and an energy carrier†. Once you understand them, most energy policy becomes transparent — including the parts that its advocates would prefer you not examine too closely. And I promise you this: by the end of this short book, you will understand more about energy than most of the people making energy policy.

Ready? Let's start with energy gradient.

Energy Gradient

The first concept is the easiest, but also the most revealing. It explains why not all energy is equal — and why the sheer quantity of energy available tells you almost nothing about how much useful work you can extract from it.

It works like this. To do useful work, energy must flow from a region of high energy concentration to a region of low concentration. This difference is called the energy gradient. The steeper the gradient, the more work you can extract. Physicists call the work-available portion of energy *exergy*†; what matters for our purposes is simply this: a steep gradient means useful energy, a shallow gradient means unusable energy (for example, waste heat).

Let's make this concrete. Consider an actual gradient — a slope on a hill. Imagine we're skiing. We're standing in the queue for a ski lift. The queue is 100 feet long and falls 10 feet. The gradient is so shallow that friction between our skis and the snow is greater than the pull of gravity, and we have to shuffle forward.

We get on the lift and ascend the mountain. The ski run is 1,000 feet long and falls 1,000 feet. The gradient is so steep that gravity overwhelms friction and we glide down without effort.

Here's the insight. Imagine we join 100 ski queues together end-to-end. The total height difference is now 1,000 feet[2] — the same as the ski run. But do we glide down it? No, because the gradient hasn't changed. Same total height, but spread over 10,000 feet[3]. It's just a long, flat shuffle.

The ski slope is a metaphor, but the physics is real. In any energy system, the gradient is the difference in concentration or temperature between the source and its surroundings. A gas flame at 1,500°C in a 15°C environment is a steep gradient — a ski run. Wind moving at 12 metres per second through still air is a shallow one — a ski queue.

And this is why you can boil an egg in a pan but not in a swimming pool. There is far more energy in

[2] 100 queues, each falling 10 feet

[3] 100 queues, each 100 feet long

the pool, but it is spread through 2,500 cubic metres of water at 20°C. The energy in the pan, although less, is concentrated in a couple of litres at 100°C. The egg doesn't "see" the total energy in the pool. It sees the temperature gradient at its shell — and in the pool, there isn't one.

An enthusiast will point out that you could, in theory, concentrate the pool's heat with a device called a heat pump — a fridge in reverse. True — but building and running the heat pump requires more high-grade energy than you'll ever extract from the pool. You haven't solved the problem. You've moved it.

Now translate that into energy policy. A gas-fired power station exploits a steep thermal gradient. We can extract a great deal of useful work from it — enough to power an advanced industrial economy. A wind turbine exploits a shallow kinetic gradient. The energy is real, but diffuse. You might think we can compensate by building more turbines. But that is like joining ski queues end-to-end: the total height difference grows, but the gradient stays the same. It's still just a long walk.

Energy Density

So gradient tells us whether an energy source can do useful work. But there is a second question that matters just as much: how much of that work can you concentrate into a small enough package to actually build a civilisation on? A society that can carry its energy with it — in a ship's hold, a fuel tank, a pipeline — can project power, move goods, and sustain complexity. A society that cannot is stuck. The concept that governs this is energy density.

Energy density measures how much energy is packed into a given mass or volume of fuel. It is the reason you can drive from London to Edinburgh on 50 litres of diesel, but you would need a battery weighing roughly half a tonne to do the same thing in an electric car. The diesel contains roughly 44 megajoules[†] per kilogram. The best lithium-ion battery on the market manages about 1 megajoule per kilogram (see Figure 1). That is a ratio of roughly 40 to 1 — and no amount of engineering has significantly closed the gap, because the gap is not an engineering problem. It is a chemistry problem. Carbon-hydrogen bonds release a great deal of energy when broken. Shuttling lithium ions between electrodes releases much less. The periodic table is not subject to software updates.

This is not a theoretical curiosity. Civilisations run on energy density. The transition from wood to coal succeeded precisely because coal is denser — roughly twice the energy per kilogram, and far more per cubic metre because it doesn't need to be dried first. That single fact made the Industrial Revolution possible. Factories could be built in cities rather than next to forests.

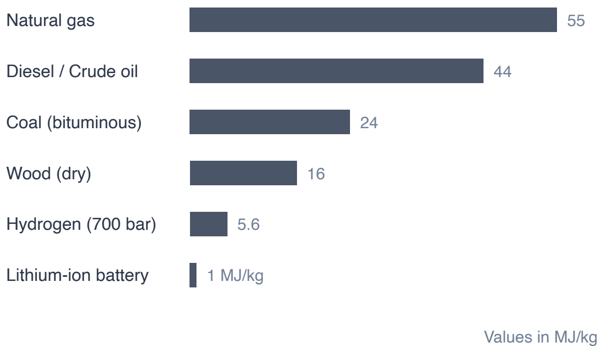

Figure 1: Energy density of common sources and storage media in megajoules per kilogram. The ratio between diesel and a lithium-ion battery — roughly 44 to 1 — is the single most important number in the energy debate.

Ships could cross oceans without filling their holds with firewood. Railways became possible.

The subsequent transition from coal to oil was another leap up the density ladder. Oil packs about 45 megajoules per kilogram versus coal's 24. It is also a liquid, which means it can be pumped, piped, and poured into a tank in minutes. That combination of high density and easy handling is what made aviation possible, what made the modern military possible, and what made the globalised supply chain possible. None of these things can run on coal, and none of them can run on batteries — not because the batteries are bad, but because the physics won't allow it.

Here is the pattern. Every successful energy transition in human history has moved *up* the density ladder: wood to coal, coal to oil, oil to nuclear. Each step concentrated more energy into less mass and less space, enabling new capabilities that were physically impossible at the previous level.

Why is the density gap between hydrocarbons[†] and renewables so large — and why can't engineering close it? Three factors, each compounding the others.

The first is the physics of the source itself. Nuclear fuel releases energy by splitting atoms; fossil fuels by breaking carbon-hydrogen bonds. Both processes liberate enormous amounts of previously stored energy from a tiny quantity of matter. Solar and wind energy, by contrast, derive from radiation that has weakened as it spreads across the vast distance from the sun. It is so diffuse, in fact, that at the height of a British summer you can spend all day in direct sunlight and still be pale blue at supper time.

The second is what we might call the compression of time and space. The diesel in your fuel tank is stored sunlight. It is the product of millions of years of photosynthesis, captured across millions of square miles of ancient forest and ocean, then compressed, cooked, and concentrated for us by colossal geological forces over aeons — all for free. When you burn a litre of diesel, you are releasing a quantity of ancient sunlight that no solar panel could collect in a human lifetime. A wind turbine or solar farm offers no such compression. It scavenges energy in real time, from the patch of sky or air directly above it, at whatever rate the weather permits.

The third is net energy. It takes energy to get energy. Gas wells must be drilled; solar panels must be manufactured. The effective density of any source is reduced by the energy required to obtain it. For nuclear and fossil fuels, that deduction is modest — they return roughly 30 units of energy for every unit invested. For wind and solar, the return is in single digits, and the manufacturing energy comes overwhelmingly from the very hydrocarbon system they propose to replace. The net density gap is even wider than the gross one.

These three factors — source physics, time-space compression, and net energy — are not policy choices. They are hard physical constraints, and no subsidy, no mandate, and no amount of wishful thinking can override them. They also explain why you can't simply compensate by building more of the dilute source. But to see why, we need one more concept.

Power Density

Energy density tells you how much energy is stored in a kilogram of fuel. But a civilisation doesn't just need energy. It needs energy *at a certain rate*. The lights must stay on now, not next week. The steel furnace must run continuously, not when the wind picks up. This introduces a new dimension: time. Power† is energy delivered per unit of time. A concentrated source can deliver energy at a ferocious rate from a small site. A diffuse source cannot — and the only way to increase its rate of delivery is to collect it from more land. That is the question energy density cannot answer on its own: how much land?

Power density measures this directly: the rate of energy flow per unit of land area, in watts† per square metre. The answer varies by a factor of a thousand, and that single fact explains more about the feasibility of energy policy than any amount of economic modelling.

Let's make this concrete. Imagine two farmers, each trying to feed a village. Farmer A has a single acre of rich, deep soil. He plants it intensively and feeds the village from one field. Farmer B has soil so thin that each acre yields one-thousandth as much.[4] To feed the same village, he needs a thousand acres — a thousand times the fencing, a thousand times the irrigation, a thousand times the labour — and his operation pushes into territory that was previously forest, or grazing land, or someone's home.

This is the power density problem. A gas-fired or nuclear power station is like Farmer A: roughly 1,000 watts from every square metre of land it occupies. A

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[4] This is the ratio between a gas or nuclear plant (1,000 W/m^2) and a wind farm at the low end of its range (1 W/m^2). At the upper end (3 W/m^2), the ratio is still over 300 to 1.

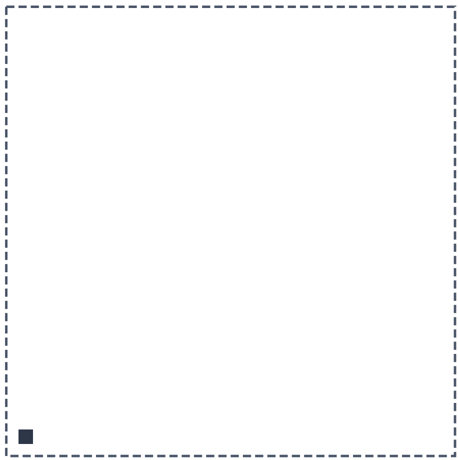

Figure 2: Land area required to generate one gigawatt of continuous power. The filled square is the gas plant (1 km²). The dashed outline is the wind farm (1,000 km², comparable to Greater London).

solar farm manages 20 to 30. A wind farm — once you account for the spacing turbines need to avoid stealing each other's wind — delivers 1 to 3 [1]. These are like Farmer B.

The arithmetic is unforgiving (see Figure 2). To replace a single gas plant with wind turbines, you need somewhere between 300 and 1,000 times more land. And that land is not empty. It is farmland, moorland, coastal seabed, or someone's horizon. The turbines must be manufactured, transported, erected on concrete foundations, connected by access roads, and linked to the grid by hundreds of miles of new transmission lines. Every square metre of that sprawl has a material cost and an energy cost.

This is not a problem that improves with scale. It gets worse. When power density is low, scaling up means spreading out, and spreading out means longer transmission distances, greater infrastructure, and more energy spent building and maintaining the collection network. At some point, the energy required to build and sustain the system begins to consume a significant fraction of the energy it produces. The system is running to stand still.

The pattern is the same one we saw with energy density. Every successful energy transition in history moved toward *higher* power density. Burning wood in a hearth: perhaps 0.5 watts per square metre of the forest that supplies it. A coal mine feeding a power station: hundreds of watts per square metre. An oil well: higher still. A nuclear reactor: the most power from the smallest footprint humanity has ever achieved.

The direction has always been the same: *concentration*. More energy from less land. More capability from a smaller footprint. The proposal to replace gas and nuclear with wind and solar reverses this trajectory entirely. It is a step backward to the kind of energy system that constrained civilisation for millennia — one that is spread thinly across the landscape, hostage to geography, weather, and the brute mathematics of area.

That matters, because land is not abstract. It is finite, and it is already spoken for. An energy system that demands hundreds of times more of that land is not merely inconvenient. It is in direct competition with food production, with ecosystems, and with the communities that live on the land it needs. The cheerful phrase "energy transition" obscures what is actually being proposed: one of the largest and most destructive land-use changes in human history. And that brings us to the question that matters: what do these three concepts, taken together, actually tell us?

The Thermodynamic Floor

Let's take stock. You now have three concepts — energy gradient, energy density, and power density — and between them they describe the physical constraints that every energy system must satisfy. No policy, no technology, and no amount of imagination, determination or investment can override them. They are the thermodynamic floor beneath civilisation.[5]

The historical record is unambiguous. Wood to coal. Coal to oil. Oil to nuclear. Each step moved up on all three measures simultaneously — steeper gradients, denser fuels, higher power density per unit of land

[5] Thermodynamics is the branch of physics that governs how energy moves and changes form. The "thermodynamic floor" is simply the set of physical rules that no energy system can break.

— unlocking capabilities that the previous level could never have supported. Railways, aviation, the globalised supply chain. The arrow has always pointed in the same direction: toward concentration.

Before we go further, there is one more distinction you need — and it is the one that most energy debates get wrong. A *fuel*† is a store of energy that exists in nature: coal in a mine, oil in a reservoir, gas in a field, uranium in rock. You can dig it up, move it, and release its energy when and where you choose. An *energy carrier*† is different. It is a way of moving energy from one place to another. Electricity is the most familiar carrier. It does not exist in nature. It must be manufactured, in real time, from a fuel, and every conversion loses energy. Hydrogen is another.[6] When someone proposes to "replace fossil fuels with electricity," they are not proposing a like-for-like swap. They are proposing to replace a fuel with a carrier — and hoping nobody notices the difference.

There are no counterexamples. And here is the part that is not discussed in polite company: every involuntary move *down* the density ladder — deforestation, resource depletion, imperial overreach — has produced not a gentle simplification but a catastrophe. People

[6]There are no hydrogen wells. Every kilogram of hydrogen must be manufactured — by splitting water with electricity, or by stripping it from natural gas — and both processes throw away roughly half the original energy. Anyone who calls hydrogen a fuel has not understood the distinction.

die, in large numbers, when the energy that sustains their society contracts faster than they can adapt. The Western Roman Empire did not "transition" to a lower-energy economy. It collapsed, and the population of its former territories fell by roughly half over two centuries [2]. That is what moving down the energy ladder looks like when it is not a choice.

The current energy policy of most Western governments proposes to do something unprecedented: move down the density ladder deliberately, replacing concentrated fossil and nuclear energy with whatever the wind and sun happen to deliver on any given afternoon. The ambition is wrapped in the language of progress — "clean energy transition," "net zero," "green growth" — but the physics points in the opposite direction. A wind turbine is a lower-gradient, lower-density, lower-power-density device than the gas plant it proposes to replace. That is not a political opinion. It is a measurement.

To conceal the consequences of this programme, its advocates have developed a vocabulary of euphemism. "Degrowth" and "efficiency" sound like prudent management. The honest term is energy rationing — and energy rationing is never a choice made by prosperous societies. It is a condition imposed by crisis. When that crisis is not resolved, the result is always the same: declining living standards, eroding social stability and — eventually — war over the resources that remain. The question is not whether a lower-energy society would be unpleasant. The question is whether it is survivable at the scale of eight billion people. The physics suggests that it is not.

But before we consider what can be done about this, we need to understand what all this energy is actually *for*. The answer is not "electricity." The answer is the four industrial processes without which modern civilisation cannot exist. That is the subject of Part II.

PART II

The Industrial Metabolism

In which we discover what civilisation actually eats, and why you can't replace the menu with electricity.

The centrepiece of current energy policy is a single proposition: replace fossil fuels with electricity generated from wind and solar. Electrify heating. Electrify transport. Electrify industry. The shorthand is "electrify everything," and it is the organising principle behind net zero, green growth, and the clean energy transition.

To understand why this will not work, you need to know what industrial civilisation actually *consumes* — not in the abstract, but at the level of specific processes at specific temperatures. You need to understand civilisation's metabolism.

A metabolism is the set of chemical processes by which a living thing converts raw materials into the substances it needs to survive. Your body has one. It takes in specific inputs — protein, carbohydrate, fat, water — in specific chemical forms and in specific quantities, transforms them, and excretes what it cannot use. You cannot substitute one input for another. You cannot replace protein with extra water and expect to survive. You cannot live on air and good intentions, however fervently you believe otherwise. If any part of this system fails — input, conversion, or output — you die. Not eventually. Quite soon.

Industrial civilisation is not a living thing, but the analogy is exact. It too has a metabolism — a set of chemical processes that convert raw materials into the substances on which its survival depends. It consumes raw materials, transforms them at extreme temperatures using specific chemical reactions, and produces the physical substances on which everything else depends.

The four most important of these products — the pillars that hold up civilisation — are steel, cement, ammonia, and plastics. Between them, they account for roughly a third of global energy use [3] and underpin virtually every object, structure, and system in the modern world. Without any one of them, industrial civilisation does not downgrade gracefully. It stops.

The critical point is that these processes do not merely *use* energy. They use hydrocarbons *as a chemical feedstock*. The carbon in steel, the calcium carbonate in cement, the hydrogen in ammonia, the polymer chains in plastic — these all come from fossil fuels, not as a fuel source that can be swapped for another, but as a raw material input to the chemistry itself. This is the fact that "electrify everything" must confront.

The Four Pillars

Steel holds up almost every building you have ever entered, almost every bridge you have ever crossed, almost every vehicle you have ever ridden in. Making it requires heating iron ore to around 1,500°C in a blast furnace, using coke — derived from coal — as both the heat source and the chemical agent that strips oxygen from the ore. The carbon is not optional.[7] Without it, the iron stays as rock. Global production: roughly 1.9 billion tons a year [4]. Without steel, there are no cities, no railways, no ships, no surgical instruments, no wind turbines.

Cement is the binding agent in concrete, the most widely used material on Earth after water. Making it requires heating limestone and clay to about 1,450°C in a rotary kiln. The calcium carbonate in the limestone releases carbon dioxide as an intrinsic part of the chemical reaction — not because the kiln burns fossil fuel (though it does), but because the chemistry *itself* produces CO_2. Even if you powered the kiln with clean electricity, roughly two-thirds of the emissions of CO_2 to the atmosphere would remain [5]. Global production:

[7] Experimental hydrogen-based routes exist but require vast quantities of clean hydrogen that do not yet exist at scale — a problem explored in Part V.

roughly 4 billion tons a year [6]. Without it, there are no foundations, no dams, no roads, no runways.

Ammonia is the basis of virtually all synthetic fertiliser, which in turn sustains roughly half the world's food supply. Making it involves a chemical process that strips hydrogen from natural gas and combines it with nitrogen from the air at 400–500°C under extreme pressure. The natural gas provides both the hydrogen feedstock and the energy to drive the reaction. Global production: nearly 200 million tons a year. Without it, crop yields collapse and billions face starvation [7].

Plastics are built from hydrocarbon chains derived almost entirely from oil and natural gas. The fossil fuel is not consumed. It is *restructured*, molecule by molecule, into materials that are lighter than metal, cheaper than glass, and more versatile than either. Global production: over 400 million tons a year [8]. Without them, there is no modern medicine, no food packaging, no insulation, no electronics.

Four materials. Four processes that require specific chemical inputs at extreme temperatures. Four dependencies on hydrocarbons not as a *fuel* but as a *feedstock*. Remove any one and the system that feeds, houses, and sustains eight billion people begins to fail. Remove all four and it ceases to exist. So what happens when someone proposes to replace these feedstocks with electricity?

The Electric Diet

There is a community of people who believe that humans can live on air and sunlight. They call themselves breatharians. They hold conferences, publish books, and maintain a sincere conviction that the human body does not require food. Periodically, one of them dies [9].

The proposal to run an industrial civilisation on electricity alone is the breatharian diet of energy policy. It begins with a grain of truth — electricity is marvellous for many things — and extends it into a fantasy: that if we simply generate enough clean electricity, we can replace every industrial process that currently depends on hydrocarbons. "Electrify everything" is a slogan, not an engineering plan.

Consider what "electrify everything" must actually mean for the four pillars. To make steel without coal, you need hydrogen — vast quantities of it — produced by splitting water with electricity. To make cement without releasing process CO_2, you would need to reinvent the chemistry of calcium carbonate, a problem no one has solved at scale. To make ammonia without natural gas, you need the same clean hydrogen, in even vaster quantities. To make plastics without oil, you need synthetic hydrocarbon feedstocks built up from CO_2 and hydrogen — a process so energy-intensive that it makes the original fossil route look efficient by comparison.

Every one of these alternatives requires enormous amounts of cheap, reliable, high-density electricity that does not yet exist. And every one of them runs into the distinction we established in Part I: electricity is not a fuel. It is an energy carrier — manufactured, in real time, from a primary source, with losses at every step. When someone says "replace fossil fuels with electricity," they are not proposing a like-for-like substitution. They are proposing to replace a fuel with a carrier — and then asking that carrier to do the chemical work that only a fuel can do.

And here is the circularity that its advocates prefer not to discuss: building the wind farms, solar arrays, battery storage, and transmission lines requires steel, cement, and plastics — which can only be produced using hydrocarbons. And because these systems wear out and must be rebuilt every twenty to thirty years, the dependency is not temporary. It is permanent. You do not use the old system to launch the new one and then switch it off. You use the old system to *sustain* the new one, indefinitely.

The honest version of "electrify everything" is therefore this: electrify the things that electricity can actually do — lighting, computing, rail transport, heat pumps — and accept that the industrial core of civilisation will continue to require hydrocarbons as a chemical input for the foreseeable future. That is not a failure of ambition. It is an acknowledgement of chemistry.

But before examining what happens when we try to build the replacement anyway, there is a prior question that most energy debates skip entirely: what is happening to the fossil fuels themselves? The answer, as Part III reveals, makes everything that follows considerably more urgent.

Part III

The Depleting Inheritance

In which we discover that the one-time endowment of fossil sunlight is running out faster than anyone in authority will admit.

Parts I and II described what energy is, what it does, and why the industrial metabolism depends on hydrocarbons not merely as fuel but as feedstock. Before asking whether renewables can replace them, there is a prior question that the energy debate has quietly buried: what is happening to the fossil fuels themselves?

This part is longer than the others, for two reasons. First, oil is the bridge fuel in any plausible transition — the energy source that must keep civilisation running while anything else is built. Its status matters more than any other single variable. Second, a widespread misunderstanding about "peak oil" has bred a complacency that is now genuinely dangerous. Both require careful dismantling.

The answer is not comfortable. And it begins with a concept that has been widely — and wrongly — dismissed.

"Peak oil" is one of those phrases that makes educated people roll their eyes. It has been predicted repeatedly, and the predictions have appeared to fail. Production kept rising. New technologies unlocked new sources. The doomers, it seemed, were wrong.

They were not wrong. They were describing a physical process that is as certain as gravity. What they did not anticipate was the response: the creation of roughly $25 trillion of imaginary money by the world's central banks — money that, among other things, made it possible to mobilise oil that the market had correctly identified as too expensive to extract. The predictions were right about the physics. They were wrong about the politics — specifically, about how far governments would go to avoid confronting the physics.

To see why, you need to understand how oil depletion actually works. The mechanics are not complicated, but they are relentless — and they are completely absent from the public debate.

The Physics of Depletion

An oil well is not a tank with a tap. When you drill into a reservoir, the oil flows under natural energy stored in the rock and its fluids — pressure from the aquifer beneath, expansion of gas dissolved in the oil, the weight of the rock itself. As you extract oil, that stored energy depletes. The pressure drops. The flow slows. Eventually you need pumps, then water injection, then gas injection, each consuming more energy and recovering less oil. Every well follows the same fundamental arc: maximum flow at the start, then decline. Workovers and new techniques can slow the rate or buy temporary recoveries, but the underlying trajectory is set by the depletion of stored energy in the reservoir. That cannot be reversed.

Now imagine a row of spinning plates on sticks — like a circus act. Each plate is an oil well. New plates are being set spinning all the time, but older plates are always slowing down and falling. To keep the same number spinning, you must start new plates at least as fast as old ones fall. To increase the total, you must start them faster. This is the fundamental dynamic of oil production: it is not a stock you draw down at will. It is a flow you must constantly renew.

The International Energy Agency quantified this in 2025. If all investment in existing oil fields were to stop tomorrow, global production would fall by 8% per year [10].[8] That may not sound much, but apply the Rule of 70 — divide 70 by the percentage decline rate — and you get the halving time. At 8%, global oil production would halve in under nine years. Not over a generation.

[8]For shale wells, the figure is far worse: production would fall by over 35% in the first twelve months.

Not by 2050. In nine years. Then halve again in the next nine years.

This is the treadmill that the oil industry now runs on every day. Nearly 90% of all upstream investment now goes simply to offsetting decline in existing fields — running to stand still. The remaining 10% is all that is available to grow production. And the treadmill is accelerating: as the world's giant fields age and newer, smaller, faster-declining sources like shale take a larger share, the decline rate steepens.

So the treadmill demands a constant supply of new fields to replace the ones that are dying. The critical question is: where do new fields come from?

Discovery Constrains Production

They come from discovery. And since you cannot produce what you have not first discovered, the pattern of discovery determines the pattern of production. This is the most basic fact in the oil industry, and the one most consistently ignored in energy policy.

Global oil discovery peaked in the 1960s, when the industry was finding upwards of 40 billion barrels a year. That era and the decade that followed opened the great provinces — the Middle East super-giants, western Siberia, Alaska, the North Sea. The tools have improved enormously since then: seismic imaging, deep-water drilling, horizontal wells, machine learning applied to geological data. The planet has been surveyed with a

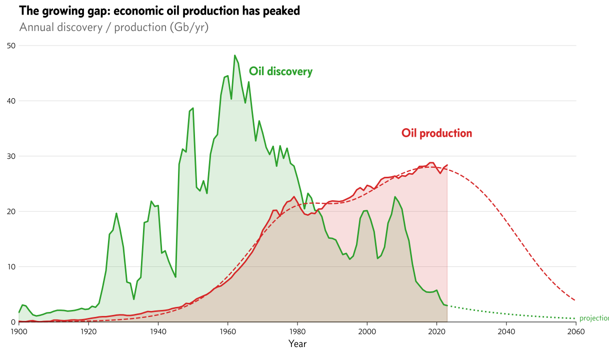

Figure 3: Global conventional oil discovery and production (excluding ultra-heavy), after Laherrère (2024). Discovery volumes peaked in the 1960s and have declined despite massive improvements in exploration technology. Production continued to rise, drawing down the finite volume already discovered. The widening gap between the two curves represents the accelerating consumption of a one-time inheritance.

thoroughness that would have astonished a 1960s geologist.

And yet discoveries have fallen, decade by decade, to roughly 5 billion barrels a year. In 2024, the world discovered around 2 billion barrels while consuming 30 billion. We are burning through our inheritance roughly fifteen times faster than we are finding new deposits. But this pattern of collapsing discovery also reveals something else — something that matters even more than the annual shortfall.

There is a simple but powerful statistical technique that allows geologists to estimate the total volume of oil the Earth will ever yield — long before the last barrel is pumped. Add up every barrel ever discovered, year by year, as a running total. Once annual discoveries began falling after the 1960s peak, the running total began to slow — and its ultimate destination became possible to project. With each subsequent decade of diminishing discovery, the projection converged. The uncertainty shrank. The geologists' term for the destination is *ultimate recoverable resource*, or URR.

Today that number is essentially known. Barring an astonishing technological breakthrough — a possibility we address later — the cumulative discovery curve has almost stopped rising and can only flatten further. The URR is not a number we are guessing at. It is a number we can already read off the curve.

Now apply this to production. You cannot pump what was never discovered. Production is capped by the URR. And the URR is already known. *The peak of global oil production is not a matter of opinion, or modelling, or politics. It is a matter of arithmetic — and the arithmetic is already done.*

Technology Cannot Close the Gap

The instinctive response is: "But technology will find more." It is worth pausing on why this is wrong.

Peak discovery — the 1960s — coincided with the Apollo programme. Humanity was landing on the Moon. In the six decades since, we have lived through the greatest technological revolution in history: electronics, miniaturisation, computing, satellite surveillance, materials science, artificial intelligence.

Every one of these has been applied to oil exploration. The result? Discovery volumes fell by over 90%.

This is not a failure of technology. It is a success of geology. The big fields were found first because they were the easiest to find. Technology finds what remains: smaller, deeper, faster-declining deposits — plates that spin down almost as soon as they start. But the treadmill needs giant fields to replace the giants that are dying. There are none left to find.

The New Saudi Arabia Test

To see how locked-in the trajectory is, try a thought experiment. Suppose tomorrow we discovered a single province containing 260 billion barrels — equivalent to Saudi Arabia's entire proven reserves, which took decades and dozens of fields to accumulate. How much difference would it make?

At current global consumption of 30 billion barrels a year, a new Saudi Arabia would supply roughly nine years of demand. But it would take ten to fifteen years to develop. During that time, the existing production base would lose far more than the new province could add. A discovery of historically unprecedented scale would delay the peak by a few years at most. It would not prevent it.

So if the physics of depletion is this clear — if discovery peaked sixty years ago and technology cannot reverse it — why do so many people believe that peak oil was wrong? The answer lies in a distinction that the public debate has never grasped.

Peak Economic Oil

Not all oil is equal. This is the fact that the "peak oil was wrong" narrative has never understood.

A barrel of conventional crude from Saudi Arabia costs roughly $10 to extract. A barrel from the Canadian oil sands costs $60 or more and requires vast quantities of natural gas to process. A barrel from a US shale well costs somewhere in between, declines violently after the first year, and must be replaced by continuous drilling. All three appear in the reserves statistics as "oil." But they are not the same resource in any sense that matters to an industrial civilisation. One sustains the system. The others barely sustain themselves.

There is an oil price below which the economy expands, and a price above which it contracts. That threshold may be hard to estimate precisely, but it exists. It partitions remaining oil into two volumes: the oil that can be extracted at a price the economy can bear — economic oil[†] — and the oil that cannot. The second volume is, for all practical purposes, indistinguishable from oil that is not there at all.

"Peak oil" always meant peak *economic* oil — though the early thinkers never needed to say so, because in their day virtually all oil was economic. Tar sands and tight shale were geological curiosities, not production targets. The claim was that the cheap, high-quality oil on which industrial growth depends would peak and decline, and that what remained would be progressively harder, more expensive, and less productive. That is exactly what happened. The distinction only became necessary when central banks flooded the financial system with imaginary money, and that money found its way into sources the market had already rejected.

Conventional oil — the cheap oil that built the modern world — peaked around 2006.[9] The International Energy Agency's *World Energy Outlook 2010* acknowledged that conventional crude production had reached its maximum and would never return to that level. The event passed almost without public comment. It should have been the most important news story of the century.

What happened instead was the 2008 global financial crisis — an event universally attributed to reckless lending, but which makes considerably more sense when understood as the first collision between a grow-

[9] Definitions of "conventional" vary between sources, and with them the precise peak year, but the difference is definitional, not physical. The discovery–production gap shown in Figure 3 makes the trajectory plain. By any reasonable definition, cheap oil has peaked and is in decline.

ing economy and a contracting energy supply — and, as we shall see in the chapter on money, not the last. Oil prices hit $147 a barrel in July 2008. Within months, the financial system broke. The causal chain — energy constraint, price spike, demand destruction, financial contagion — is visible in retrospect to anyone willing to look.

The $25 Trillion Response

When conventional oil peaked, the world faced a choice: acknowledge the constraint and begin adapting, or find a way to keep the growth story running a little longer. It chose the latter.

The instrument was imaginary money. Between 2008 and 2025, the US Federal Reserve and its counterparts conjured roughly $25 trillion into existence through quantitative easing and near-zero interest rates. A significant share of that money flowed into the American shale oil industry — an industry that had existed in experimental form for decades but had never been commercially viable, because the oil it targeted was too tightly locked in rock to extract at a profit.

Cheap capital changed the arithmetic. With borrowing costs near zero, companies could drill at a loss and refinance indefinitely. US oil production tripled from roughly 5 million barrels a day in 2008 to over 13 million by 2024. The shale revolution was hailed as proof that human ingenuity had once again overcome physical limits.

But shale oil is not conventional oil. A shale well must be hydraulically fractured — rock shattered at high pressure to release oil trapped in microscopic pores — and its production drops by 25 to 40 percent in the first year. To maintain output, you must drill continuously. To grow output, you must drill exponentially. The industry did not discover a new oil province. It built a treadmill — and the US shale industry was cash-flow negative for over a decade to keep it turning.

Now the bill is coming due. The best acreage — the Tier 1 locations in the Permian Basin, the Bakken, the Eagle Ford — is exhausting. In 2024, for the first time, productivity per lateral foot of drilling declined. The industry was drilling longer wells to extract less oil. The treadmill was accelerating, and the runner was slowing down.

So the claim that "peak oil was wrong" amounts to this: we printed $25 trillion of imaginary money to mobilise a vast volume of uneconomic oil, and because total production kept rising, we declared the problem solved. The physics did not change. The accounting did. And the time we bought was borrowed from the future — because every barrel of uneconomic oil extracted today is a barrel that will not be available tomorrow, when the need will be greater and the alternatives fewer.

The Ledger

Let us draw up the account.

Rystad Energy — the industry's most widely cited independent data source — estimates that at current production rates, the world's proven *economic* oil reserves will last roughly fourteen years [11]. Fourteen years is not a generation. It is not a planning horizon. It is the time it takes to design, approve, finance, and build the replacement for a single power station.

The optimist will point to the 1.6 trillion barrels of "proven reserves" that appear in official statistics and declare that we have decades of supply. But that number deserves its scare quotes. Nearly 80% of it comes from OPEC member states that self-report without independent audit.[10] The figure also includes oil that is uneconomic, inaccessible, or so energy-intensive to extract that it barely returns more than it consumes. The number that matters is not the oil in the ground. It is the oil that can be extracted at a price the economy can bear. That number is much smaller — and it is shrinking.

Gas is in a different position. Proven reserves stand at roughly fifty years of current consumption. This is

[10]In the 1980s, when OPEC began linking production quotas to reported reserves, member states collectively added roughly 300 billion barrels to their claimed reserves overnight — without a single new discovery. Those barrels remain in the statistics today.

a significant buffer — but it is not a solution to the oil problem, because oil and gas are not interchangeable. Oil is a liquid. It powers virtually all transport: every car, every truck, every ship, every aircraft. It is the feedstock for plastics, pharmaceuticals, and the entire petrochemical supply chain described in Part II. Gas can heat buildings, generate electricity, and provide some petrochemical feedstock — but it cannot fuel a truck fleet, fly an aircraft, or replace naphtha in a refinery. The depletion of oil is therefore not softened by the abundance of gas. It is a separate crisis, running on its own clock.

Now put the ledger together with what this book has argued so far.

The hydrocarbon endowment is finite and depleting. Oil — the most energy-dense, most versatile, most irreplaceable fraction — is depleting fastest. The shale response bought time but masked the decline of the economic reserves on which civilisation depends. And the endowment we are depleting is the same endowment we would need to build *any* replacement — including one that might actually work.

This is the context in which every proposed energy transition must be judged. It is not enough for a replacement to "work" in laboratory conditions or in a spreadsheet. It must work while the inheritance that funds it is shrinking. Every barrel of the remaining endowment matters. Every barrel spent on a system that requires permanent hydrocarbon support — and that must be rebuilt every generation using hydrocarbons — is a barrel unavailable for the bridge to something that can actually sustain itself.

We cannot afford to waste a single barrel. The next three parts ask whether the proposed replacements can pass that test. The answers are not reassuring.

Part IV

The Renewables Paradox

In which we discover that renewables aren't renewable, and that building the replacement for fossil fuels requires more fossil fuels than it saves.

It's not what an energy system produces that sustains civilisation. It's what is left after the system has fed itself - the *net* output. Every energy source consumes energy — to drill the well, mine the ore, build the infrastructure, and deliver the output. What matters is how much is left over. A conventional oil well returns roughly thirty units of energy for every one invested. The energy tax is trivial. The surplus is enormous. For most of the fossil fuel era, the distinction between gross and net has barely mattered.

Wind turbines and solar panels also produce energy. That is not in dispute. But they must also be mined, manufactured, installed, connected, backed with storage, and replaced when they wear out — and every one of those steps consumes energy. The question is not "do they produce energy?" but "how much is left over to power civilisation?" The answer is less reassuring than advocates suggest — and it gets worse the harder you look.

Part IV examines this question in five steps. First, the bridge fuel problem — why a transition that destroys its concentrated energy sources cannot generate the surplus energy needed to replace itself. Second, the energy cliff — the hidden mathematics of energy return that makes a small decline in efficiency catastrophic. Third, the storage problem — what happens when you try to make an intermittent source do the job of a continuous one, and what it actually costs. Fourth, the physical bill of materials — the steel, concrete, copper, and lithium that the buildout demands, and where it all comes from. Fifth, the replacement treadmill — what happens when a system with a twenty-five-year lifespan built from non-renewable resources must be rebuilt, again and again, forever.

The Bridge Fuel Problem

Every energy transition in history has been like changing an aircraft's engines in flight. The new system must be built while the old one keeps running — because you cannot stop feeding, heating, and transporting eight billion people while the work is done. Four billion of them depend on food grown with fossil-fuel fertiliser. They cannot wait.

This is the bridge fuel problem: the energy needed to bridge from the present system to the future one while keeping everything running. Every successful transition has met two conditions [12]. First, there was a large surplus of the current energy source still available. Second, the new source was *denser* — more energy from less material and less land. Wood to coal, coal to oil, oil to nuclear: each time, the old source funded the construction of something better.

The proposed transition violates both conditions. It asks us to use high-density energy to build low-density energy infrastructure, hoping the new system can eventually sustain itself. But if the new system returns less net energy than the fossil fuels used to build it, you can neither maintain current civilisation nor construct its replacement. You fail to solve the bridge fuel problem.

History has a name for this: collapse. It is what happened to the Western Roman Empire when it deforested its accessible fuel supply and was forced down the energy ladder.

The Energy Cliff

The ratio between the energy you get from a source and the energy you spend obtaining it is called EROEI† — Energy Return on Energy Invested (see Figure 4). It is the defining ratio of any energy system, because it determines how much useful energy is left over after building, operating, maintaining, and replacing your energy system to do everything else: to heat homes, to run factories, to grow food, to sustain a civilisation.

At an EROEI of 30:1, you invest one unit of energy and get thirty back. Twenty-nine are available for society. The energy cost of obtaining your energy is modest — about 3% of the total. This is roughly where conventional oil and nuclear sit [13]. The system runs comfortably. There is abundant surplus.

At 10:1, you invest one unit and get ten back. Nine are available. The cost has risen to 10%, but the system still functions. This is roughly where some estimates place wind, before storage and grid costs are included.

Here is where intuition fails. At 5:1, you invest one unit and get five back. Four are available — but the cost of obtaining your energy has leapt from 10% to 20%. At 3:1, it's 33%. At 2:1, you're spending half your energy just getting energy. At 1.5:1, two-thirds. The relationship is not linear. It is an exponential curve and there is a point on that curve where a small decline in EROEI

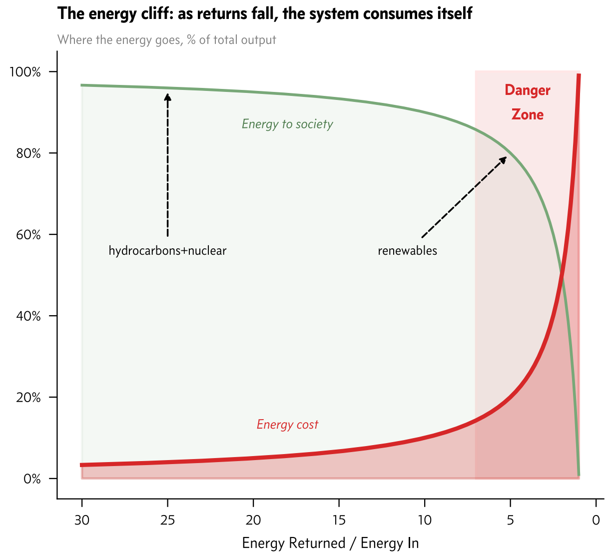

Figure 4: The energy cliff. As EROEI declines from left to right, the share of total output available to society (green) collapses while the share consumed by the energy system itself (red) grows. Hydrocarbons and nuclear sit comfortably on the left. Wind and solar, once storage and grid costs are included, sit in the danger zone — where history shows us societies cannot function.

produces a catastrophic collapse in the energy available to society. This is the energy cliff.

EROEI estimates are imprecise — critics of all persuasions agree on this. But the cliff means that imprecision matters far more at the bottom than the top. At 30:1, an error of ten units is an inconvenience. At 8:1 — wind and solar territory — the same error can wipe out civilisation.

The cliff matters for another reason. Someone with no undertanding of the physics might argue that an energy source is viable as long as it returns more than it consumes — that an EROEI of, say, 1.1:1 is "still positive." In gross terms, it is. But at 1.1:1, delivering the same net energy as a 30:1 system requires roughly *thirty* complete energy systems — thirty times the turbines, the land, the steel, the concrete, the copper. You have not built one energy system. You have built thirty, and most of the energy they produce goes into keeping each other running.

Combine that with the power density gap from Part I — 300 to 1,000 times more land per unit of power — and you are not describing a wind farm. You are describing a continent devoted entirely to generating the energy required to generate energy.

The usual reply to this observation is that technology will solve the problem. But technology, by definition, is the application of surplus energy to solve problems. It then follows that the one problem technology cannot solve is energy deficit.

The next chapter shows what this means in practice — because the EROEI figures most commonly cited for wind and solar are not measuring what you think they are.

The Storage Problem

The Energy Returned over Energy In (EROEI) figures most commonly cited for wind and solar measure the energy returned by the *device* — the turbine, the solar panel, etc. — not by the *system* needed to make the device compatible with the demands of civilisation. The difference is storage. And the difference is catastrophic.

A wind turbine in isolation may return 16 units of energy for every unit invested. But a wind turbine in isolation generates intermittent energy, and civilisation tolerates intermittent energy about as well as you tolerate an intermittent air supply. You don't want your baby in a neonatal unit that works occasionally. An energy system must deliver power reliably, on demand.

That means storage — for example batteries, pumped water storage, or hydrogen — each of which consumes energy to build and loses energy in every charge-discharge cycle. It means grid infrastructure to balance supply across geography and time. It means backup generation for the days when the wind does not blow and the sun does not shine. Each addition subtracts from the system EROEI, pushing the real number further down the cliff.

How much storage? The above are abstract claims until you test them against a real country. The United Kingdom is a useful case: a large, wealthy, wind-rich island that has committed by law to net zero by 2050. If the storage arithmetic works anywhere in the temperate world, it should work here.

A 2023 Royal Society study modelled 37 years of UK weather data against projected electricity demand over the next 30 years and arrived at a sobering answer [14]. The problem is not merely the *Dunkelflaute* — the dark doldrums of a windless winter week. The data reveal that UK wind output can remain persistently below its long-run median for two to three consecutive *years*, producing cumulative energy deficits that dwarf anything a battery can absorb. Meeting demand through a multi-year wind drought requires tens of terawatt-hours of stored energy — energy that must have been be deposited years earlier during a sustained surplus.

The United Kingdom currently possesses about 30 GWh of pumped hydro storage and 1.6 GWh of grid-scale batteries [14]. The required storage is tens of TWh. That is not a rounding error. It is a shortfall of three orders of magnitude — a factor of roughly a thousand. To close the gap with lithium-ion batteries at current costs would require something in the region of two to three trillion pounds — approximately the entire annual GDP of the United Kingdom — spent on batteries alone. Batteries that degrade and must be replaced every ten to fifteen years. And this is for electricity only, which accounts for roughly one fifth of UK final energy demand. Electrify heating, transport, and industry, as current policy assumes, and the numbers become farcical.

And storage is not even the whole of the problem. No battery or hydrogen store can guarantee supply through a three-year wind drought. For that, you need backup generation — gas turbines, most likely — capable of meeting the full demand of the grid. These must be built, maintained, staffed, and connected, even though they will sit idle most of the time. In a system dominated by wind and solar, the backup fleet runs at a capacity factor so low that the electricity it produces, on the rare occasions it is called upon, is ruinously expensive. You have not replaced the fossil fuel system. You have built the renewable system on top of it, and you are paying for both.

Now recall the energy cliff from the previous chapter. A wind turbine's claimed EROEI of 16:1 measures the device alone. Add the colossal storage, grid, and backup needed to make it a reliable power source, and the system EROEI drops to roughly 4:1 [13] — deep into the danger zone where the curve steepens towards civilisational collapse. And even that figure assumes pumped hydro, the most efficient storage available. With batteries, it is worse still.

Whatever your reason for wanting an energy transition, a transition that consumes more energy than it liberates is not a solution to anything. It is the most expensive and elaborate method ever devised for committing civilisational suicide.

The Bill of Materials

The energy cliff is an abstraction until you translate it into physical reality. So let's do that now.

A single 5-megawatt wind turbine contains roughly 900 tons of steel, 1,500 tons of concrete, 45 tons of composite, and 8 tons of copper. A utility-scale solar farm requires roughly 5,000 tons of steel and 11,000 tons of concrete per gigawatt of rated capacity. The batteries required to back either source add lithium, cobalt, nickel, and manganese in quantities that increase with every hour of storage demanded. These are large numbers. But they are only the *visible* part of the bill. The invisible part is larger.

Consider what it takes to put a single wind turbine on a hilltop. The steel in the tower was smelted from iron ore in a blast furnace burning coke. The ore was mined by diesel-powered excavators, transported by diesel trucks to a rail head, carried by diesel locomotives to a port, and shipped across an ocean by a vessel burning heavy fuel oil. The concrete in the foundation was mixed from cement fired in a gas-burning kiln, from limestone quarried by diesel machinery. The copper in the generator was mined in Chile or the Congo, refined in a fossil-fuelled smelter, drawn into wire in a factory powered by a coal-fired grid. The rare earth magnets were extracted from ore in Inner Mongolia using acids produced in a petrochemical plant. The fibreglass blades are made from resins derived from oil. The lubricant in the gearbox is a petroleum product. The road built to reach the site was paved with tar from a refinery. The crane that lifted the aerodynamic shell into place runs on diesel. The vessel that installed the subsea cable burns marine fuel oil. The computer on which the maintenance contract was drafted is housed in a plastic casing made from ethylene derived from natural gas.

This is what we call the Global Industrial Manufacturing System. Every link in that chain is a hydrocarbon operation. Not some of them. Not most of them. *Every single one*. The supply chain that builds the "clean energy system" is, from the mine face to the turbine blade, a fossil fuel enterprise. This is not a transitional inconvenience that will resolve itself as the buildout matures. It is the structure of industrial civilisation, and electricity cannot replace it — because, as we saw in Part II, the processes at every link require hydrocarbons not as a fuel but as a feedstock.

The International Energy Agency estimates that a net-zero transition would require, by 2040, roughly seventeen times the current global production of lithium, five times the cobalt, and three times the copper [15] — from mines that do not yet exist, in jurisdictions that are not stable, using energy from the system being replaced. McKinsey estimates the capital cost of the net-zero transition at $275 trillion [16] — roughly $9.2 trillion a year for three decades, or 7.5% of global GDP. And even that, they concede, is likely an underestimate.

The wind is renewable. The turbine is not. Every component is a finite, non-renewable, hydrocarbon-dependent industrial product with a fixed lifespan. And as the last chapter notes, this is just the first instalment.

The Treadmill

A wind turbine lasts 20 to 25 years. A solar panel, 25 to 30. A gas plant operates for 40 or more. A nuclear plant, 60 to 80. A renewables-based energy system must therefore be *entirely rebuilt* two or three times within the operational life of the conventional system it replaces — and each rebuild demands the full bill of materials again.

The system does not build once and then produce. It builds, produces, degrades, and rebuilds — in a cycle that never ends and never gets cheaper in energy terms, because the materials are consumed, not merely borrowed. A turbine blade cannot be recycled into a new turbine blade. The concrete in a foundation is not recoverable. The lithium in a spent battery can be partially reclaimed, but at significant energy cost. This is not maintenance. It is reconstruction.

Now put the three problems together. A system on the wrong side of the energy cliff requires multiples of generating capacity to deliver the same net output of the system it tries to replace. Each multiple demands its own bill of materials. Each bill must be paid again every generation. The total is the initial buildout, *multiplied by the number of replacement cycles*, multiplied again by the EROEI penalty. The numbers never stop growing, because the cycle never ends.

This is the Renewables Paradox in its full form. A material buildout of historically unprecedented scale, powered by fossil fuels, rebuilt every generation, with a net energy return that drives it over the cliff. It is not a transition away from the hydrocarbon system. It is an expansion of the hydrocarbon system's workload, undertaken in the name of eliminating it.

But surely there must be an escape — efficiency, hydrogen, green growth? Part V tests the three most popular candidates. Then Part VI follows the consequences into money, and Part VII asks what an honest response would look like.

Part V

The Escape Hatches

In which we test the three most popular reasons for believing that none of the foregoing matters, and find that they don't work either.

By now you may be feeling uncomfortable. The dominant energy supply is depleting, the proposed replacement returns less net energy than the system it replaces, and the physical buildout is beyond anything attempted in human history. Surely there must be an escape.

Enthusiasts of renewable energy systems commonly offer three. The first is efficiency: we will simply use less energy to do the same work. The second is hydrogen: a clean, storable fuel that solves the intermittency problem. The third is decoupling: the economy will grow even as energy consumption falls, because we are shifting to services and information.

Each sounds plausible. None of them work.

The Efficiency Illusion

The problem is straightforward: the energy supply is depleting and the proposed replacement delivers less net energy. The most popular response is that we will not need as much. We will use energy more efficiently — better insulation, better engines, better lighting — and do the same work with less fuel. Efficiency will close the gap that physics has opened.

It will not. In 1865, the economist William Stanley Jevons noticed that Britain had dramatically improved the efficiency of its steam engines. Coal was being used more productively than at any point in history. And coal consumption was soaring.

Why? Because more efficient engines made coal *cheaper to use*, which made people use *more* of it — in more places, for more purposes, in industries that had never previously been worth powering. This is the Jevons Paradox[†], and it has held for 160 years.

Consider lighting. The LED bulb uses roughly 80% less electricity than the incandescent bulb it replaced. If efficiency reduced consumption, global electricity use for lighting should have collapsed. It did not. It rose. Cheap, efficient light made it economical to illuminate car parks, building facades, advertising hoardings, and entire city skylines that no one would have lit with incandescent bulbs. The world now has vastly more lit surfaces, and total electricity consumed by lighting continues to increase [17].

Or consider cars. American fuel economy standards have roughly doubled the efficiency of new vehicles since 1975. In the same period, vehicle miles travelled rose by 40%. People responded to cheaper motoring not by driving the same distance on less fuel, but by driving further, buying heavier vehicles, and moving to suburbs that required longer commutes. Total US gasoline consumption did not fall.

The pattern holds at every scale. Economy-wide studies consistently find that more than half of the energy savings predicted by efficiency improvements are consumed by increased activity — a phenomenon economists call the *rebound effect*. The most comprehensive review of the evidence, covering 33 studies, found an average economy-wide rebound of 58% [18]. That means for every ten units of energy that improved efficiency should have saved, fewer than five were actually saved. The rest were spent on doing more.

Efficiency, in short, is not a source of energy. It is a way of using energy more productively — which, in practice, means using more of it. No country in history has reduced its aggregate energy consumption through efficiency gains while maintaining or growing its economy. Not one. The idea that efficiency can substitute for supply is not supported by a single empirical example anywhere on earth. It is an article of faith dressed as engineering.

The Hydrogen Mirage

Hydrogen is the most abundant element in the universe. It is also the most seductive distraction in energy policy, because it is not a fuel at all. It is a way of storing and moving energy that has already been generated — and it loses most of it in the process.

Hydrogen is not an energy source — there are no hydrogen wells. Every kilogram of hydrogen must be *manufactured* — by splitting water with electricity, or by stripping it from natural gas. It is an energy carrier: a way of moving energy from one place to another, with losses at every step.

The losses are not modest. Start with renewable electricity — which, as Part IV showed, has already consumed most of its own energy output just being built. Use it to split water in an electrolyser: you lose another 25–35% of what remains. Compress the hydrogen for storage: you lose another 10–15%. Convert it back to electricity through a fuel cell when you need it: you lose another 40–50%. The round-trip efficiency of the full chain — electricity in, hydrogen, electricity out — is roughly 30–40% [19]. For every three units of renewable electricity you feed into the system, you get roughly one back. The other two are waste heat.

Compare this with a lithium-ion battery, which returns 85–95% of what you put in. Hydrogen does not solve the storage problem. It makes it three times worse.

And the scale required is staggering. The world currently produces about 95 million tonnes of hydrogen per year. Virtually all of it — roughly 95% — is made from natural gas and coal [20]. To produce the same quantity from electrolysis using renewable electricity would require approximately 3,600 TWh of electricity per year — roughly the entire annual electricity generation of the European Union. That is before any *new* uses for hydrogen: storage, transport, industrial heat. Just to replace what we already make from fossil fuels would require doubling Europe's electricity system and dedicating the entirety of the new capacity to hydrogen.

There is also the matter of the infrastructure that does not exist. Hydrogen is the smallest molecule in nature. It leaks through seals, valves, and welds that are perfectly tight for natural gas. It diffuses into the crystal structure of steel, embrittling it over time — weakening pipelines, pressure vessels, and turbine components in ways that are difficult to detect and expensive to prevent. You cannot simply repurpose the existing gas grid. You would need to build a new one, from scratch, out of materials resistant to hydrogen attack, at a cost no government has seriously estimated — because no government has seriously tried. Oh, and high-pressure hydrogen can ignite spontaneously when it escapes: the shock wave from a rupture is enough to light it.

The hydrogen economy, in short, takes expensive renewable electricity, throws away two thirds of it, stores the remainder in a gas that destroys its own containers, and calls the result clean energy. It does not solve the intermittency problem. It hides the cost.

The Decoupling Delusion

Every net-zero plan on earth rests on an assumption so central that it is rarely stated aloud: that the economy can keep growing while using less energy. This is called decoupling — the idea that GDP and energy consumption, having risen together for the entire history of industrial civilisation, can now be made to go in opposite directions. Green growth. More from less.

The evidence for it is an accounting trick.

When Britain, for example, claims that its carbon emissions have fallen since 1990, it is counting only what is burned *within* its borders. It is not counting the energy embodied in the steel, cement, electronics, clothing, and manufactured goods it imports — predominantly from China, where the coal is actually burned. The Office for National Statistics found that by 2007, the United Kingdom's consumption-based emissions were 37% higher than its territorial emissions [21]. The country had not decoupled. It had *offshored*.

This is not a minor discrepancy. Wiedmann and colleagues, analysing the material footprint of 186 countries, found that the resources consumed by wealthy nations through trade were roughly three times larger than the physical quantity of goods crossing their borders [22]. Their conclusion was blunt: apparent decoupling in advanced economies was smaller than reported, or nonexistent.

At the global level, the picture is unambiguous. World primary energy consumption has risen every year for which records exist, barring brief dips during wars and recessions. In 2024, it rose by 2.2% — faster than the average of the previous decade [23]. No amount of reclassifying British GDP from manufacturing to services changes the fact that the *world* is using more energy, not less, to produce more output, not less. The services economy has not dematerialised economic activity. It has relocated it.

The deepest objection to decoupling is not statistical but thermodynamic. GDP measures economic activity. Economic activity is physical transformation — mining, smelting, building, growing, cooking, transporting, heating, computing. Every one of those verbs describes an energy conversion. A hospital consumes energy. A data centre consumes energy. A university consumes energy. A lawyer's office is heated, lit, cleaned, and supplied with paper, coffee, electronics, and human beings who ate breakfast — all of which required energy to produce and deliver. The "weightless economy" weighs exactly as much as the economy. It is the economy.

The most comprehensive review of the evidence — 835 empirical studies, analysed by Haberl and colleagues — concluded that the only countries to have achieved sustained absolute reductions in energy use or emissions were those that had experienced economic crisis [24]. Not green policy. Not innovation. Recession. When GDP falls, energy use falls. When GDP grows, energy use grows. The relationship has not been broken. It has been hidden behind a shipping container from Shenzhen.

The escape hatches are closed. What remains is the question of how to pay for net-zero's astronomical costs, and what destroying an energy system does to a financial system.

Part VI

Energy and Your Money

In which we discover that a £10 note is a claim on a future quantity of energy, and that printing more money does not create more energy.

Parts I to V described a physical system: what energy is, what is happening to its supply, why renewables cannot replace it, and why the proposed escape hatches do not work. This part follows the consequences into the economy, because the economy is not a separate thing. It is the physical system, counted in money.

Three chapters follow. The first argues that money is not wealth but a claim on energy, and that the dominant school of economics has failed to understand this. The second examines the policy that proposes to print money to finance an energy transition, and finds it circular. The third asks what all of this means for your future.

The Energy Token

A ten-pound note does not contain value. It is a *promise* that somewhere in the economy, someone will burn energy to transform raw materials into something you want — a loaf of bread, a hospital visit, an hour of heating. Every transaction in a modern economy is, at bottom, a claim on a future act of energy conversion. Money is the token. Energy is the thing.

This is literal, not figurative. The bread exists because a combine harvester burned diesel, a mill burned gas, an oven burned electricity generated from gas or coal. Remove the energy and the bread does not exist. The money to buy it becomes a claim on nothing — a piece of paper, or a number on a screen, that refers to something that can no longer be produced.

Neoclassical economics† does not see it this way. Its models contain no concept of energy gradient, energy density, or thermodynamic constraint. Energy appears as just another commodity — interchangeable with labour, capital, or technology. If one input becomes scarce, the model assumes the others will substitute.

This is the assumption on which the entire modern financial system is built: that economic growth can continue regardless of what happens to the energy supply, because human ingenuity will always find a way around physical constraints. Need energy? Just make some.

This assumption is energy illiterate, and Parts I to III of this book have shown why. Everything we call civilisation — every city, every factory, every hospital, every pension — has been built on a one-time endowment of fossil sunlight[†] that took hundreds of millions of years to accumulate. That energy is not a substitutable input. It is the master input — the one without which no other input functions. Labour without energy is manual labour. Capital equipment without energy is scrap metal. Technology without energy is just an idea.

The implications for money are immediate. Since the economy is, at root, a system for converting energy into goods and services, then the money supply must bear some relationship to the energy supply. When the two move together — which it has for the last 100 years — money retains its meaning. When they diverge — when the money supply grows while the energy supply contracts — each unit of money claims a smaller share of a shrinking pool of real goods. The name for this is inflation[†], but the cause is not monetary. It is thermodynamic.

Funny Money

We saw earlier that McKinsey estimates the capital cost of a net-zero transition at $275 trillion — roughly $9.2

trillion a year for three decades. No government on earth can raise that sum from taxation. So where does the money come from?

There is a school of thought that says the question does not matter, because governments that issue their own currency can never run out of money. This is Modern Monetary Theory†, and its core claim is simple: a sovereign government that borrows in its own currency cannot go bankrupt, because it can always create more currency to meet its obligations. Idle resources — unemployed workers, unused factories — can be mobilised simply by spending new money into existence. The only constraint is inflation, and inflation can be managed by government policy. The logic is seductive, and it has become the implausible intellectual foundation of net zero financing. Not one country has explained how it intends to pay for the energy transition. The unspoken answer is: we will print the money.

The error is in the phrase "idle resources." A factory is not idle in the way a banknote in a drawer is idle. A factory is a machine for converting energy into goods. Without energy, the factory is not an idle resource. It is an inert object — a large, expensive building full of metal that does nothing. An unemployed worker is not an idle resource in the relevant sense either. She is a person who can convert food energy into physical or mental labour. But the output of that labour depends entirely on the energy-intensive tools, transport, and systems that surround her. In a high-energy economy, one worker with a digger moves a thousand tons of earth a day. In a low-energy economy, the same worker with a shovel moves ten. The worker has not changed. The energy available to her has. MMT assumes that money can mobilise resources. But resources are mobilised by energy, and money is merely the accounting system that tracks the results.

The circularity is devastating. The net zero programme proposes to spend trillions of new money — printed, borrowed, or conjured from sovereign monetary authority — to build a new energy system. But the new energy system, as Parts I to III have shown, delivers less net energy than the one it replaces. The money is therefore a claim on an energy supply that is *shrinking* as a direct consequence of the programme the money is financing. You are borrowing against future economic output to build a system that *reduces* future economic output. Every pound printed to finance the transition dilutes the energy backing of every pound already in circulation. This is not a theoretical risk. It is an arithmetic certainty.

This has happened many times before. When 1930′s Germany — the Weimar Republic — printed money to meet obligations it could not fund from real output, the result was not prosperity. It was the destruction of the currency, and with it the savings, the pensions, and the livelihoods of an entire nation. The mechanism is always the same: the supply of money grows faster than the supply of real goods and services — which is to say, faster than the supply of transformed energy — and prices rise until the currency ceases to function as a store of value. The difference between Weimar and the net zero programme is that Weimar was attempting to pay war reparations it could not afford. Net zero is *deliberately dismantling* the energy system that gives the currency its meaning, while printing money to do so. It is Weimar with intent.

There is a simpler way to say this. You cannot print energy. You cannot legislate energy. You cannot vote for energy. You can only extract it from physical reality according to the laws described in this book, and if your energy policy violates those laws, no quantity of money — however cleverly created — will save you from the consequences.

The Promise

If the previous chapters seemed abstract, this one is not. It is about your retirement, and whether you will have one.

Every pension system in the world — state or private, funded or pay-as-you-go — is a claim on future economic output. There is no vault of goods with your name on it. When you retire, your income depends on the economy's ability to continue producing real goods and services for the rest of your life. That ability depends on energy. Contract the energy supply, and the economy contracts with it. The promise remains. The capacity to honour it does not.

A private pension is no safer. Pension funds invest in equities, bonds, and property — all of which depend on economic growth for their returns. When the economy contracts, asset prices fall. There is no asset class that escapes, because every asset class is, ultimately, a claim on the output of the energy system.

The honest name for this is not an energy transition. It is a default on every promise made to every person who expected to retire in comfort.

Part VII

Forging a New Realism

In which we set aside comfortable fictions and ask what an honest energy policy would actually look like.

If you have read this far, you now know more about the physics of energy than most of the people making energy policy. That is not flattery. It is an indictment.

You know that every successful energy transition in history moved up the density ladder. You know that the proposed transition moves down it. You know that the industrial metabolism requires hydrocarbons as feedstock, not just fuel. You know that the fossil inheritance is depleting, that the escape hatches do not work, and that printing money cannot repeal the laws of thermodynamics. The question is no longer "what is wrong?" The question is "what do we do?"

Two things follow from the physics. The first is that there exists exactly one proven technology capable of moving civilisation up the energy ladder: nuclear power. The second is that an honest energy policy must be built on what the physics permits, not on what the politics would prefer. The next chapter examines the first. The chapter after it proposes the second.

The Nuclear Question

This book has argued that every successful energy transition in history moved in the same direction: toward steeper gradients, denser fuels, and higher power density per unit of land. Wood to coal. Coal to oil. Oil to — what?

The physics answers the question before the politics gets involved. Nuclear fission releases energy by splitting atoms. The energy density of uranium is roughly two million times that of coal and three million times that of wood. A single fuel pellet the size of a fingertip contains as much energy as a tonne of coal, three barrels of oil, or seventeen thousand cubic feet of natural gas. The power density of a nuclear plant — roughly 1,000 watts per square metre of land — matches gas and exceeds every renewable source by two to three orders of magnitude. The gradient is ferocious: reactor temperatures of 300–1,000°C depending on design, sustained continuously, rain or shine, day and night.

By every measure established in Part I of this book, nuclear is the next rung on the ladder. It is the only energy source available to humanity that is denser, more concentrated, and more reliable than the fossil fuels it would replace. The numbers are not ambiguous.

And the fuel supply is vast. Known uranium reserves, using current reactor technology, could power global civilisation for several decades. With breeder reactors — which convert abundant uranium-238 into fissile plutonium — the supply extends to thousands of years. With thorium, which is three times more abundant than uranium, it extends further still. Unlike oil, unlike gas, unlike coal, the nuclear fuel supply is not depleting on any timescale that matters to human civilisation.

So why are we not building it?

The honest answer is that nuclear power was defeated not by physics but by politics. Beginning in the 1970s, a sustained and effective campaign — funded in part, it is now acknowledged, by fossil fuel interests, and amplified by environmental organisations whose fundraising depended on public fear — succeeded in making nuclear power culturally unacceptable across much of the Western world. The campaign exploited three events: Three Mile Island in 1979, Chernobyl in 1986, and Fukushima in 2011. Each was real. None was what it was claimed to be.

Three Mile Island killed nobody. The partial meltdown was contained by the reactor's safety systems — which is to say, the engineering worked. Chernobyl was a Soviet-era reactor of a design that no Western country has ever built or would ever license, operated in violation of its own safety procedures during an unauthorised experiment. Fukushima was struck by the largest earthquake in Japan's recorded history, followed by a tsunami that killed eighteen thousand people. The reactor meltdown, over the following months, killed one person from radiation exposure. The evacuation — ordered in panic and widely regarded as disproportionate — killed over two thousand, mostly elderly people displaced from their homes.

Compare this with the toll of the energy sources that nuclear was prevented from replacing. Coal-fired power generation kills roughly 800,000 people a year through air pollution. Hydroelectric dam failures have killed hundreds of thousands. Even rooftop solar, per unit of energy produced, has a higher death rate from installation falls than nuclear has from all causes — including Chernobyl and Fukushima. Nuclear power is, by any objective measure, the safest form of energy generation ever invented. It was not rejected because it was dangerous. It was rejected because it was feared, and fear is easier to campaign on than arithmetic.

The result is a generation of lost capacity. In the 1970s, France built its nuclear fleet in fifteen years and today generates roughly 70% of its electricity from nuclear at among the lowest carbon emissions and electricity prices in Europe. Had other Western nations followed that path, the carbon emissions that now dominate the policy debate would already have been reduced by a quantity that dwarfs everything wind and solar have achieved in the decades since.

The cost argument against nuclear is real but misunderstood. Nuclear plants are expensive to build. They are cheap to run. The high construction costs are overwhelmingly a consequence of regulatory complexity that has compounded over decades — not because the reactors are inherently dangerous, but because the regulatory framework was designed, under political pressure, to make construction as slow and expensive as possible. Countries that have streamlined their regulatory process — South Korea, China — build nuclear plants on time and on budget. The West's inability to do so is a political choice, not a physical constraint.

A new generation of reactor designs — small modular reactors, molten salt reactors, high-temperature gas reactors — promises to reduce construction times, lower capital costs, and improve safety margins that are already the best in the energy industry. These are not speculative. Several are in advanced licensing or under construction. They represent the first genuinely new nuclear technology in decades, and they arrive at precisely the moment the physics demands them.

But time matters. A nuclear plant takes seven to fifteen years to build, depending on the regulatory environment. The fossil inheritance, as Part III showed, is depleting on a similar timescale. Every year of delay is a year of depleting the bridge fuel needed to sustain civilisation while the new system is built. The window is not infinite. If the remaining hydrocarbon surplus is squandered on energy systems that cannot sustain themselves — the renewables treadmill of Part IV — there may not be enough left to build the one system that can.

Nuclear power is not a complete answer. It generates electricity, and electricity, as Part II showed, cannot replace hydrocarbons as a chemical feedstock. Steel, cement, ammonia, and plastics will continue to require fossil inputs for the foreseeable future. What nuclear can do is eliminate the use of fossil fuels for electricity generation — currently the single largest use — freeing the remaining hydrocarbons for the irreplaceable industrial processes that only they can serve. It buys time, and time is the one resource that is running out fastest.

The question is not whether nuclear power is perfect. It is whether it is better than the alternative. The alternative, as this book has shown, is a depleting fossil inheritance with no viable replacement — a slow-motion energy crisis disguised as a green transition. Against that, nuclear is not merely better. It is the only option consistent with the physics.

A Blueprint

Everything in this book reduces to a single observation: energy policy must obey the laws of physics. If it does, options exist. If it does not, no amount of money, legislation, or good intention will prevent the consequences. What follows is a seven-point blueprint for an energy policy grounded in physical reality. Each point follows directly from the argument that precedes it. None requires a technological miracle. All require political honesty.

The specifics here are written for the United Kingdom, but the physics is universal. Any advanced industrial economy faces the same constraints — depletion, density, thermodynamics — and the same framework applies. The details of domestic geology and regulation will differ; the logic does not.

1. Accept physical reality

The thermodynamic floor described in Part I is not a policy position. It is the ground on which all policy must stand. Energy gradient, energy density, and power density are measurements, not opinions. Any proposal that violates them will fail, regardless of the political will behind it. The first act of an honest energy policy is to require that every energy investment be evaluated against these three measures — and to reject any that falls below the threshold at which industrial civilisation can sustain itself. No more funding for technologies on the wrong side of the energy cliff. No more targets set by politicians who do not understand the units.

2. Protect the remaining inheritance

Part III showed that the fossil endowment is finite and depleting faster than any official projection admits. Oil has perhaps fourteen years of proven reserves at current production. This is not a resource to be squandered on an energy system that returns less energy than it consumes. The remaining hydrocarbons are bridge fuel — the energy needed to build whatever comes next. Every barrel burned to manufacture a wind turbine that will be scrapped in twenty-five years and rebuilt from scratch is a barrel unavailable for the transition that might actually work. Protecting the inheritance means spending it on systems that move civilisation *up* the density ladder, not down it.

3. Maximise domestic production

The geopolitical implications of energy depletion are severe. A nation that depends on imported energy is a nation at the mercy of its suppliers. The United Kingdom sits on substantial remaining reserves of oil, gas, and — critically — nuclear fuel capability.[11] An honest energy policy would maximise domestic production of all three, not to prolong the fossil era indefinitely, but to ensure that the bridge fuel needed for the transition is under sovereign control. This means streamlining the regulatory process for onshore and offshore development, providing fiscal incentives for extending the productive life of existing assets, and treating domestic

[11]The UK does not mine uranium, but it has the full fuel cycle: enrichment (Urenco, Capenhurst) and fuel fabrication (Westinghouse, Springfields). The strategically significant capability is turning imported uranium into reactor fuel, and the UK is one of very few Western nations that can do this end to end.

energy production as what it is: a matter of national security.

4. Fast-track nuclear

The previous chapter made the physics case. Nuclear fission is the only proven technology that moves up the density ladder. The policy case is equally clear: the regulatory framework that has made nuclear prohibitively slow and expensive in the West is a political artefact, not a physical necessity. Countries that have reformed their regulatory process build reactors on time and on budget. The United Kingdom should commit to a large-scale nuclear expansion programme, prioritising small modular reactors for speed of deployment and advanced designs for long-term capacity. The regulatory barriers that have delayed construction for decades should be dismantled — not the safety standards, but the procedural complexity that was designed to obstruct rather than protect.

5. Stop funding what cannot work

Parts IV and V demonstrated that the renewables programme, as currently conceived, cannot sustain an industrial civilisation. Its net energy return is too low, its material demands are too high, its storage requirements are physically unachievable, and its claimed escape hatches — efficiency, hydrogen, decoupling — do not survive contact with the evidence. An honest policy would stop pretending otherwise. This means ending public subsidies and support mechanisms for large-scale wind and solar deployment, revoking the planning privileges that override local opposition, and removing the levies and surcharges that load the cost onto household energy bills. The savings should be redirected to nuclear and to the domestic hydrocarbon production that bridges the gap.

6. Anchor money to energy

Part VI argued that money is a claim on energy and that printing money while contracting the energy supply is a recipe for currency collapse. The logical conclusion is that a sound monetary policy must be anchored to the energy supply — not abstractly, but explicitly. Just as the gold standard once constrained governments from debasing their currency, an energy standard would constrain them from issuing claims on energy that does not exist. The details of such a mechanism are beyond the scope of a pocket guide, but the principle is straightforward: the money supply should grow no faster than the energy supply. Any government that prints money to finance an energy transition that *reduces* the energy supply is debasing its currency by definition. Recognising this is the first step toward preventing it.

7. Trust the public with the truth

This book was written on the conviction that energy physics is not difficult — it is merely unfamiliar. You have now read it. You understand gradient, density, and power density. You understand why the industrial metabolism cannot be electrified. You understand the depletion curve, the energy cliff, and the storage chasm. You are equipped to evaluate any energy policy proposal against the laws of physics, and to recognise when those laws are being ignored.

That is not a small thing. Democratic accountability depends on an informed public. An energy policy that cannot survive public scrutiny deserves to fail. An energy policy that *can* survive it — one built on physics rather than wishful thinking — is the only kind worth having. The purpose of this book is to ensure that the scrutiny is competent.

Some contraction is unavoidable. The era of cheap, abundant fossil energy is ending whether we plan for it or not. The question is not whether living standards will adjust — they will — but whether the adjustment is a managed descent into a durable, lower-throughput civilisation powered by nuclear energy and husbanded hydrocarbons, or an unmanaged collapse into something much worse. Every year of delay, every billion spent on systems that cannot work, narrows the window for the first outcome and widens it for the second.

The physics is not negotiable. But the response to it is. That is what makes this a book about hope.

Glossary

Biophysical economics A school of economics that treats energy, not money, as the fundamental driver of economic activity. In this view, GDP is a downstream consequence of energy throughput, and the money supply must ultimately be anchored to the energy supply.

Bridge fuel The energy needed to sustain civilisation during an energy transition while the new system is being built. Every successful transition in history has required a large surplus of the current source and a denser replacement. The proposed transition violates both conditions.

Capacity factor The fraction of time an energy source actually produces power at its rated maximum. A gas plant might achieve 85–90%; a wind turbine typically manages 25–35%.

Energy carrier A means of moving energy from one place to another. Electricity is the most common energy carrier: it does not exist in nature but must be manufactured from a primary source. Hydrogen is another. Unlike a fuel, a carrier contains no energy of its own — it must be charged or produced, always at a conversion loss.

Energy density The amount of energy stored per unit of mass or volume, typically measured in megajoules per kilogram (MJ/kg). Diesel: 44 MJ/kg. Lithium-ion battery: 1 MJ/kg.

Energy transition A change in the primary energy source on which a society depends. Historical transitions — wood to coal, coal to oil, oil to nuclear — each moved to a denser, more concentrated source. The transition now proposed is unprecedented: it asks us to move in the opposite direction, from concentrated to diffuse.

Energy gradient The difference in energy concentration between a source and its surroundings. A steep gradient (e.g. a gas flame at 1,500°C in a 15°C room) means energy can do useful work. A shallow gradient (e.g. a swimming pool at 20°C) means it cannot.

Economic oil Oil that can be extracted at a price the economy can bear. The distinction between economic and uneconomic oil is the key to understanding peak oil: the planet contains vast quantities of hydrocarbons, but only the fraction extractable at a tolerable price sustains industrial civilisation. The rest is, for practical purposes, indistinguishable from oil that is not there at all.

EROEI Energy Return on Energy Invested. The ratio of energy delivered by a source to the energy required to build and operate it. A ratio below roughly 7:1 cannot sustain an industrial society.

Exergy The portion of energy that is available to do useful work, as distinct from the total energy present.

A swimming pool contains a great deal of energy but almost no exergy.

Fossil sunlight Hydrocarbons — coal, oil, and natural gas — understood as stored solar energy from hundreds of millions of years of photosynthesis, compressed and concentrated by geological time. A one-time endowment, not a renewable flow.

Fuel A store of energy that exists in nature and can be extracted and used. Coal, oil, natural gas, and uranium are fuels. Electricity and hydrogen are not — they are energy carriers that must be manufactured from fuels or other primary sources.

Hydrocarbon A molecule built from hydrogen and carbon atoms. Coal, oil, and natural gas are hydrocarbons. They serve industrial civilisation in two distinct roles: as a *fuel* (burned to release energy) and as a *feedstock* (consumed as a raw material in chemical processes such as steelmaking, fertiliser production, and plastics manufacturing). The second role cannot be replaced by electricity.

Inflation (thermodynamic) A rise in the general price level caused not by monetary policy alone but by a widening gap between the money supply and the energy available to produce real goods and services. In this view, printing money while contracting the energy supply is inherently inflationary.

Modern Monetary Theory (MMT) The claim that a government issuing its own currency can never run out of money, because it can always create more. MMT assumes that "idle resources" can be mobilised by spending new money into existence. It does not account for the energy required to mobilise those resources, and is the implausible intellectual foundation of net zero financing.

Neoclassical economics The dominant school of economics since the late 19th century. Its models treat the economy as a system of exchange between rational agents and assume that scarce inputs can always be substituted by other inputs. Energy, when it appears at all, is treated as an ordinary commodity rather than the master input on which all other inputs depend. This book argues that neoclassical economics is energy illiterate.

Jevons Paradox The observation, first made by William Stanley Jevons in 1865, that improving the efficiency of fuel use tends to *increase* total consumption rather than reduce it. Cheaper energy per unit of work makes people do more work. No country has ever reduced its aggregate energy consumption through efficiency gains alone.

Joule (J) The SI unit of energy. One joule is roughly the energy needed to lift a small apple one metre. A kilojoule (kJ) is 1,000 joules; a megajoule (MJ) is 1,000,000 joules — roughly the energy in a peanut butter sandwich.

Power The rate at which energy is converted or transferred, measured in watts. One watt is one joule per second.

Power density The rate of energy flow per unit of land area, measured in watts per square metre (W/m^2). Gas plant: 1,000 W/m^2. Solar farm: 20–30 W/m^2. Wind farm: 1–3 W/m^2.

Watt (W) The SI unit of power — one joule per second. A kilowatt (kW) is 1,000 watts; a megawatt (MW) is 1,000,000 watts. A typical UK home uses about 1 kW on average.

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About the Author

Richard Lyon is an electrical engineer, petroleum engineer, and energy economist. He began his career as a pilot in the Royal Air Force before spending over twenty five years in the oil and gas industry, holding senior operational and commercial roles in the UK, Norway, Azerbaijan, Congo, and Cameroon.

He holds a BEng in Electrical and Electronic Engineering, an MEng in Petroleum Engineering from Heriot-Watt University, and an MSc in Energy Economics with Distinction from the Centre for Energy, Petroleum and Mineral Law and Policy at Dundee. His master's research focused on quanifying the degree of optimism in institutional estimates of remaining oil reserves.

This book grew from a conviction, formed over three decades of producing, managing, and studying energy, that the gap between energy policy and physical reality has become dangerous — and that the public are perfectly able to acquire and apply the knowledge needed to challenge the policies being made in their name.

What Next?

This book is a starting point, not a conclusion. If you've read this far and you want to do something about it, here's how.

Join a growing community of people who are deepening their understanding of energy and thinking hard about solutions. I'm there, I hold regular conversations, and I'd like to meet you.

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You can't boil an egg in a swimming pool. There's plenty of energy in the pool — but it's too spread out to do anything useful. That single fact explains more about the state of energy policy than a thousand government reports.

In this short, sharp book, Richard Lyon — electrical engineer, petroleum engineer, energy economist, and former RAF pilot — strips the energy debate back to the physics. What he finds is alarming: the fossil fuels are running out, the proposed replacements can't do the job, and the people in charge don't understand the science well enough to know.

But this is not a counsel of despair. There is a way through — if we stop wasting what remains on systems that can't work and start building the one that can.

"When you've read it, you'll understand more about energy than most of the people making energy policy."