The Cleantech Revolution

It’s exponential, disruptive, and now

Kingsmill Bond

November, 2024

Executive Summary

- **The energy system is being transformed by the exponential forces of renewables, electrification, and efficiency.**
- **The orthodox view of slow change is wrong**. New clean technologies beat old fossil commodities because clean technologies' costs fall over time on learning curves, they are universal, and they grow quickly.
- **Exponential change has been remarkable in the past decade**. Cleantech costs have fallen by up to 80 percent, while investment is up nearly tenfold and solar generation has risen twelvefold. Electricity has become the largest source of useful energy, and the deep force of efficiency has reduced energy demand by a fifth.
- **Change is led by China**. Half the growth in cleantech is from China, but exponential growth is also happening in the OECD and across the Global South as Asia electrifies.
- **Red flags across the fossil fuel system**. New fossil electricity capacity peaked in 2010, oil and gas capex in 2014, and internal combustion engine (ICE) car sales in 2017. Fossil demand peaked for industry in 2014, for buildings in 2018, most likely for electricity in 2023, and will shortly peak in transport.
- **The drivers of growth are more powerful than the barriers**. Falling cleantech costs, the energy security of eternal renewables, Chinese leadership, and a race to the top will continue to overwhelm a fragile fossil fuel system which wastes two-thirds of its primary energy and fails to pay for its externality costs.
- **So exponential growth of cleantech will continue**. By 2030, we will be installing 1,000 GW of solar a year and selling 6,000 GWh of batteries a year, making possible the COP goal of tripling renewable capacity. Electrification rates will double to 0.5% a year, and efficiency gains will increase to over 3% a year.
- **The fossil fuel system faces inexorable decline**. Renewables will drive fossil fuels out of electricity generation, electrification will push fossils out of final energy, and efficiency will reduce fossil waste. Some 75% of fossil fuel demand is exposed to rapidly growing cleantech alternatives, so stranded assets are inevitable.
- **Wider implications of change**. The goals of the Paris Agreement are feasible, and the Global South will continue to leapfrog to cleantech.
- **This is the pivot decade.** When cleantech costs become irresistible, the renewable capacity is built, fossil fuel demand reaches the end of its plateau, and the transition is priced into markets.
- **Now is the time to act**. We need to build out renewables and electrify energy use, make good bets on small modular technologies, and harvest the enormous efficiency opportunity. The direction of change is inevitable, but the speed is up to us.

RMI

Index

Index

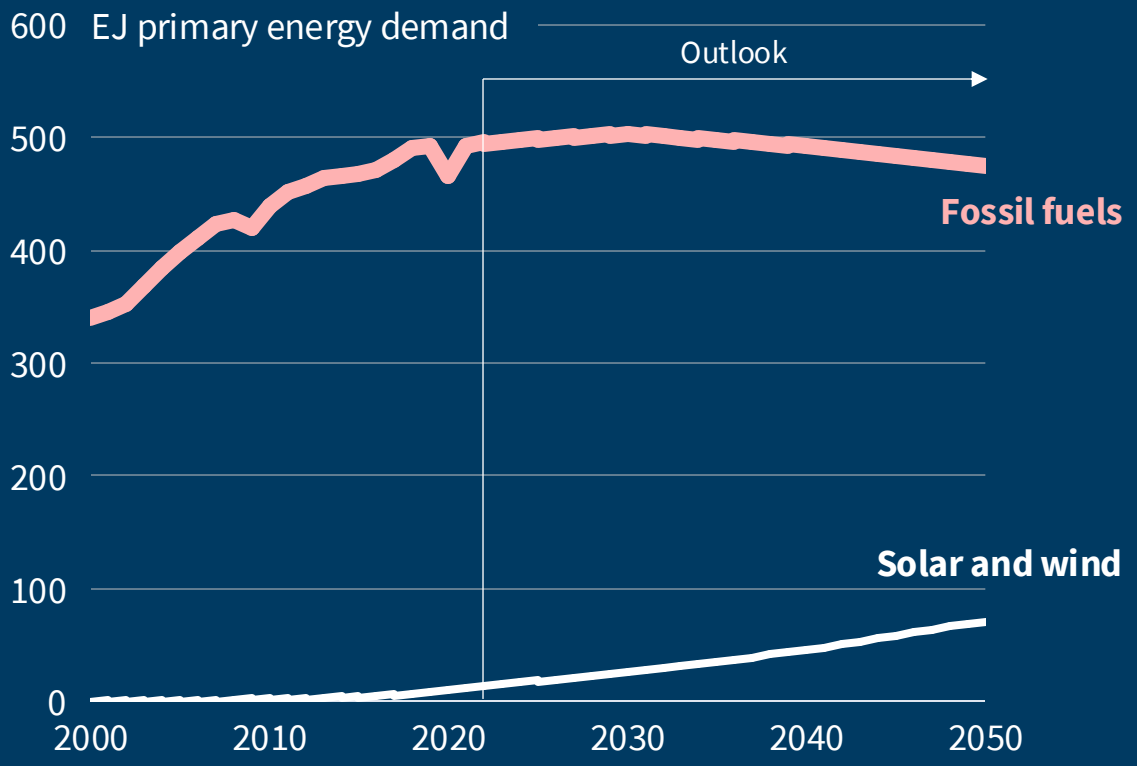
1 Introduction

- There are two main perspectives on the energy transition: the old incumbent view of business-as-usual; and the new insurgent view of exponential change.
- At heart this is the longstanding battle of commodities versus technologies. Design and technologies beat commodities because they enjoy learning curves and are limitless. So costs fall over time, and growth is exponential.
- New energy comes from manufactured, modular, scalable, clean technologies; old energy is from centralized, heavy, dirty commodities.
- Old energy forecasting has failed in the face of the new energy reality. Linear forecasts constrained by barriers to growth have consistently been overwhelmed by exponential change.
- There are three key levers in the energy transition: Renewables; Electrification; and Efficiency.

The two visions of the energy future

The **old commodities** narrative of business-as-usual: reducing fossil fuel demand will be slow, expensive, and painful

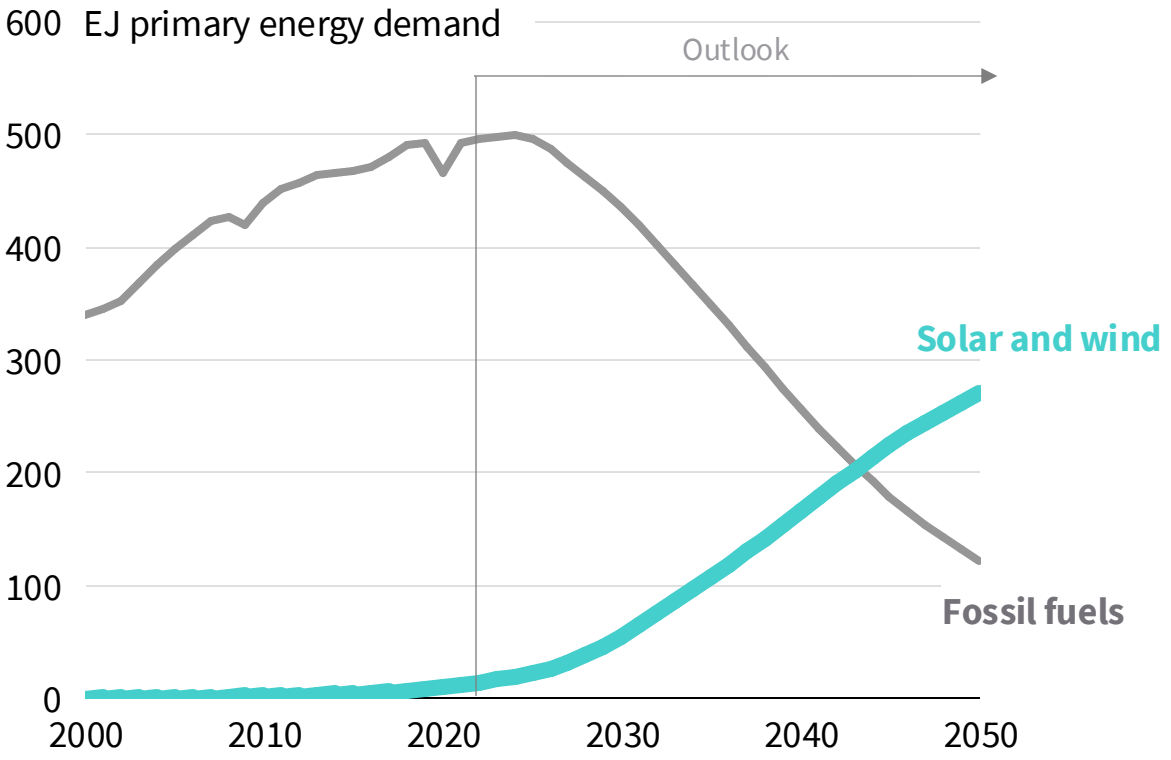
The old guard's energy outlook



Source: Exxon Mobil Global Outlook 2023.

The **new technology** narrative of exponential and beneficial change: a shift to a cheaper, faster, and distributed energy system

The new technology insurgent's energy outlook

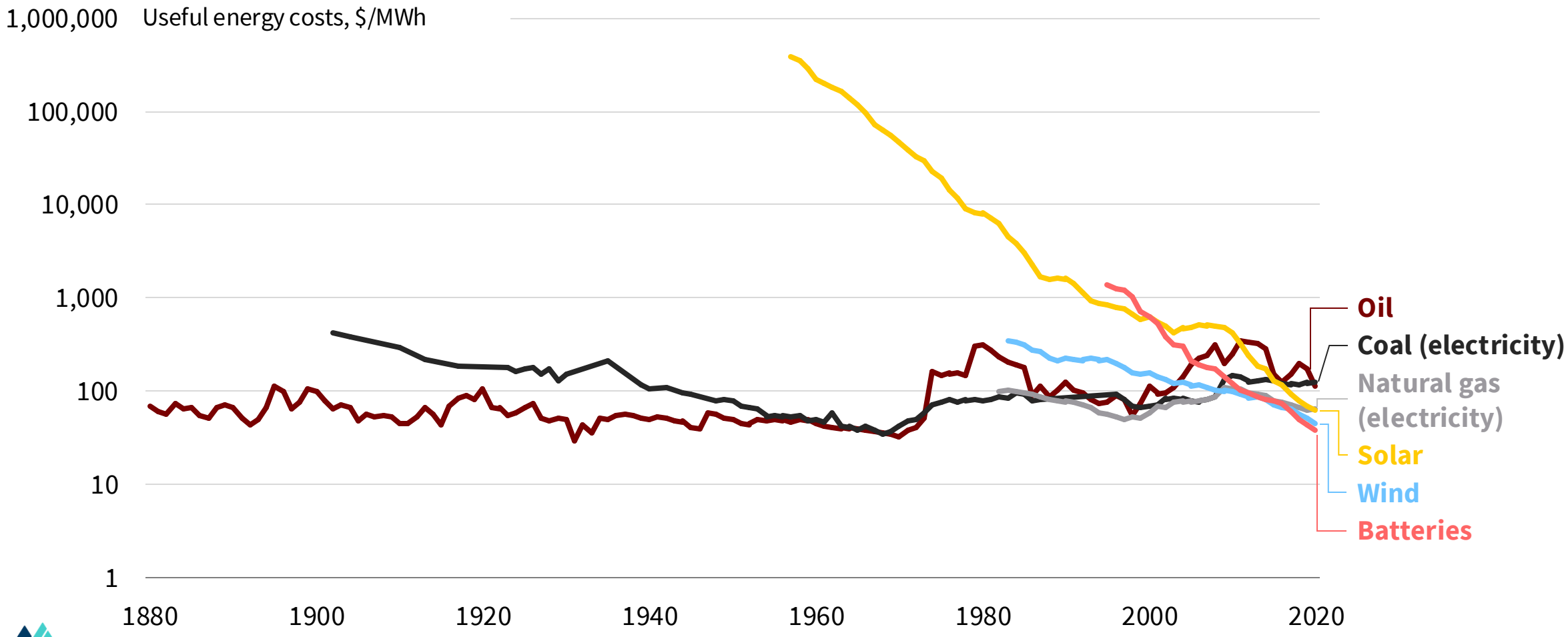


Source: Rystad Energy 1.6°C Scenario.

Technologies beat commodities on costs

Manufactured technologies (e.g., solar and wind) enjoy cost learning curves; (fossil) commodities don't

Historical costs of energy sources

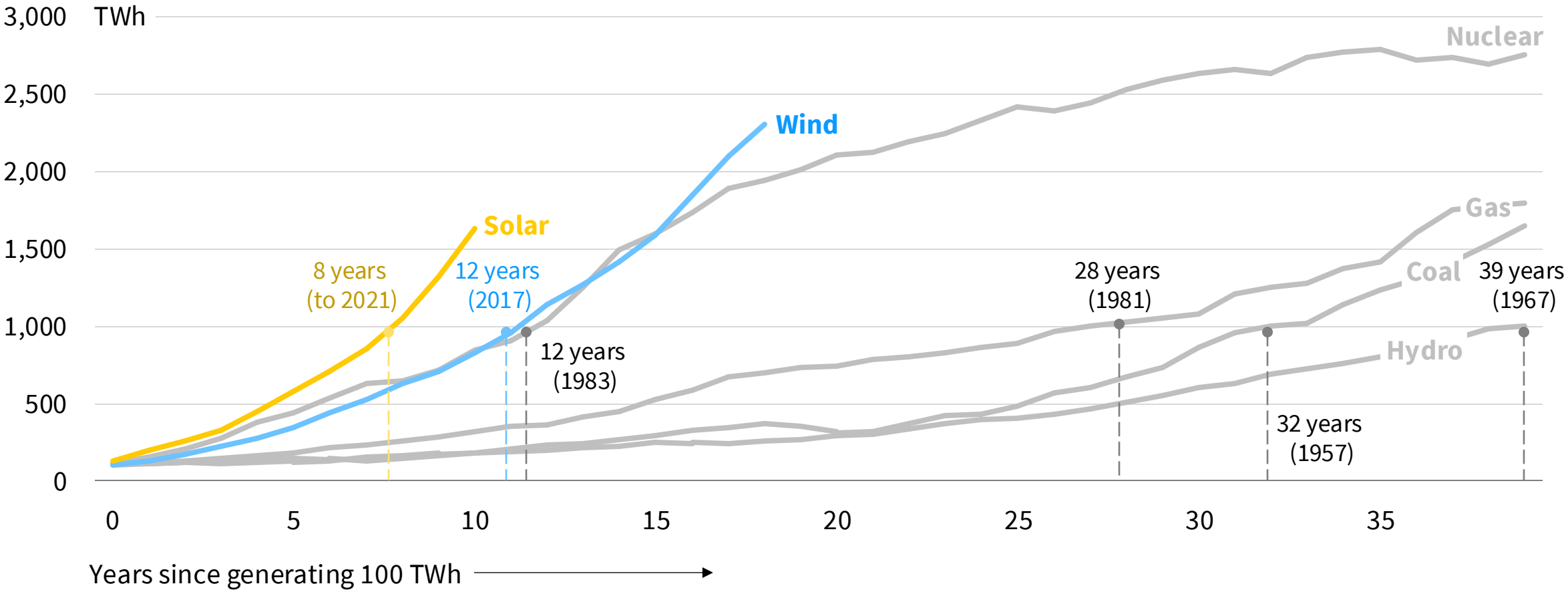


Source: Way et al. 2022. Individual fossil fuel technologies of course do have learning curves; but because of depletion and cartels, fossil fuel prices have not shown structural decline over time.

Technologies beat commodities on speed

Manufactured technologies grow fast; commodities grow slowly

Electricity generation after reaching 100 TWh



Source: Ember Global Electricity Review 2024; Wind and solar generation data from Ember annual electricity data, nuclear, gas, coal and hydro generation data from Pinto et al. (2023). This graphic is inspired by a chart from Shell featured in Nat Bullard's deck. In 2024, nuclear has a 10–15 year lead time.

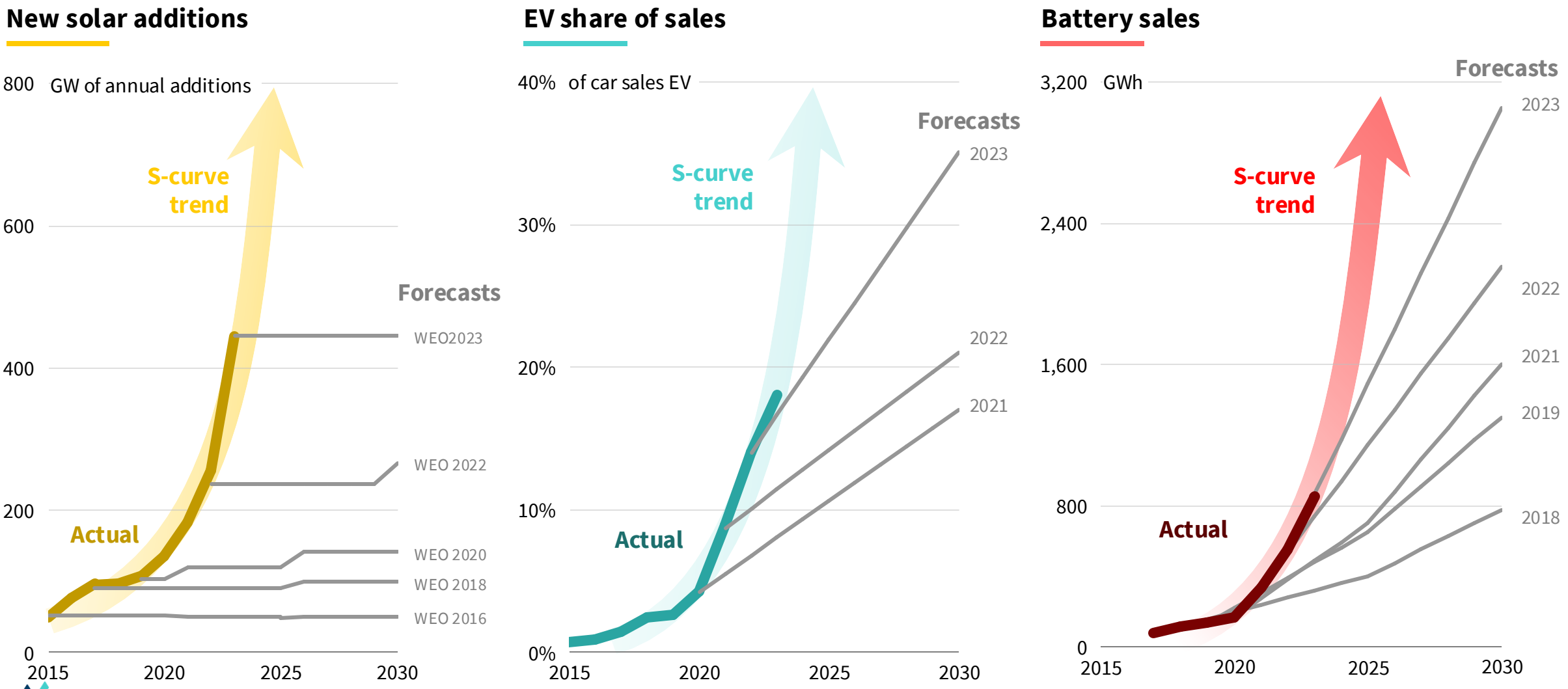
New energy is fundamentally different to old energy

THE AGE OF CARBON	THE AGE OF RENEWABLES
Finite	Eternal
Fiery, heavy molecules	Obedient, light electrons
Geographically concentrated	Available everywhere
Wasteful	Efficient
Continuous material flow	Circular
Analogue	Digital
Trillions of dollars of annual rents to oligarchs	No superprofits
Malthusian commodity-based system	Schumpeterian technology-based system
Concentrates power	Localizes and distributes power
Kills millions from air pollution	Saves millions from air pollution
Produced the greatest externality in history[1]	100 times lower impact on nature

1 Sir Nicholas Stern, "The greatest market failure the world has seen."
Source: RMI.

Incumbents have underestimated the speed of change

Even neutral actors modeled in **linear** terms. But change has been exponential

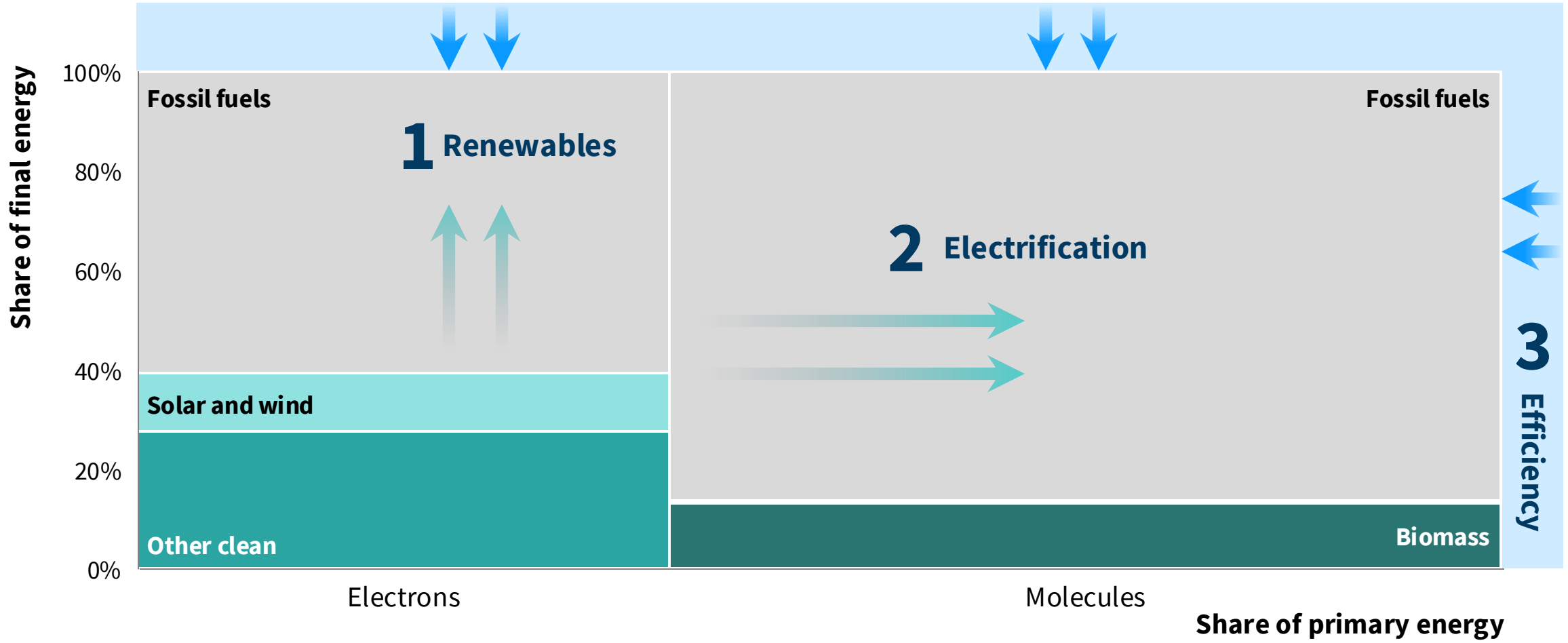


Source: BNEF (solar and battery actuals), IEA STEPS for WEO forecasts , RMI annotation.

There are three big levers of change

Renewables, electrification, and efficiency are rapidly transforming the energy system

Global energy demand in 2022



Source: IEA WEO 2023. The primary energy split is the amount of primary energy going to electricity (electrons) or other (molecules).

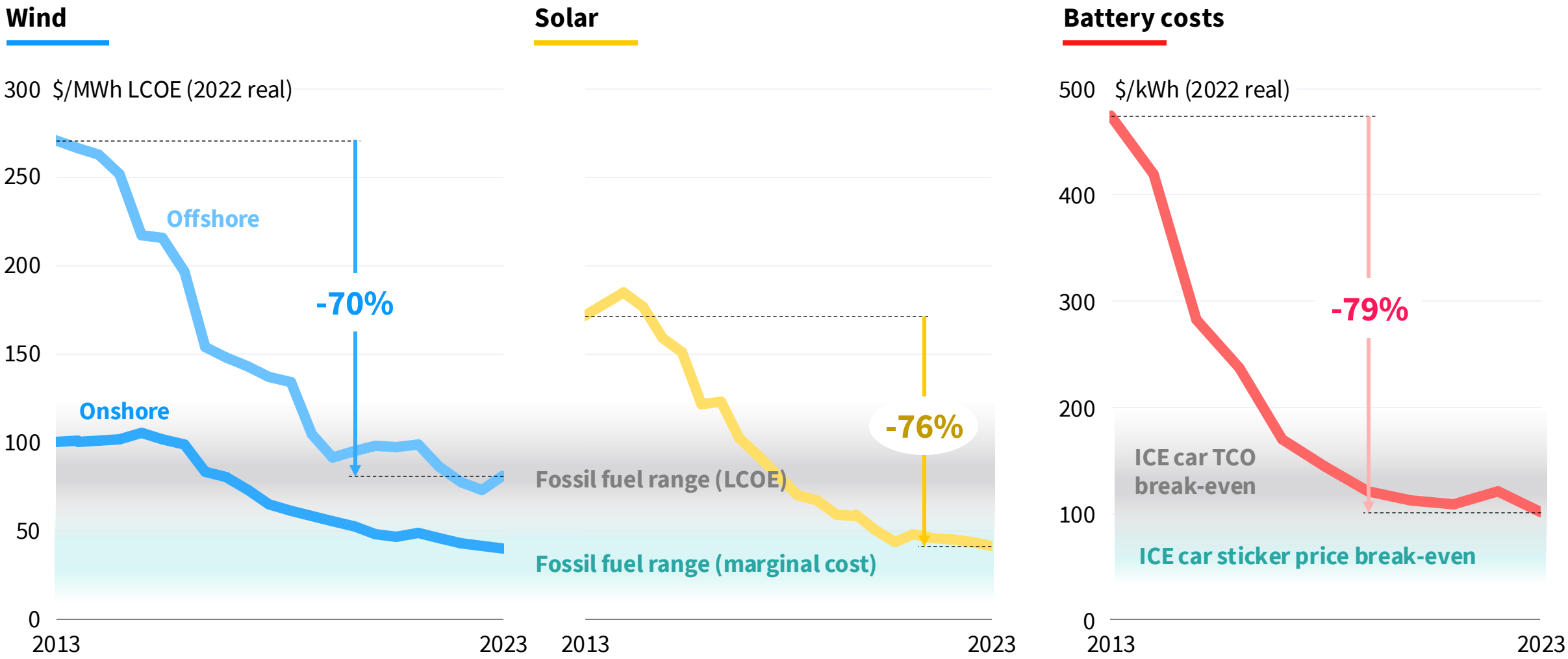
Index

2 Exponential growth so far

- There is clear evidence three drivers of changes are growing exponentially: renewables, electrification, and efficiency.
- Cleantech costs fall by around 20% for every doubling in deployment and have fallen by up to 80% in a decade.
- Capital is pouring into cleantech. Getting to the first trillion of annual investment took decades; the second trillion will take only 4 years.
- Solar generation is doubling every 2-3 years and battery storage every year. Solar is poised to deploy the largest amount of generation capacity, and batteries are about to overtake pumped hydro.
- The supply chain is already in place for enough solar and batteries for net zero.
- Electricity supply has been growing inexorably for a century and is now the largest supplier of useful energy.
- Efficiency is the deep force of the energy transition, saving one fifth of total demand over the last decade.
- China leads the exponential story and is poised to be the first major electrostate. Exponential change is happening in the OECD and across the Global South as Asia leapfrogs the OECD in electrification.

Cleantech costs have fallen rapidly

Clean technology costs fall by around 20% for every doubling of deployment — Wright's Law

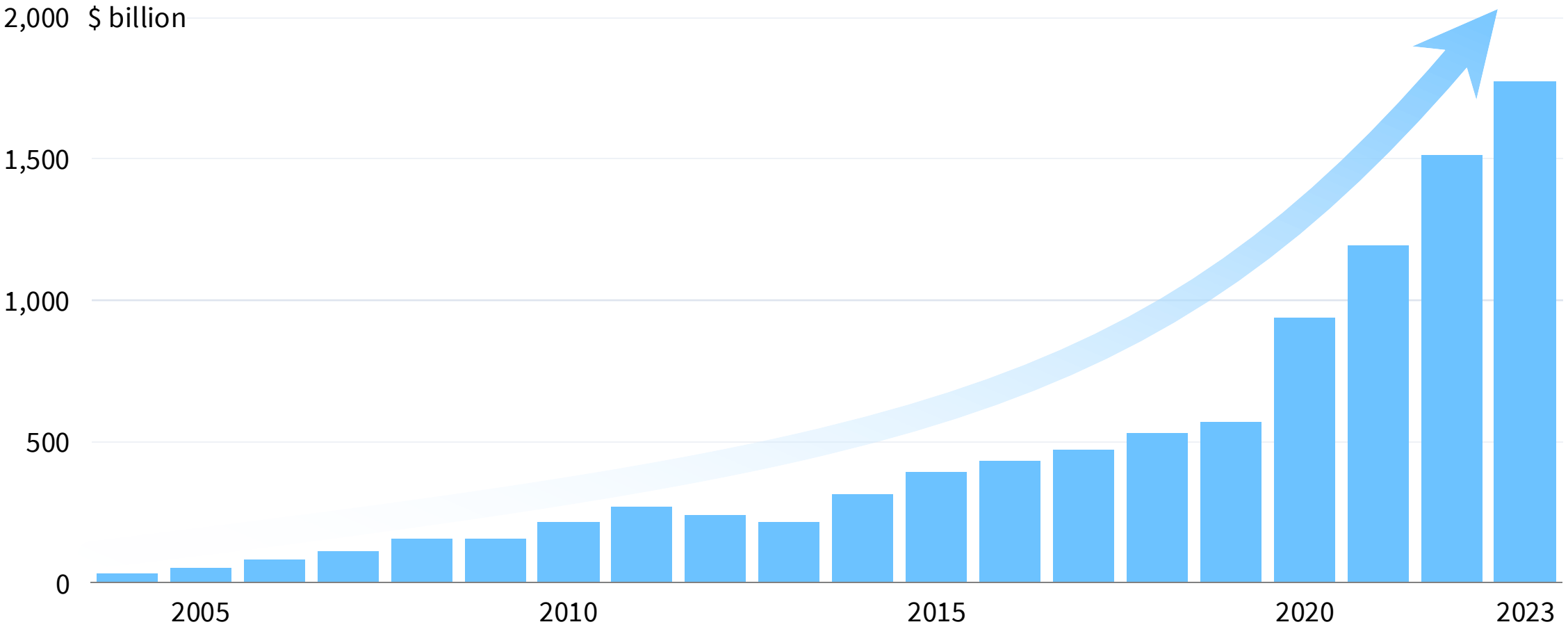


RMI *Source: BNEF, RMI ranges.*

Capital has poured into cleantech

The first cleantech trillion took decades; the second trillion will happen in four years

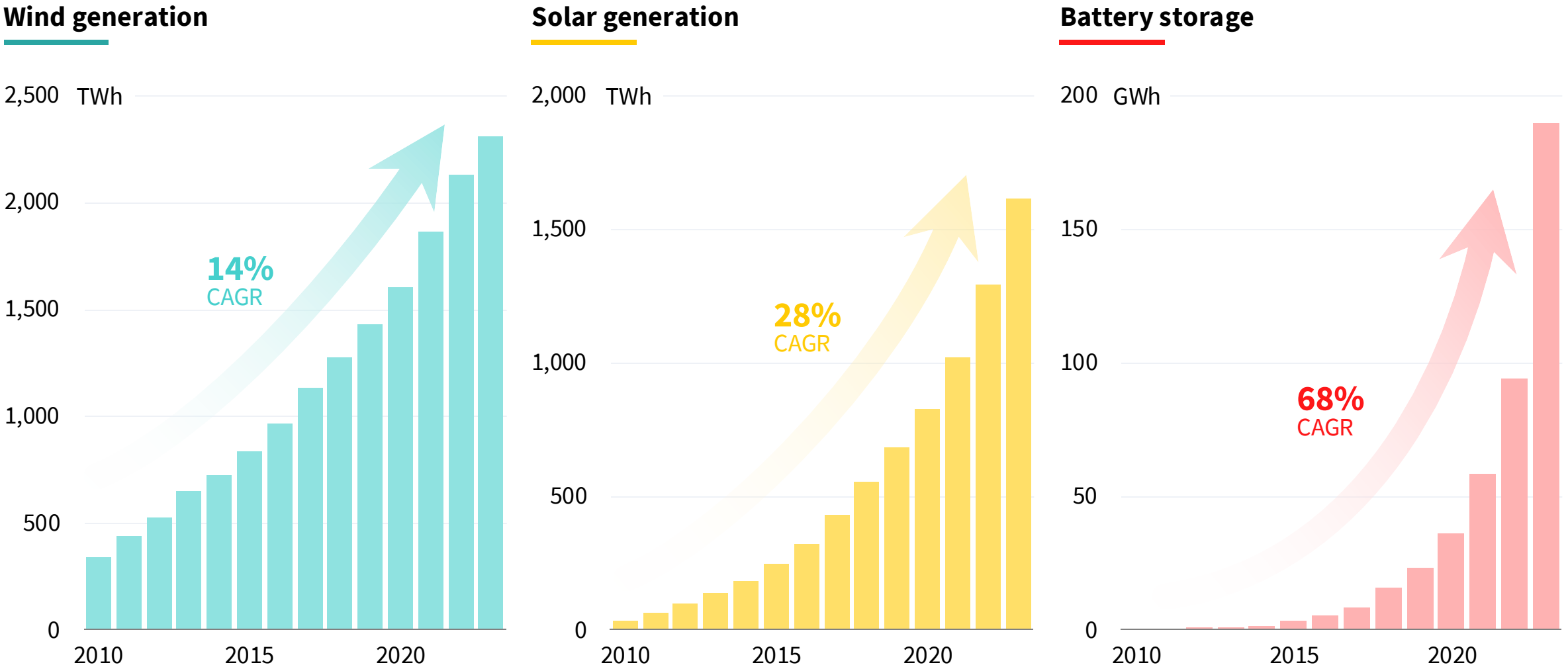
Cleantech investment



RMI Source: BNEF.

Leading to exponential growth in renewables

Global solar generation has been doubling every 2–3 years, and battery storage capacity every year

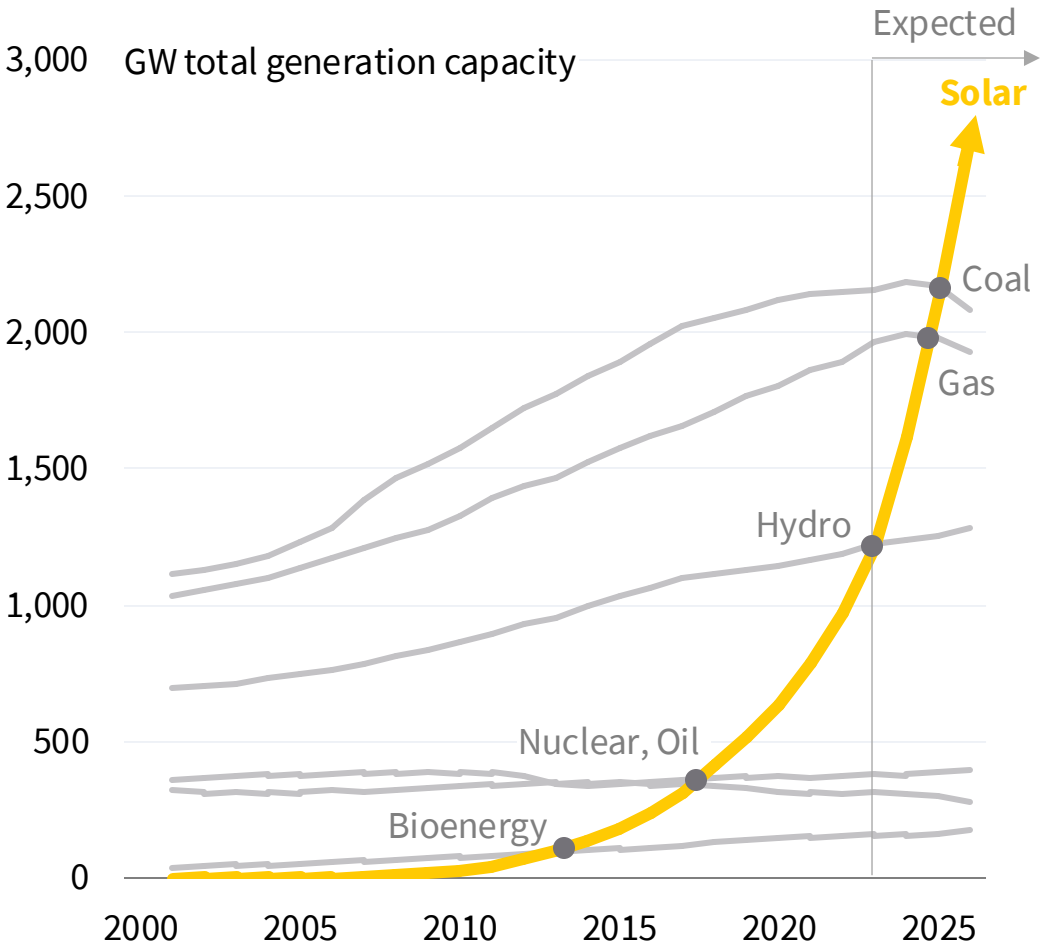


Source: IEA, BNEF; Note: CAGR is the compound annual growth rate between 2013 and 2023.

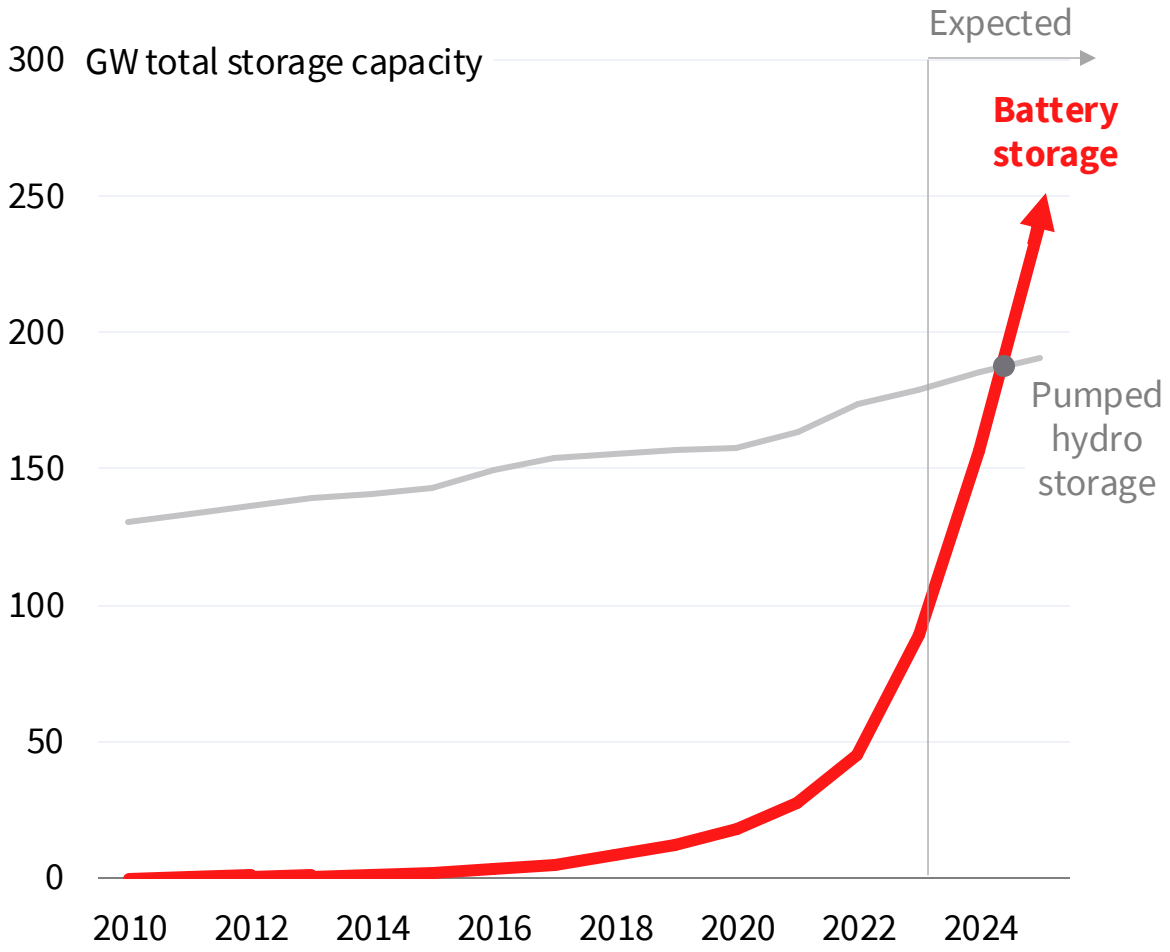
Solar and batteries are taking over

Solar will shortly overtake every other type of capacity, and battery storage will leapfrog pumped hydro

Solar



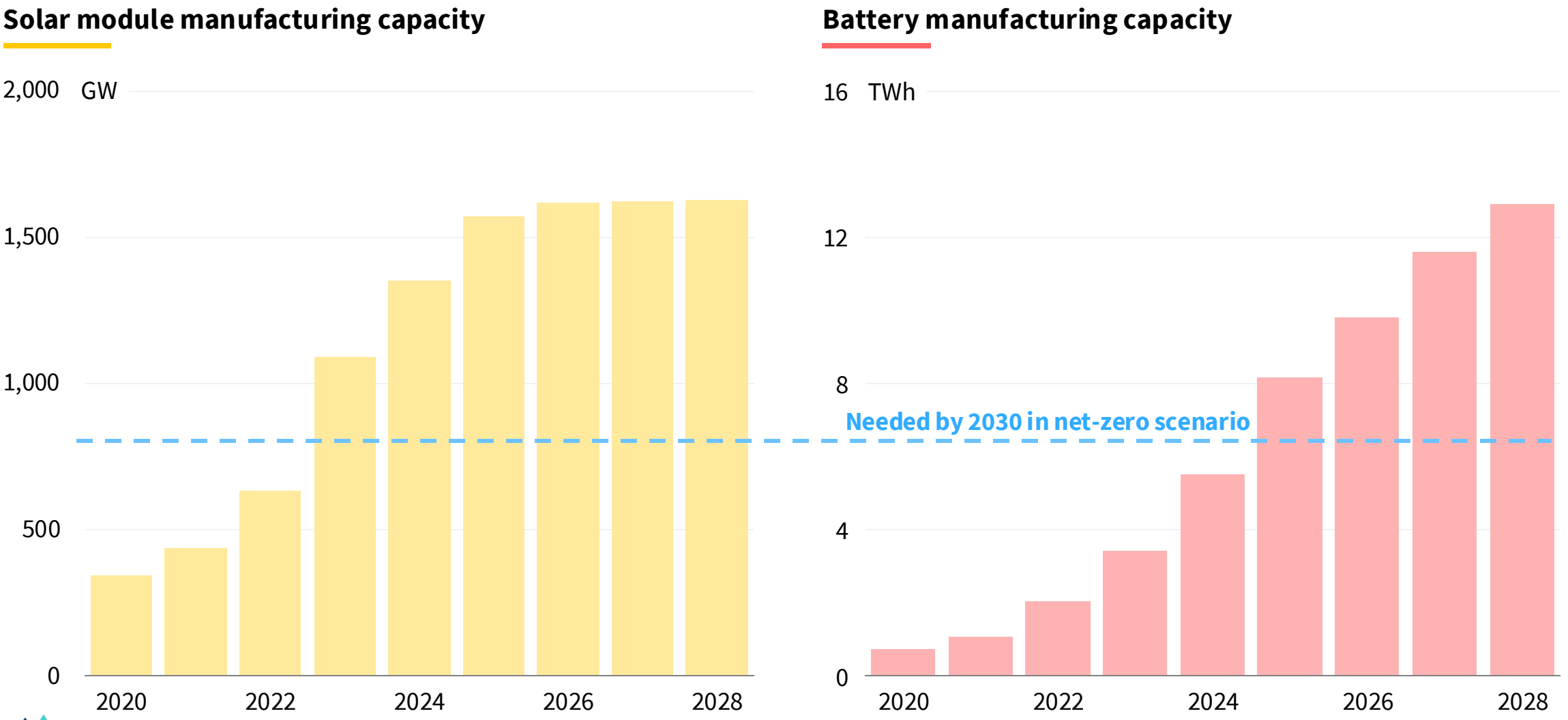
Batteries



RMI *Source: BNEF, IEA.*

The supply chain is in place

Companies already plan to construct more solar and battery capacity by 2030 than is needed to reach net zero

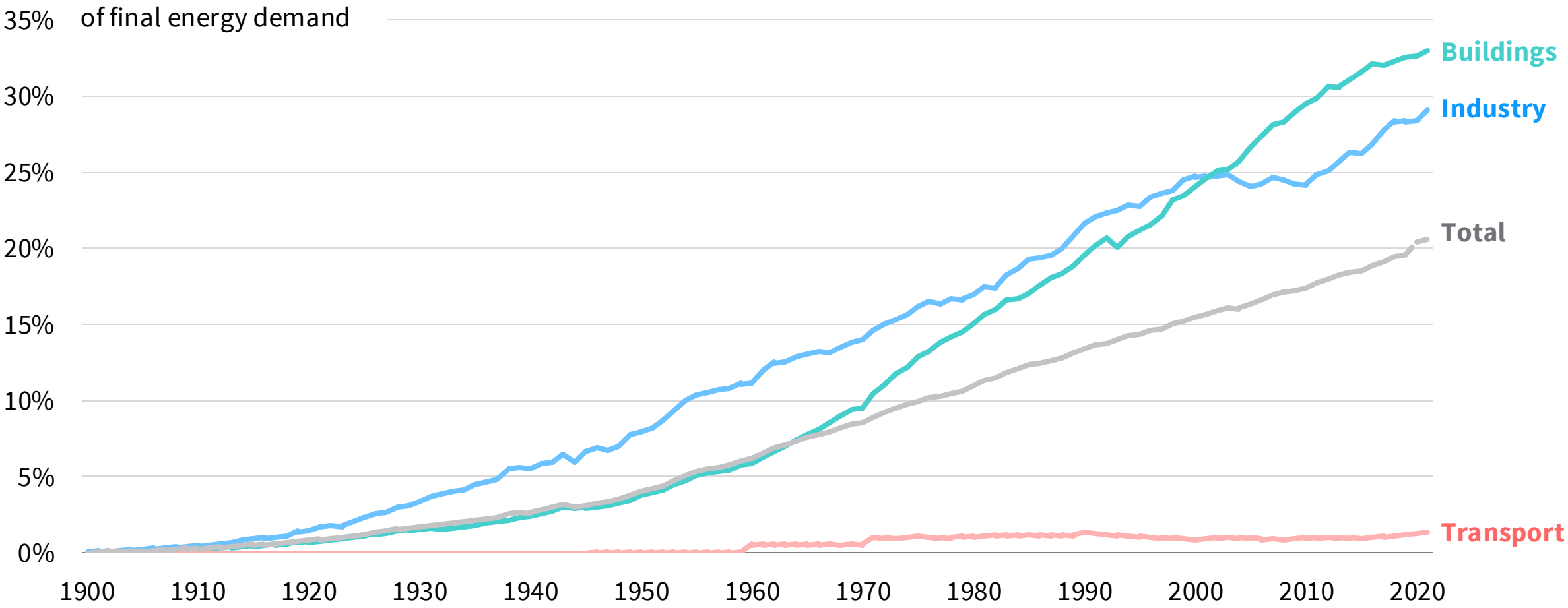


Source: IEA, BNEF.

A century of electrification

Buildings and industry have been electrifying for 120 years; now transport joins the party

Electricity share of final energy demand by sector



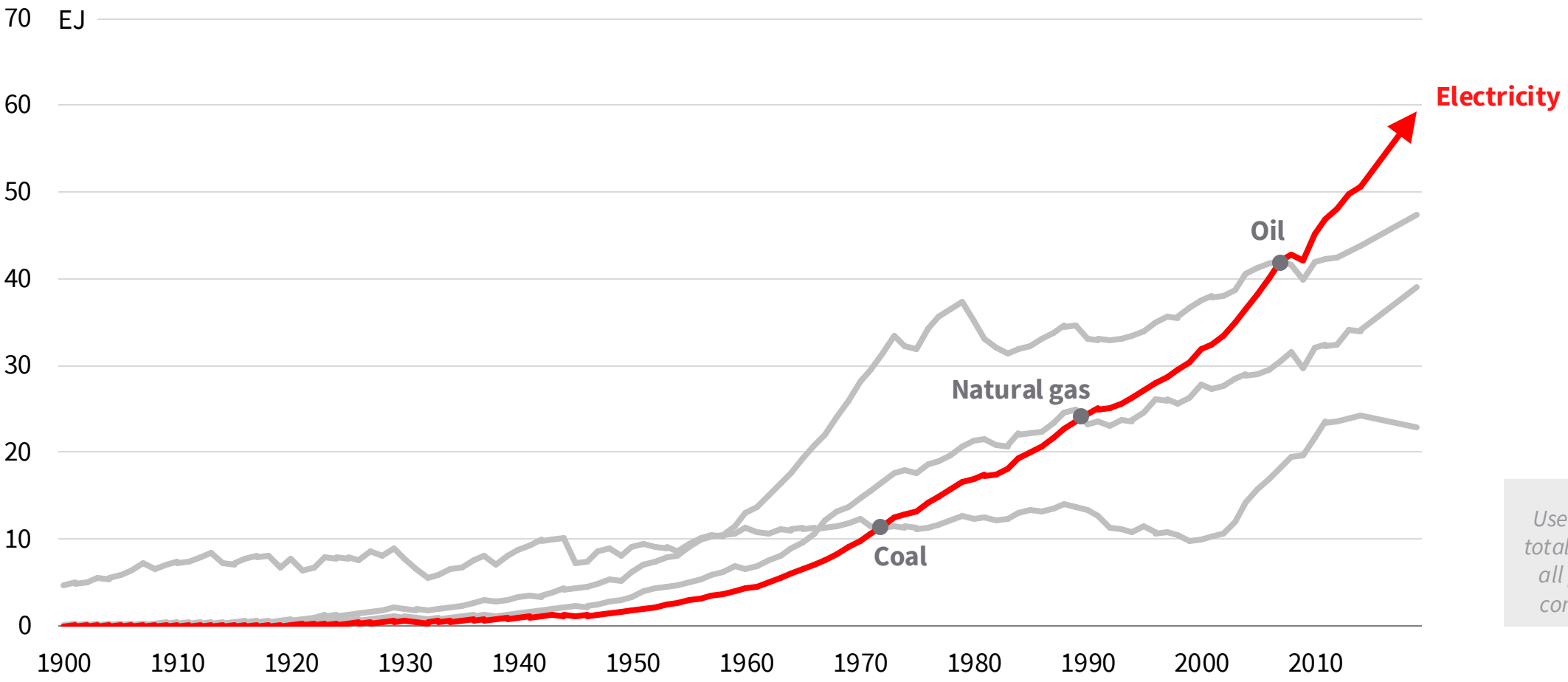
RMI

Source: IIASA, IEA WEB.

Electricity is the new King of Energy

Electricity is the largest supplier of useful energy

Useful energy supply

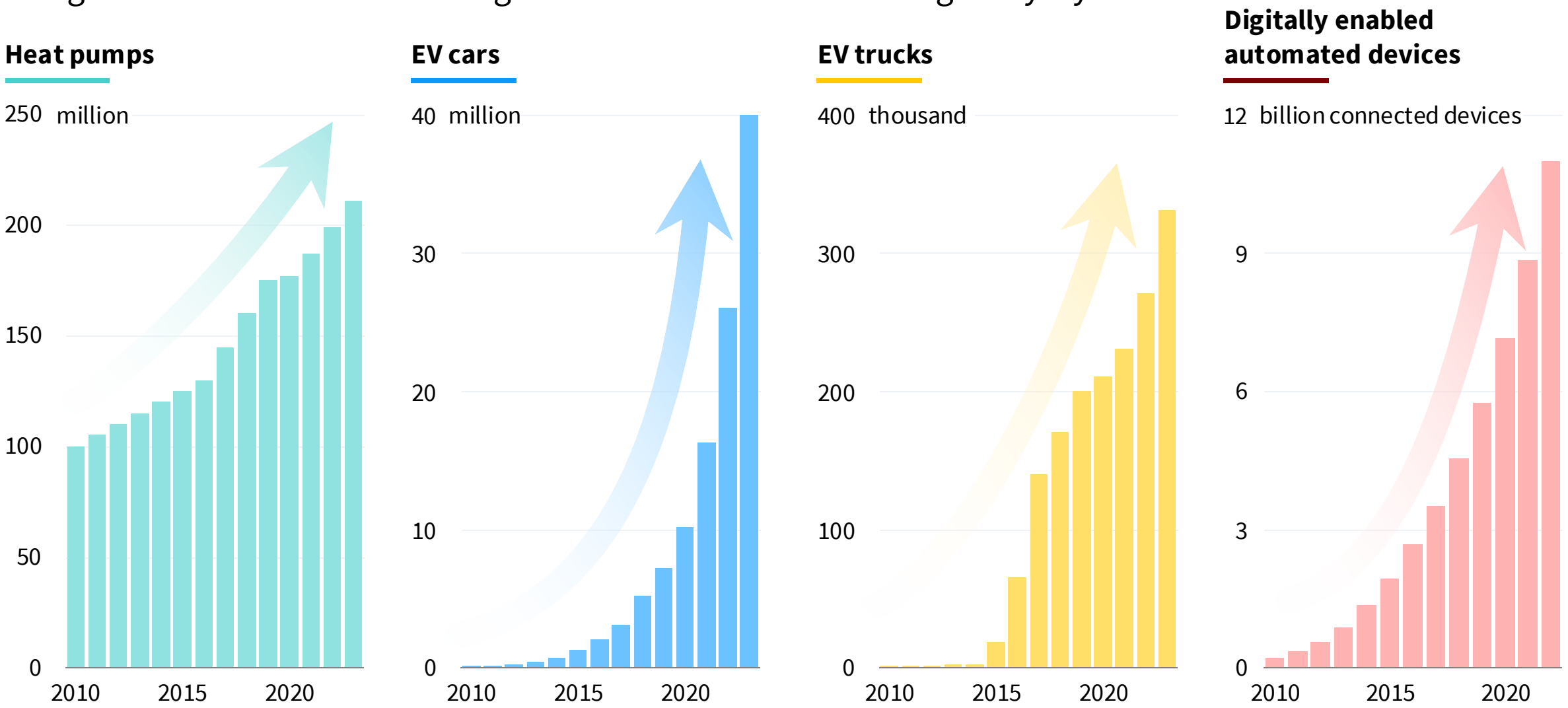


Useful energy is the total energy left after all processing and conversion losses.

Note: All sectors excluding non-energy uses. Estimates for useful energy differ, and here we have taken data from IIASA, which has prepared the most detailed data we have seen.
Source: IIASA.

We are poised to electrify the rest of the system

The global stock of EV cars and digital devices has been doubling every 2 years

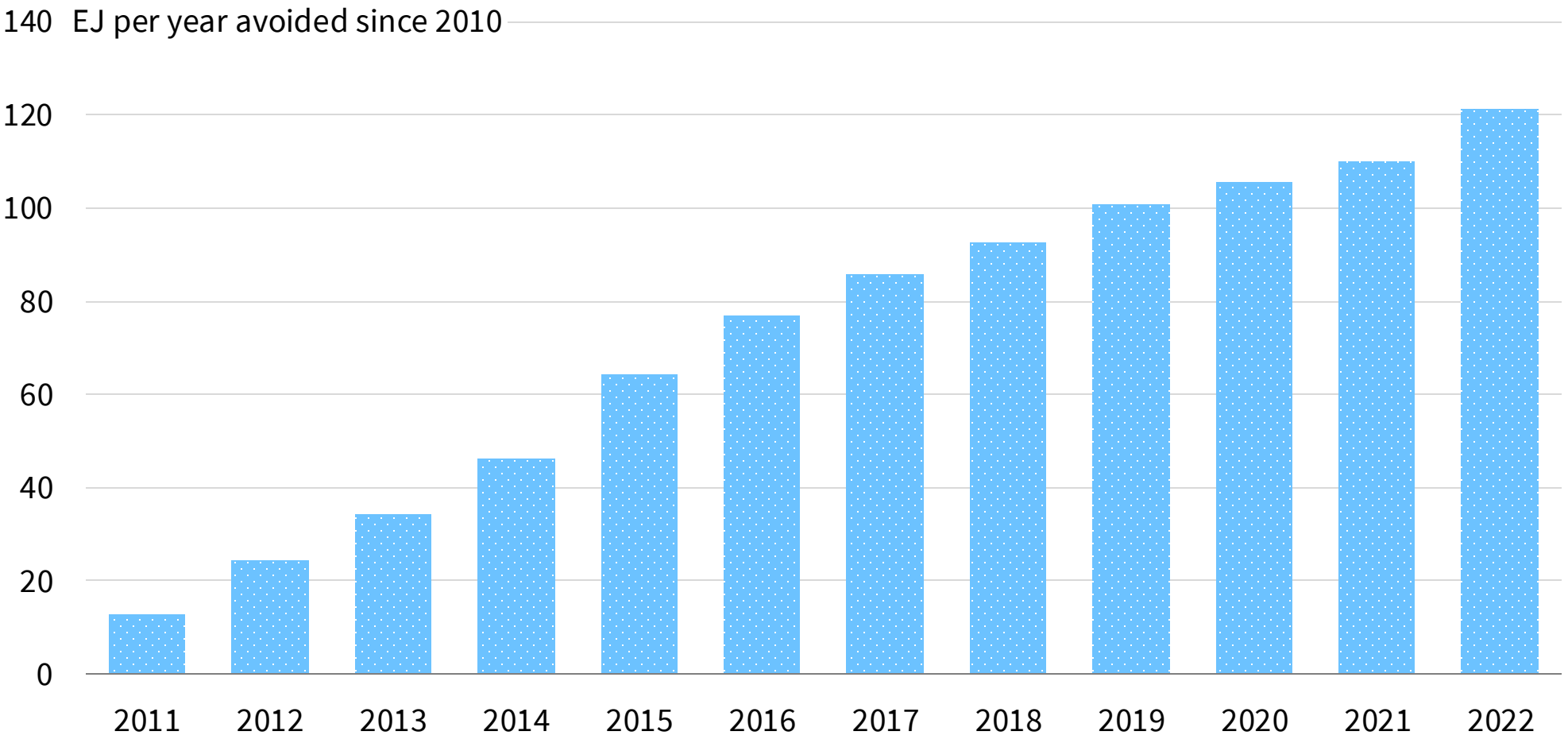


Source: IEA, Carbon Brief for heat pumps.

Efficiency is the Deep Force of change

Efficiency gains since 2010 have reduced energy demand growth more than any other factor

Efficiency gains



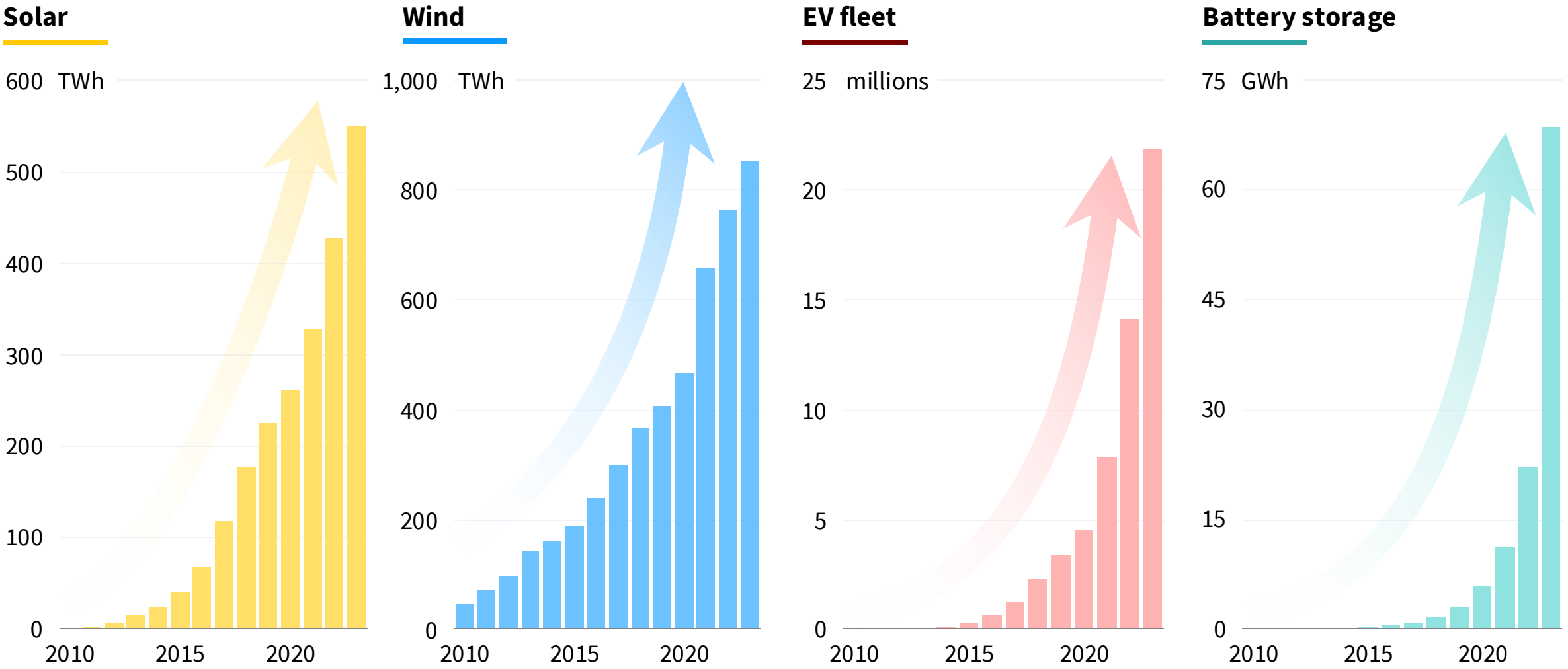
Avoided energy

Efficiency gains over the last decade were one fifth of primary energy demand in 2022 of 632 EJ

Source: IEA WEB, IEA WEO, RMI calculations. Energy efficiency here is simply defined as the difference between GDP growth and energy demand growth.

Super-fast growth in China drives change

In a decade, solar generation increased by 35 times, wind 9 times; EVs and batteries scaled even faster

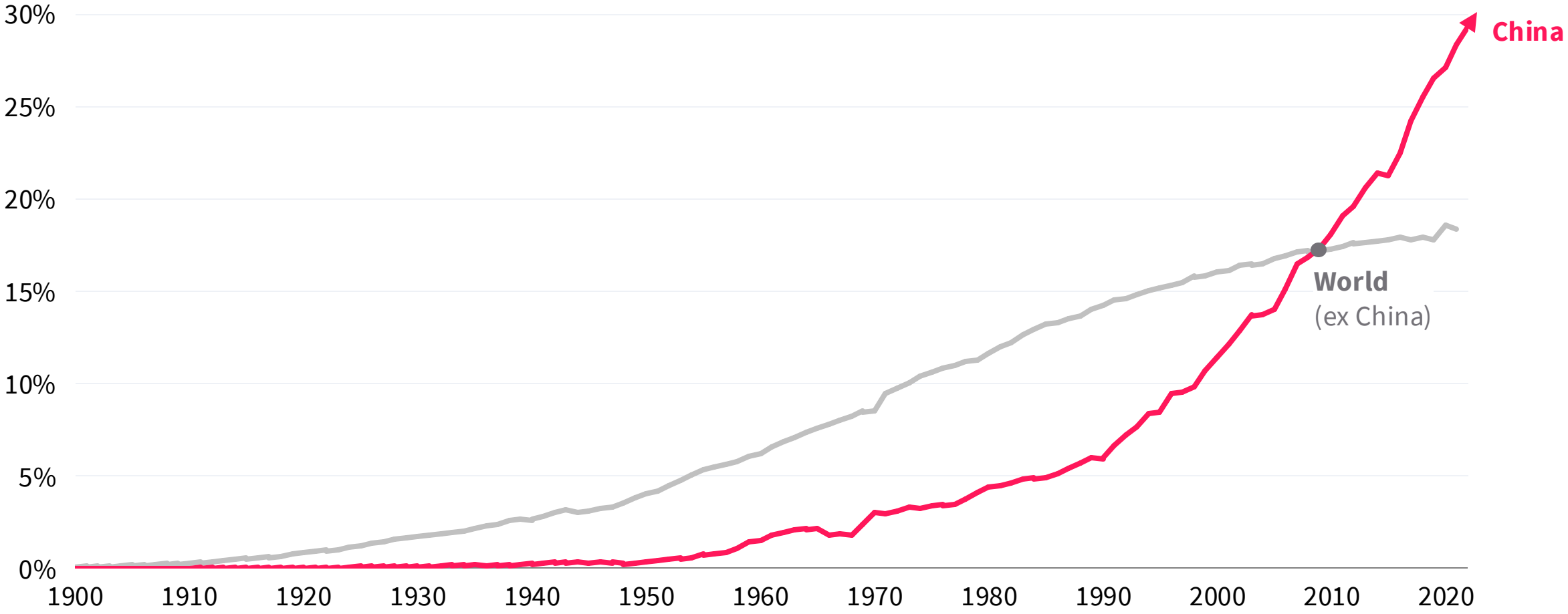


RMI *Source: IEA, BNEF.*

China has become the first major electrostate

China has been electrifying at 10 percentage points per decade, nine times faster than the rest of the world

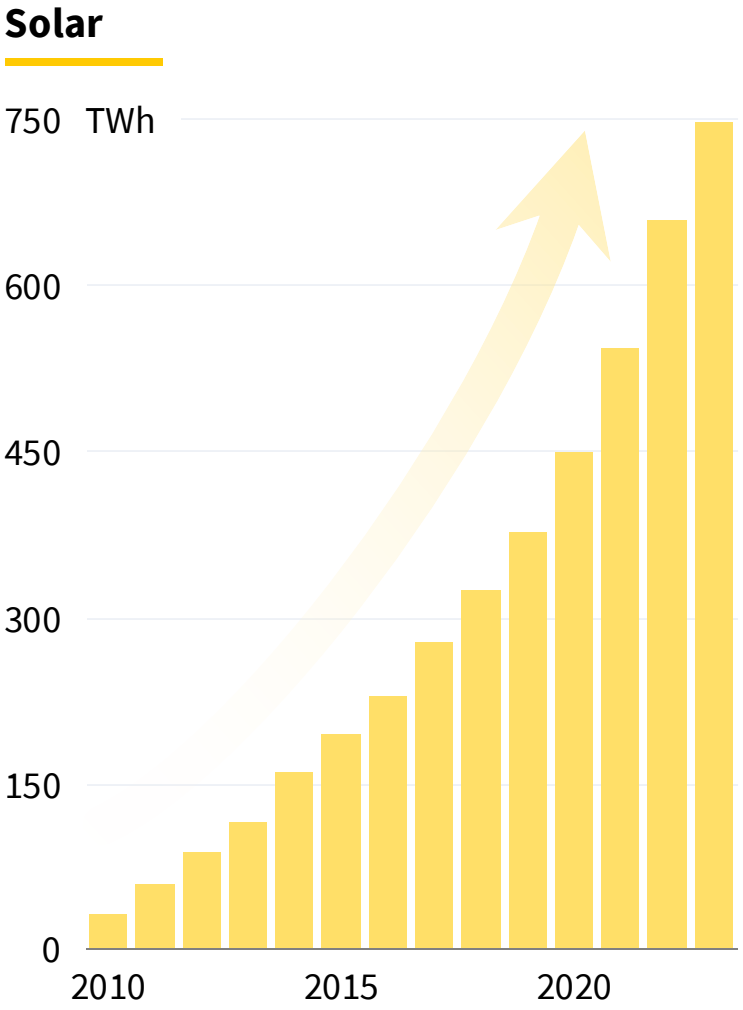
Electricity share of final energy

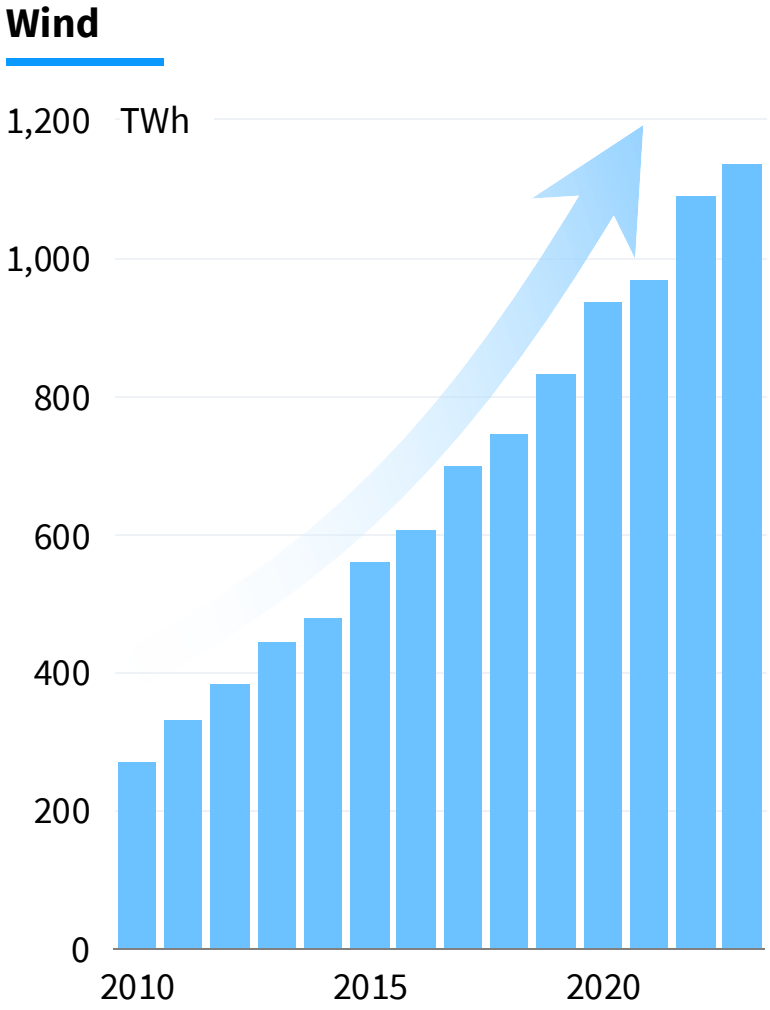


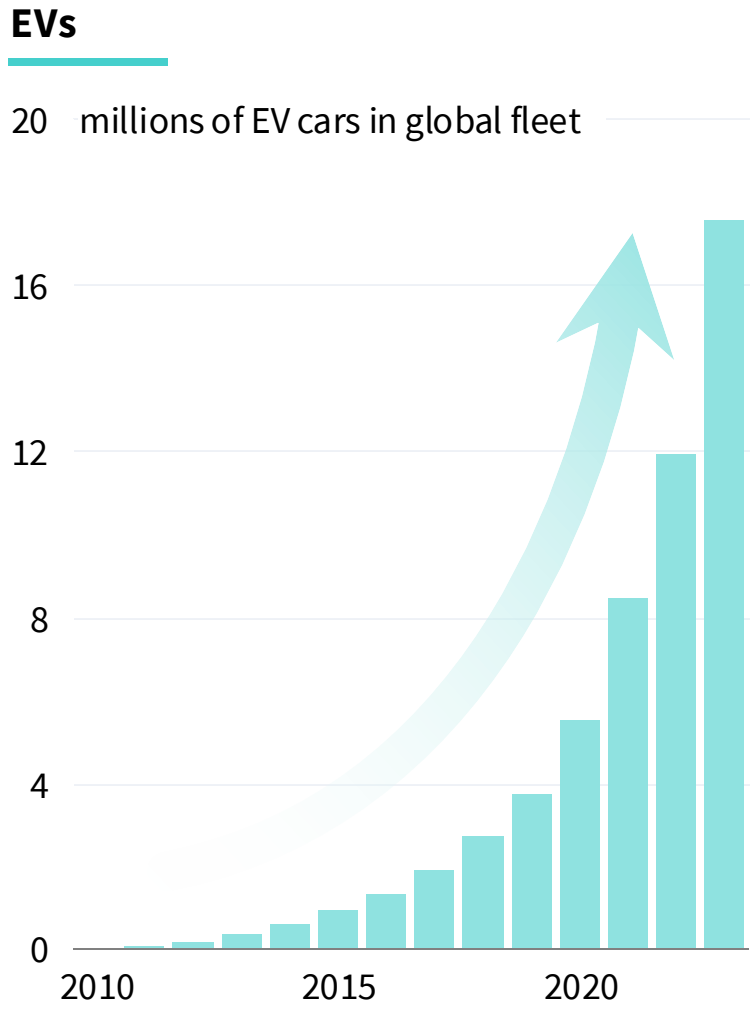
Notes: IIASA data to 1971, IEA onward.
Source: IIASA, IEA WEB. WEB defines final energy slightly differently than WEO.

Exponential growth is also happening in the OECD

Over the past decade, solar generation went up 7 times, wind 3 times, and EVs sales up over 50 times





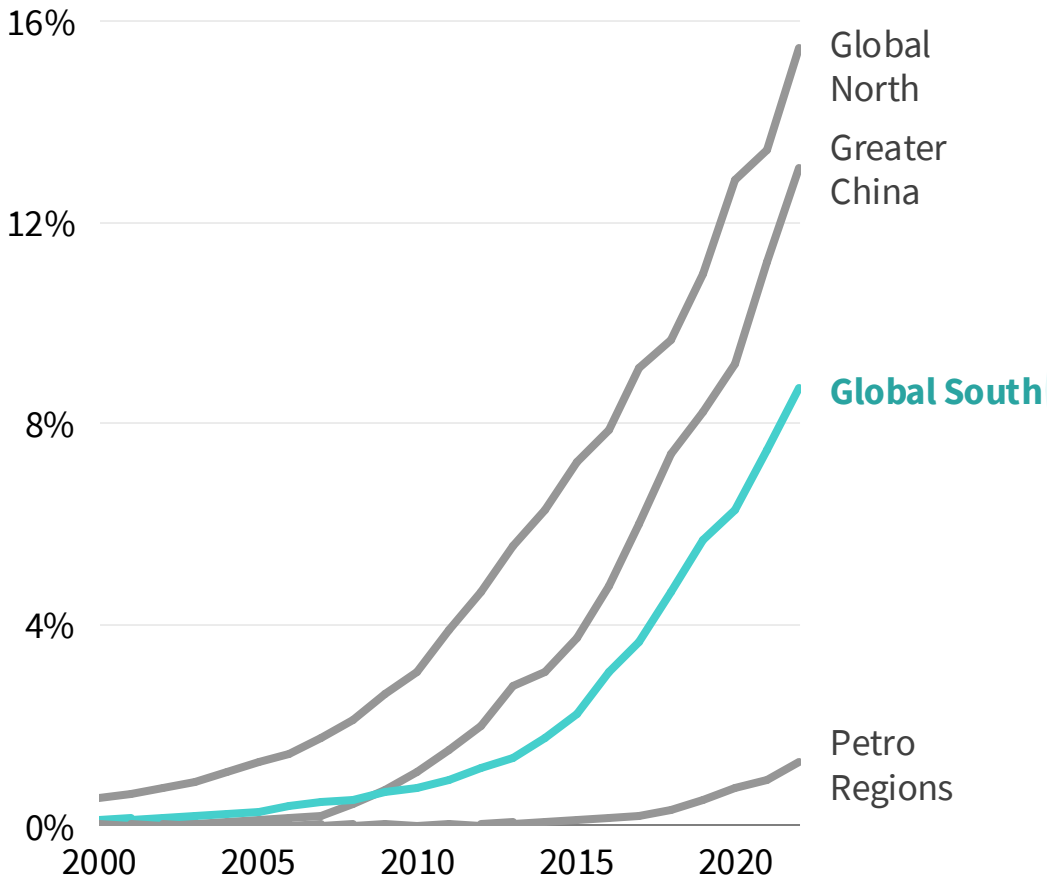


RMI *Source: Ember, IEA.*

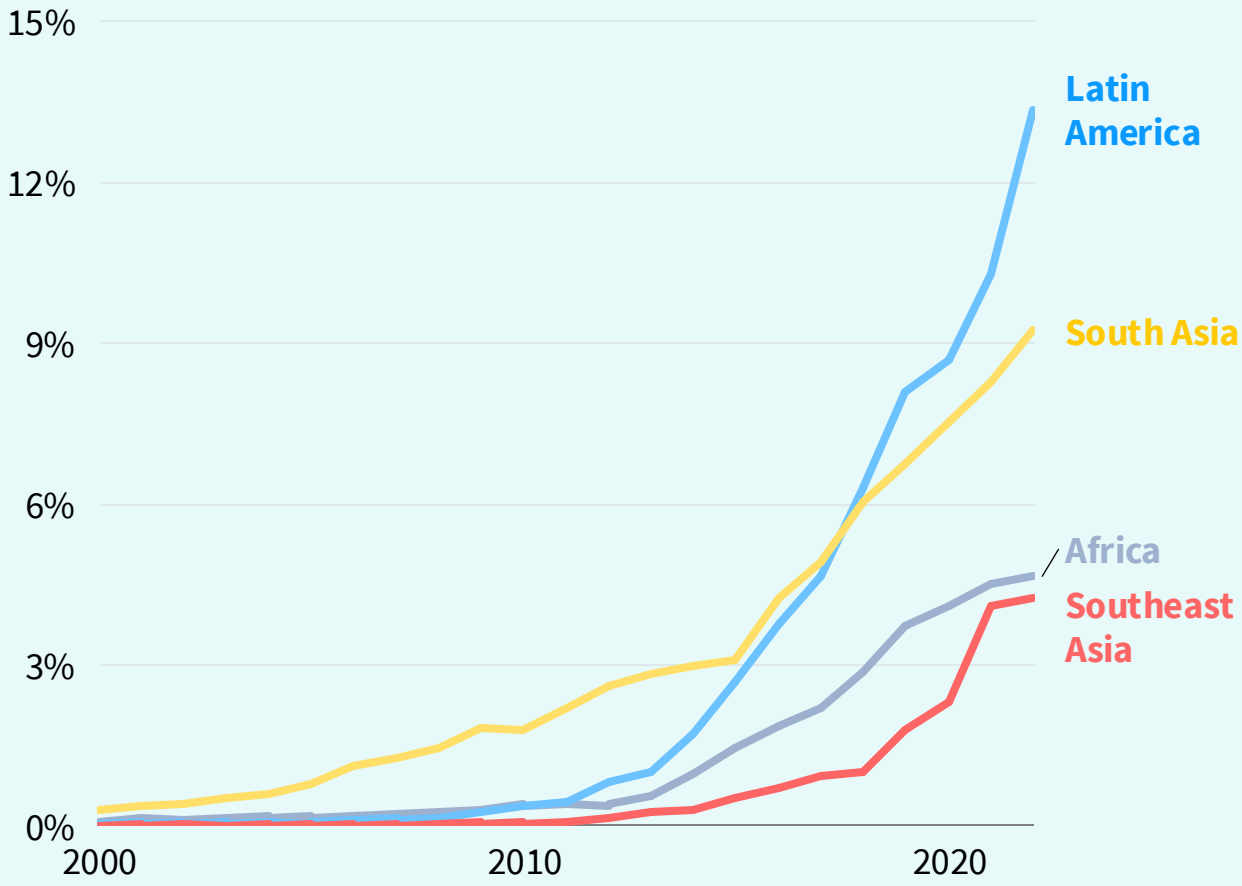
Renewables are following an S-curve in the Global South

Solar and wind generation are growing rapidly, just like in the Global North and China

Solar & wind share of generation by region



Solar & wind share of generation by Global South sub-region

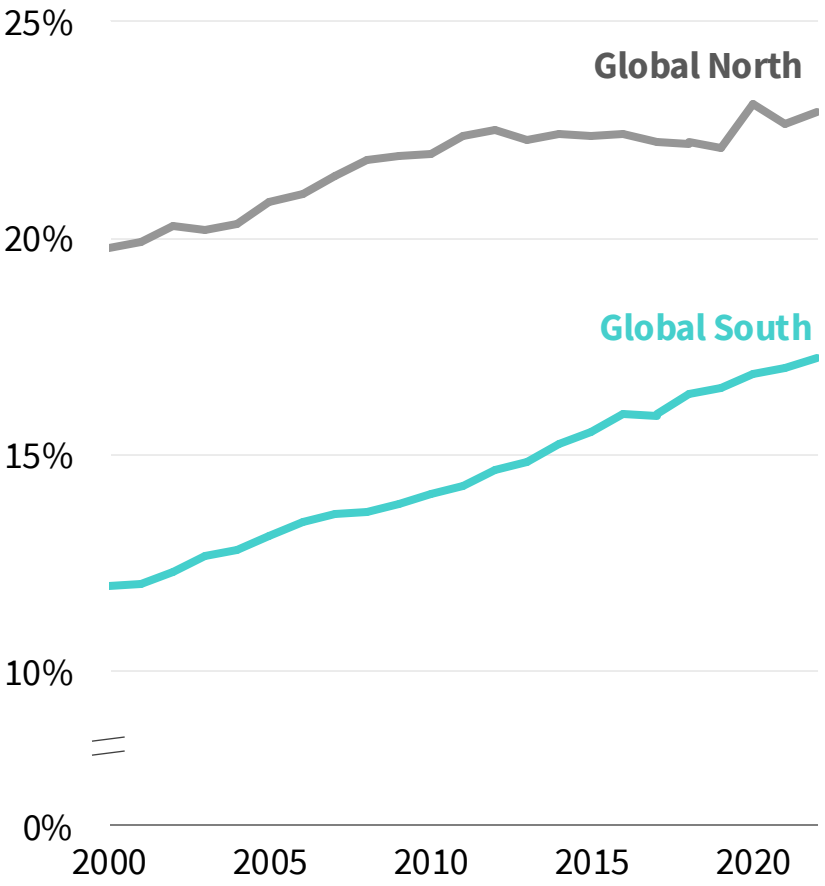


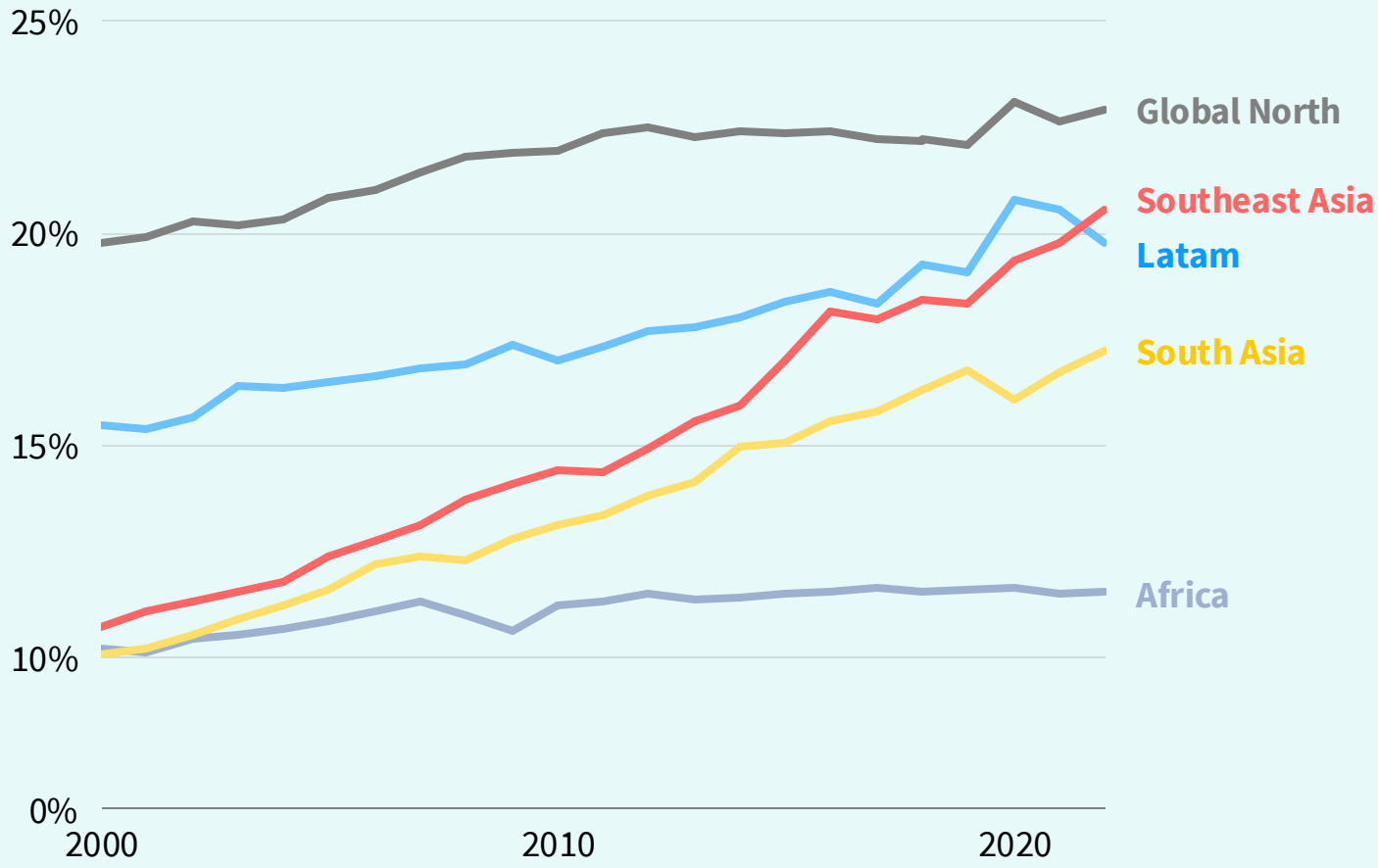
RMI *Source: IEA, RMI framing.*

Electric catch-up

The Global South is quickly catching up to Global North levels of electrification

Electricity as a share of final energy consumption





Source: IEA, RMI framing

Index

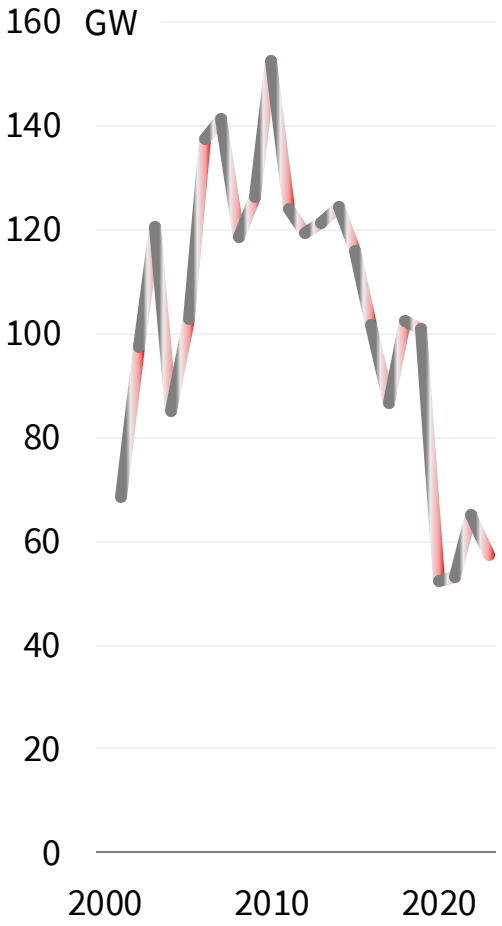
3 The era of peaking fossil fuel demand

- Pessimists keep raising barriers to change; optimists keep solving them.
- Early warning signals for fossils include peak new fossil fuel electricity capacity (2010), peak capex for oil and gas (2014), peak ICE demand (2017), and peak per capita fossil demand (2012–18).
- Global fossil fuel demand for industry peaked in 2014, and in buildings in 2018.
- Fossil fuel demand likely peaked in electricity in 2023 and will peak in transport before the end of the decade.
- OECD fossil fuel demand peaked in 2007, and every major area of demand has peaked in the United States.
- China is the pivot nation in the transition away from fossil fuels, and most areas of demand have clearly peaked there.
- Peaks are showing up across the Global South, from South America to South Africa and Thailand.

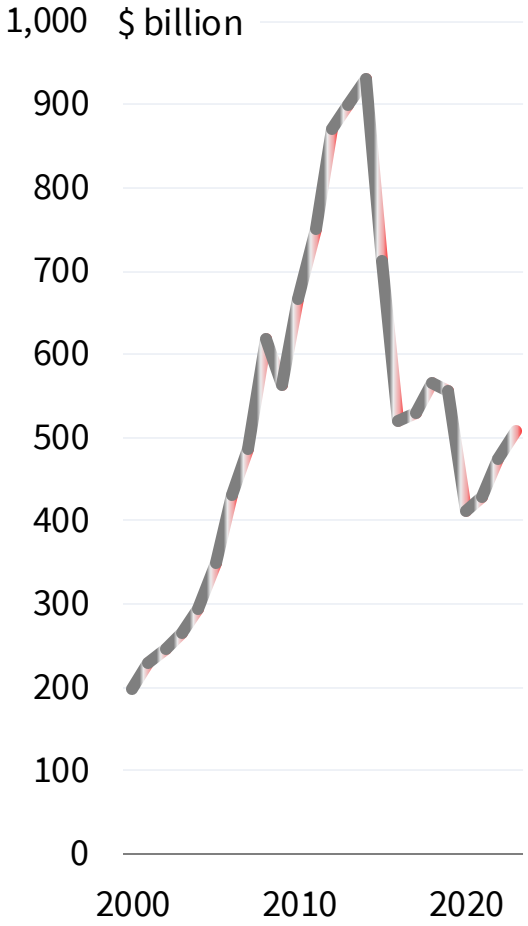
Flashing red lights all over the fossil fuel system

As growth turns to decline

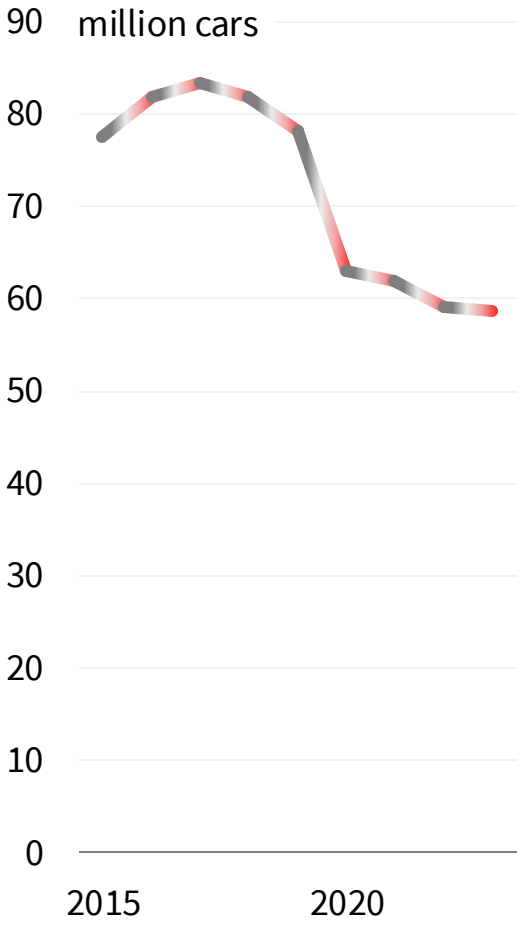
Fossil fuel capacity additions



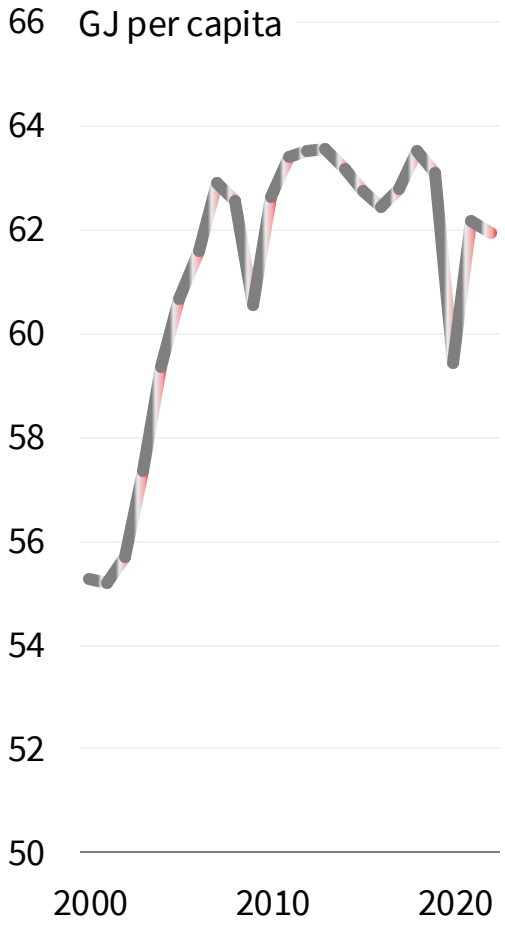
Oil and gas capex



ICE sales



Fossil fuel demand

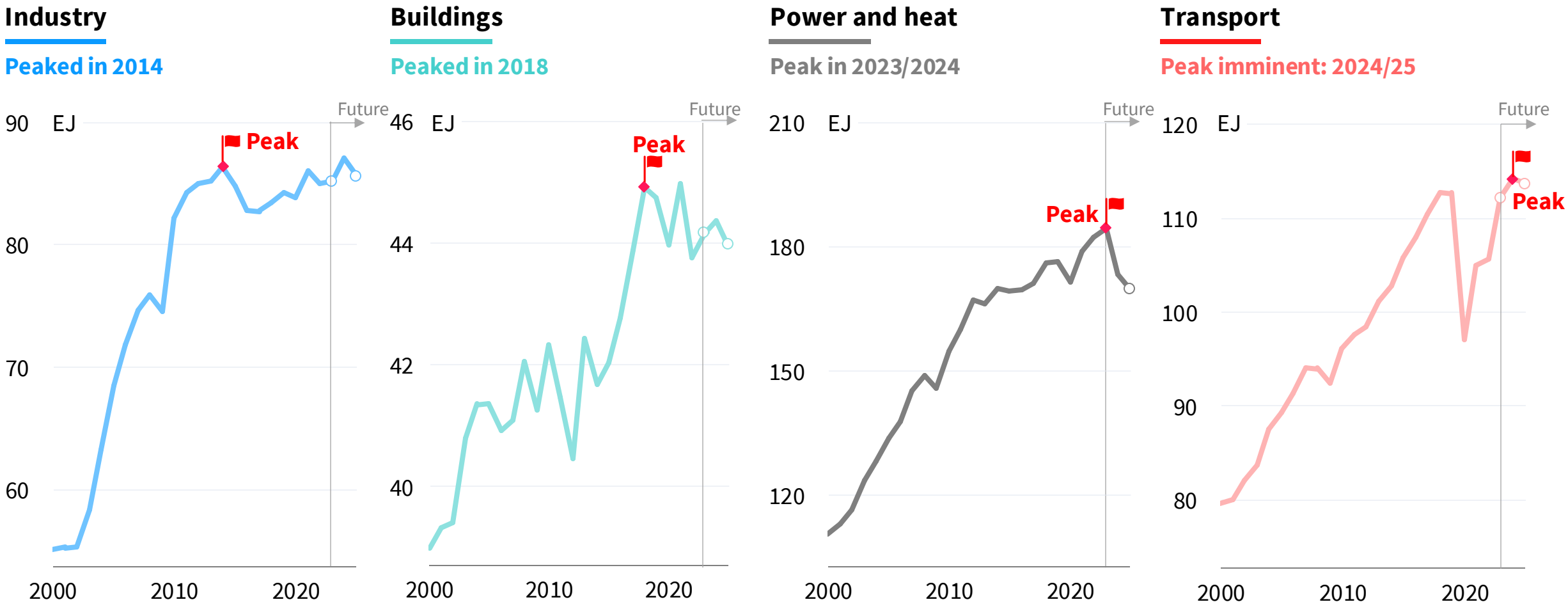


Source: Ember (new fossil fuel electricity generation capacity), IEA WEI (oil and gas upstream capex), BNEF (ICE sales), Energy Institute (global fossil fuel demand pp).
Note fossil fuel capacity additions are a net figure.

The era of peaking fossils is here

Building and industry peak fossil fuels are behind us; electricity and transport are peaking now

Fossil fuel demand by sector



RMI

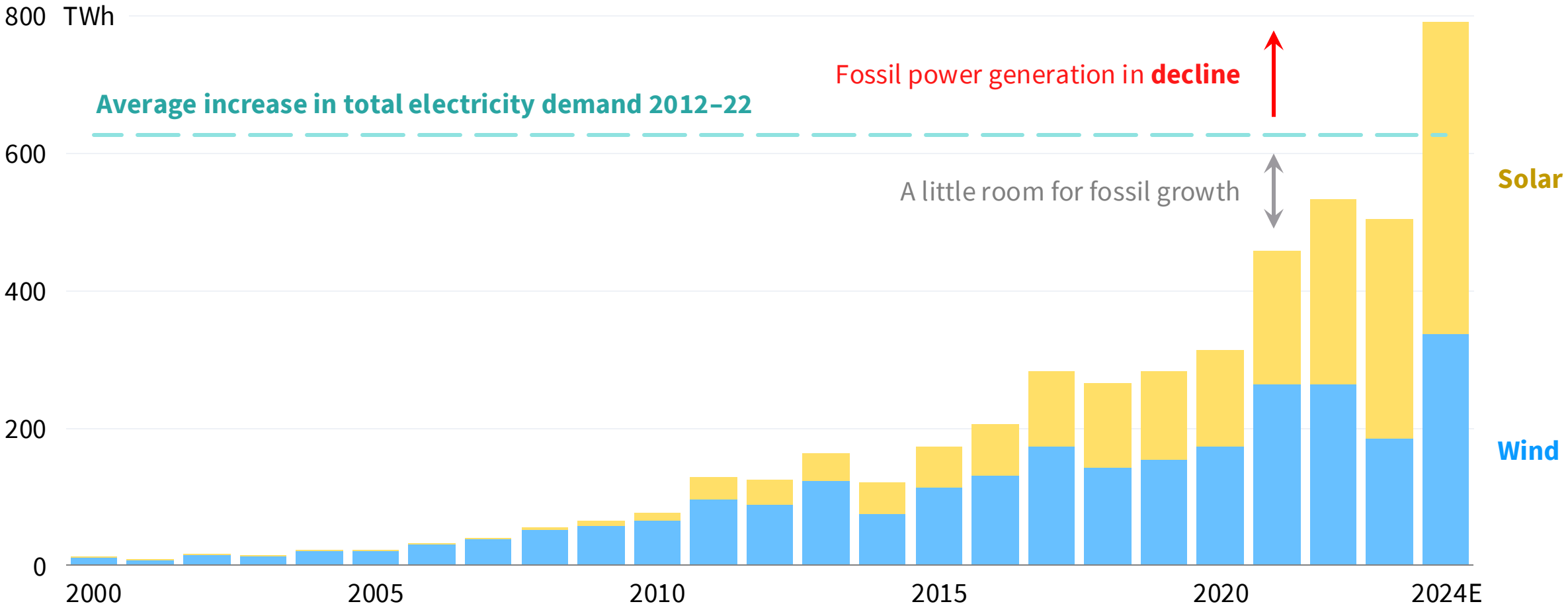
Source: BNEF NEO 2024 NZS.

Power & transport peak last, but have the fastest growing challengers

Peak fossil fuel demand in electricity

Solar and wind provided 500 out of 600 TWh of demand growth in 2023, and will break through average growth this year

Change in electricity generation

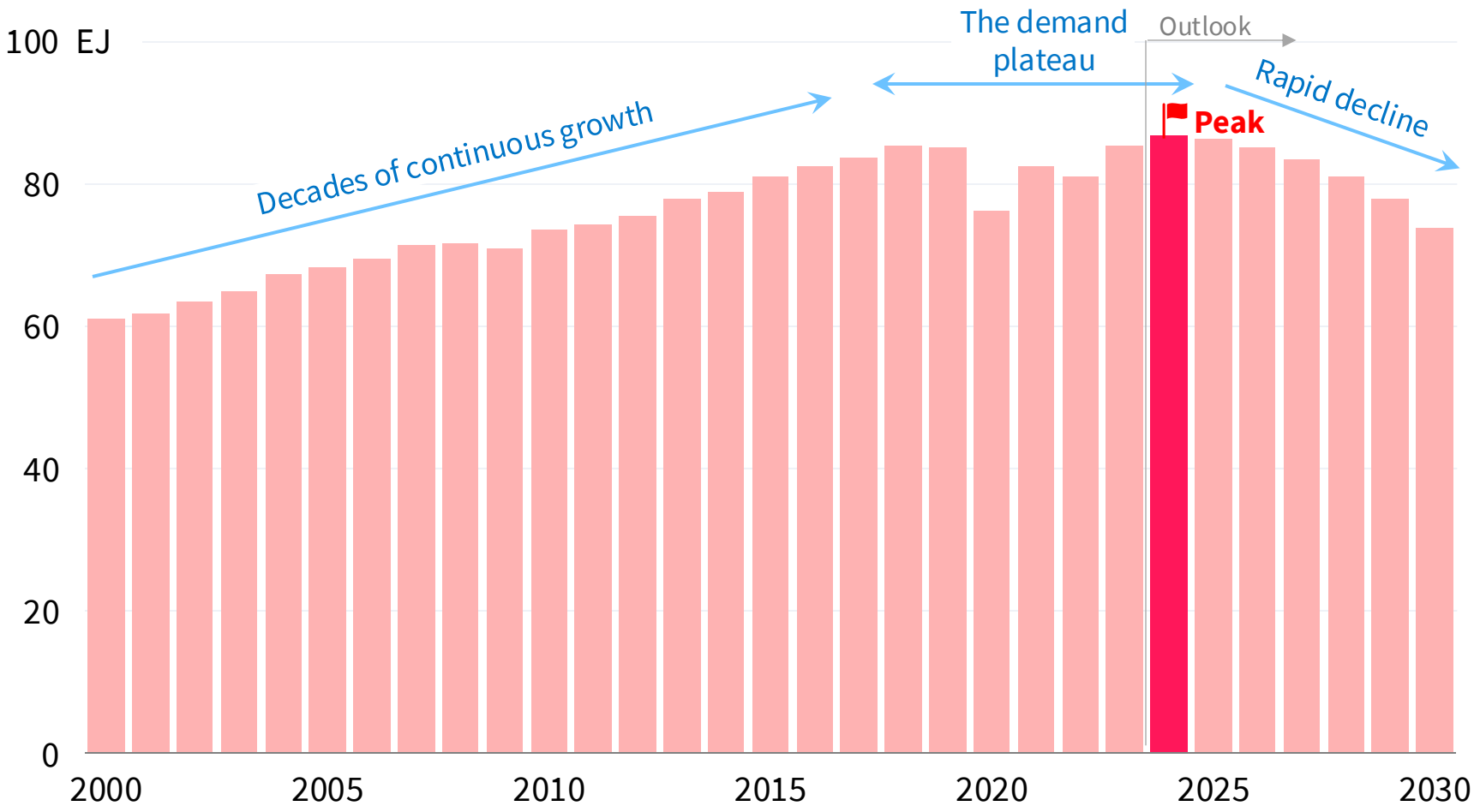


Source: IEA Renewables 2023.

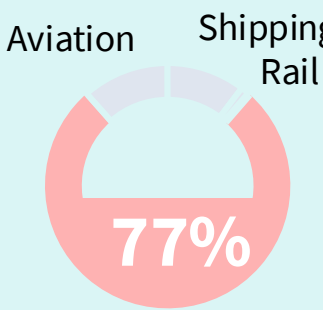
A plateau in road oil demand

Decades of growth stagnate before turning into rapid decline

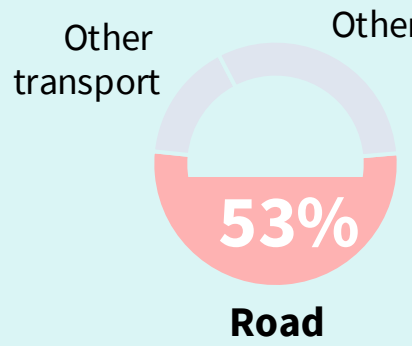
Road oil demand



Oil demand for transport, 2023



Oil demand total, 2023



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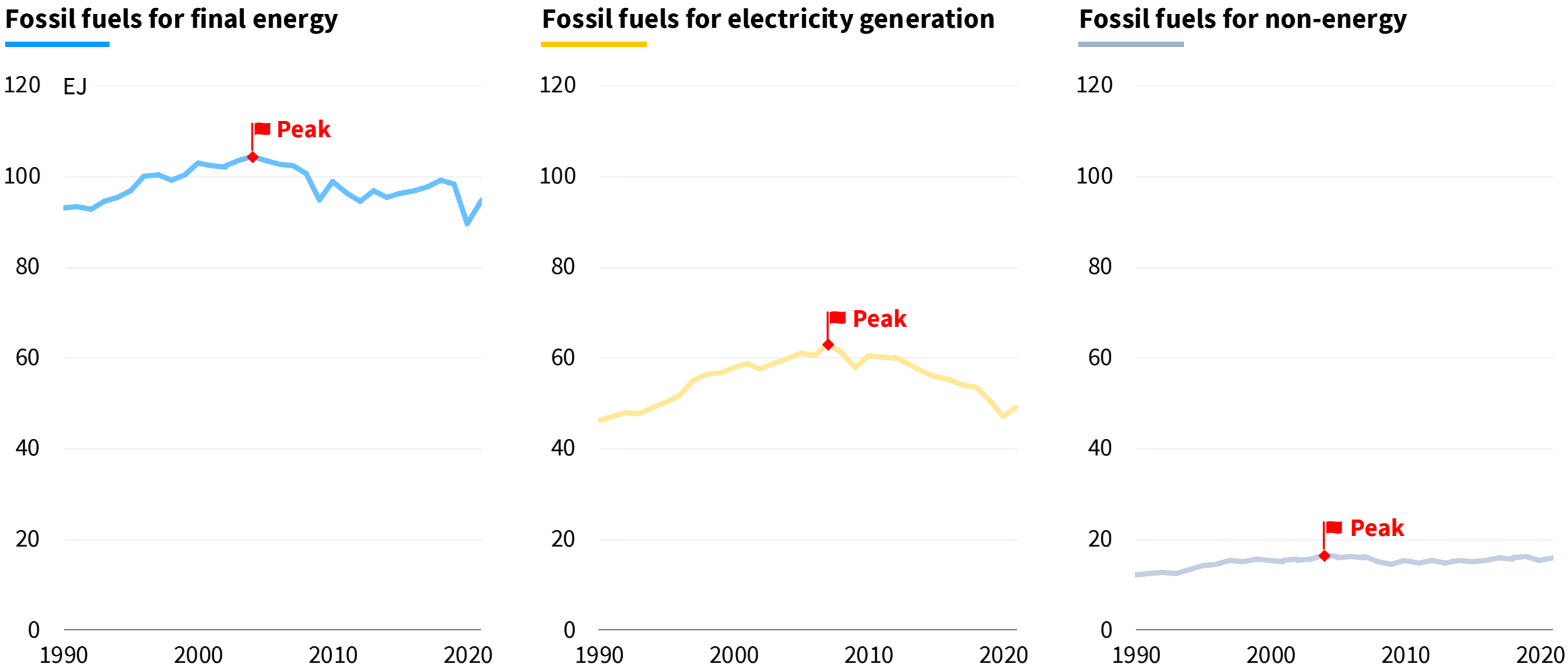
Source: BNEF NEO2024 NZS.

OECD fossil fuel demand peaked a generation ago

OECD fossil fuel demand for final energy peaked in 2005 and for electricity generation in 2007

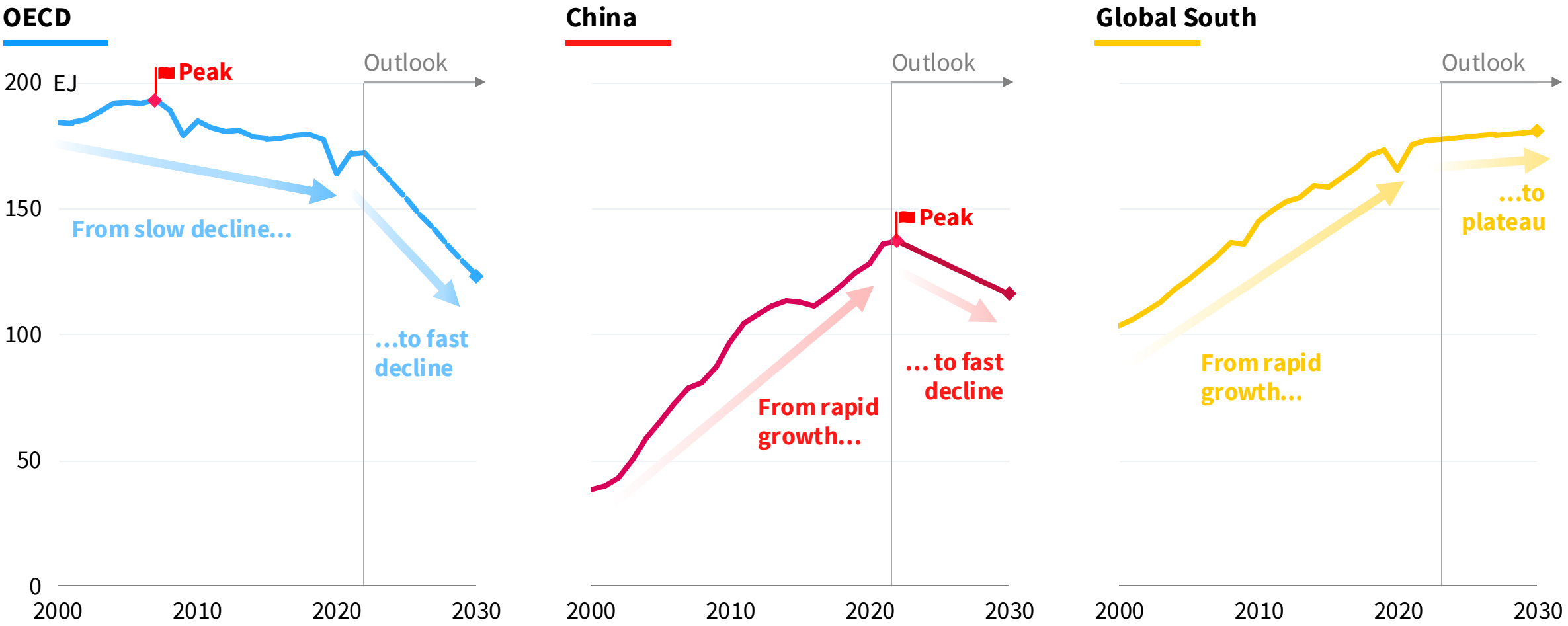


Source: IEA WEB.

China is the global pivot nation

When China peaks, the world peaks

Primary fossil fuel demand by region



Source. IEA APS scenario.

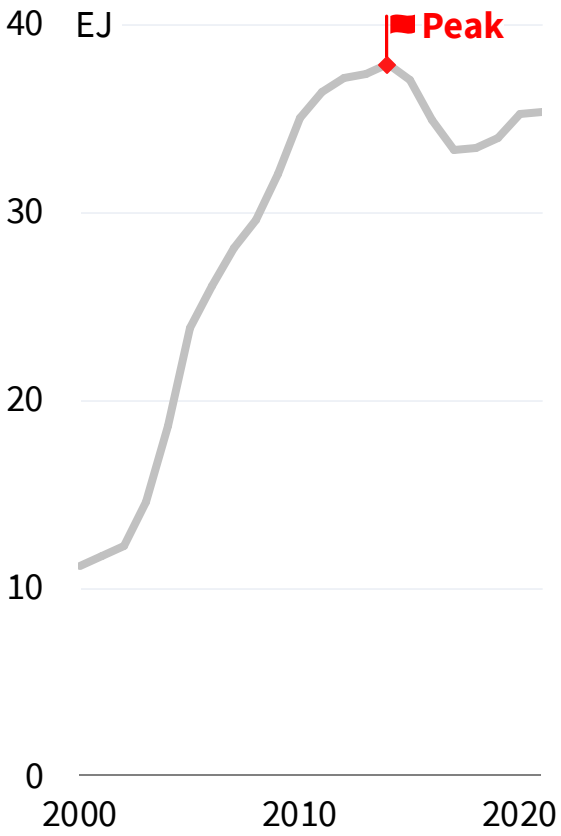
China has driven two-thirds of fossil fuel demand growth in the past decade

Fossil fuel demand is peaking across the Chinese system

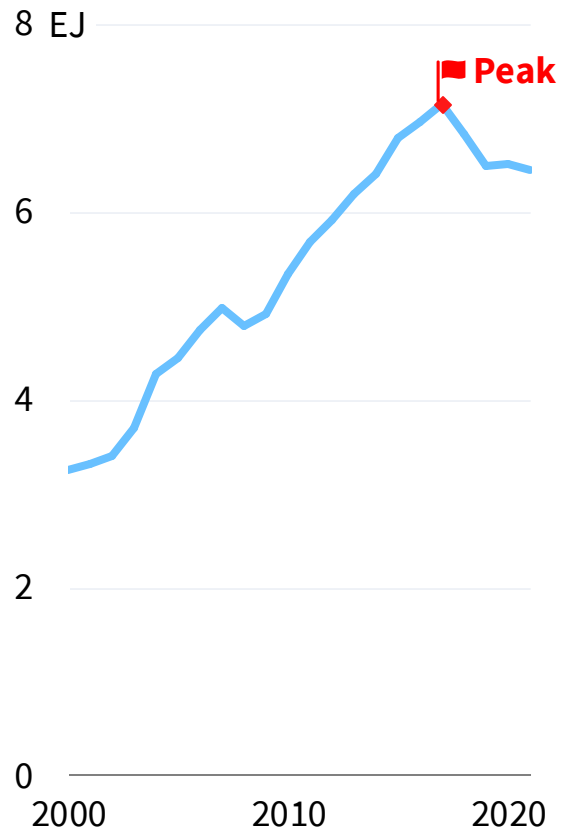
Peaks in industry and buildings are behind us, electricity peaked in 2023, and transport is coming soon

Peaking behind us

Fossil fuels in industry

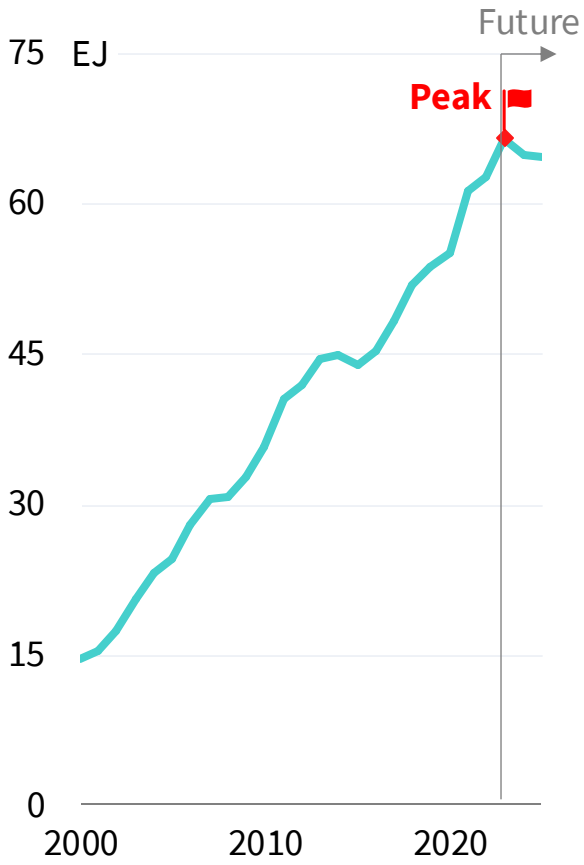


Fossil fuels in buildings



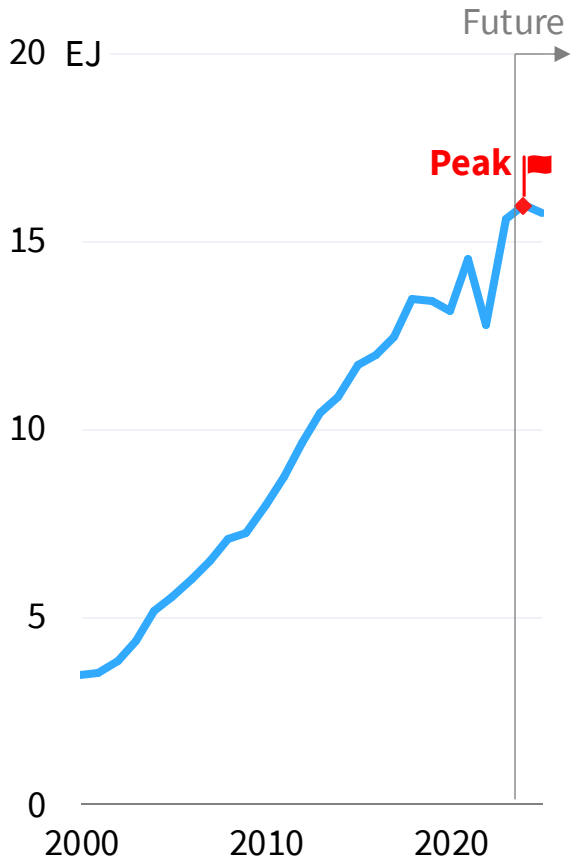
Peaking now

Fossil fuels in electricity



Peaking shortly

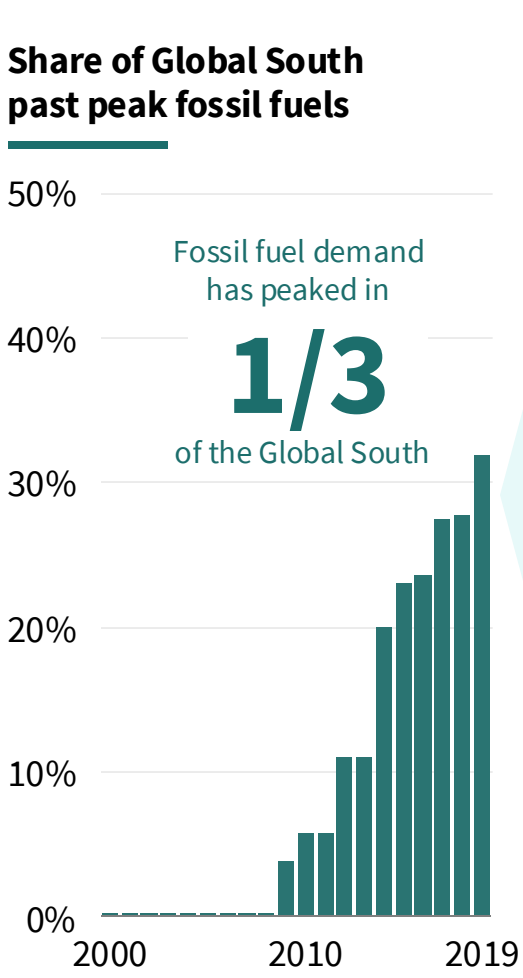
Fossil fuels in transport

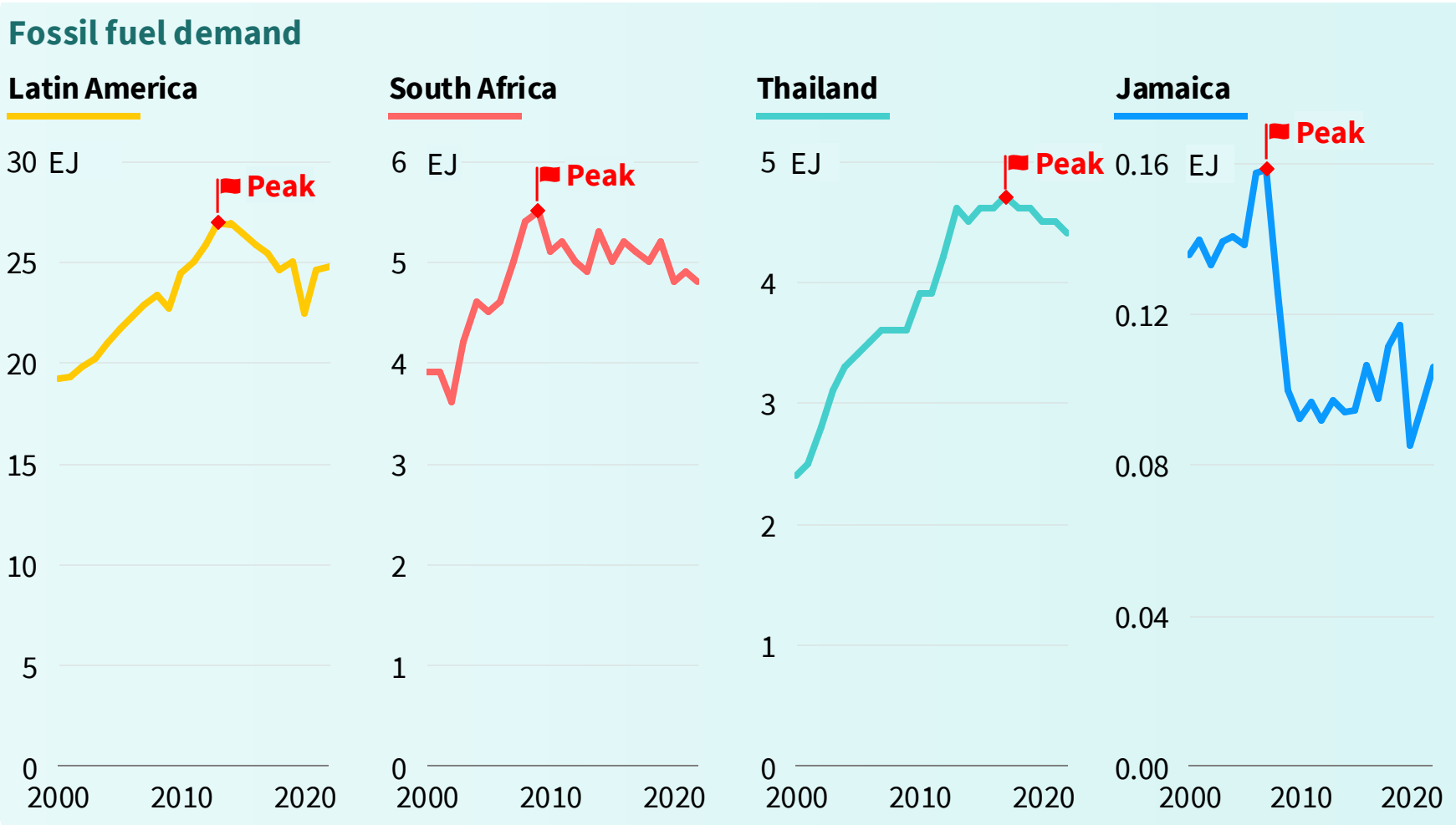


Source: IEA WEB (past), Ember, IEA Electricity 2024 (electricity generation forecast), BNEF NZS (transport forward).

Fossil fuel demand has peaked in one-third of the Global South

Fossil fuel demand has already peaked in Latin America, South Africa, Thailand, and many others





Note: share of the Global South measured by energy demand and fossil fuels measured in primary energy.
Source: IEA, RMI framing.

Index

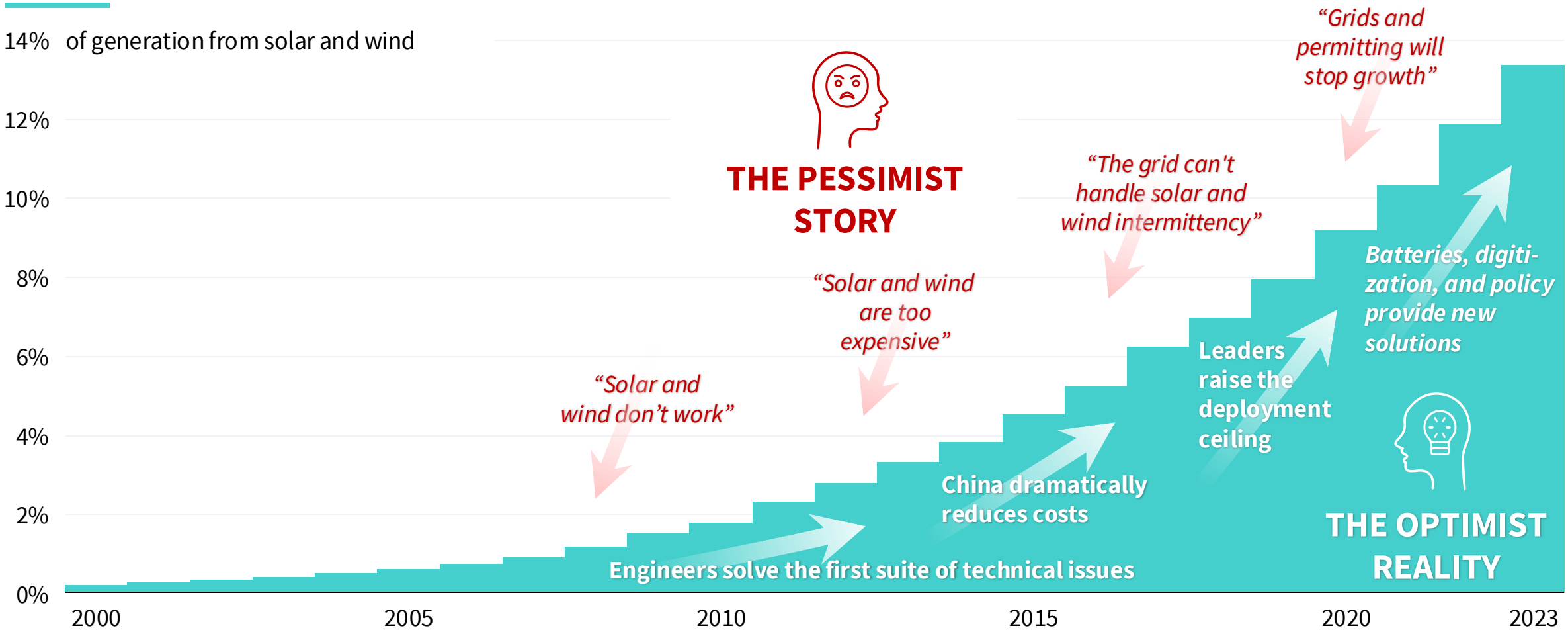
4 Why rapid change will continue

- Cleantech costs will keep falling at around 20% for every doubling of deployment as technology gets better and spreads around the world.
- Fossil fuels are vulnerable because they have huge unpaid externalities (up to $7 trillion a year), get large subsidies ($1 trillion a year), and waste two-thirds of their energy.
- Cleantech provides energy security: 86% of people live in fossil-importing countries today; renewable resources are 100 times larger than fossil fuels, and available everywhere.
- The world's largest energy consumer, China, lacks oil and gas, and cleantech is a path to leadership, clean air, and zero emissions. So, China will continue to deploy cleantech rapidly.
- There is a race to the top as others try to catch up. Cleantech is now 10% of global GDP growth, and there is a race to lead the cleantech industries of the future. Meanwhile, as the world burns, so policy pressure will rise.
- The three drivers of change — renewables, electrification and efficiency — are self-reinforcing.
- Clean technologies will continue to follow S-curves, cascading across sectors and geographies. Change at the frontier is hard, but most countries can copy the leaders.

Pessimists sound clever; optimists change the world

The incumbents have been predicting the end of the transition for decades

Pessimist's and optimist's take on solar and wind uptake

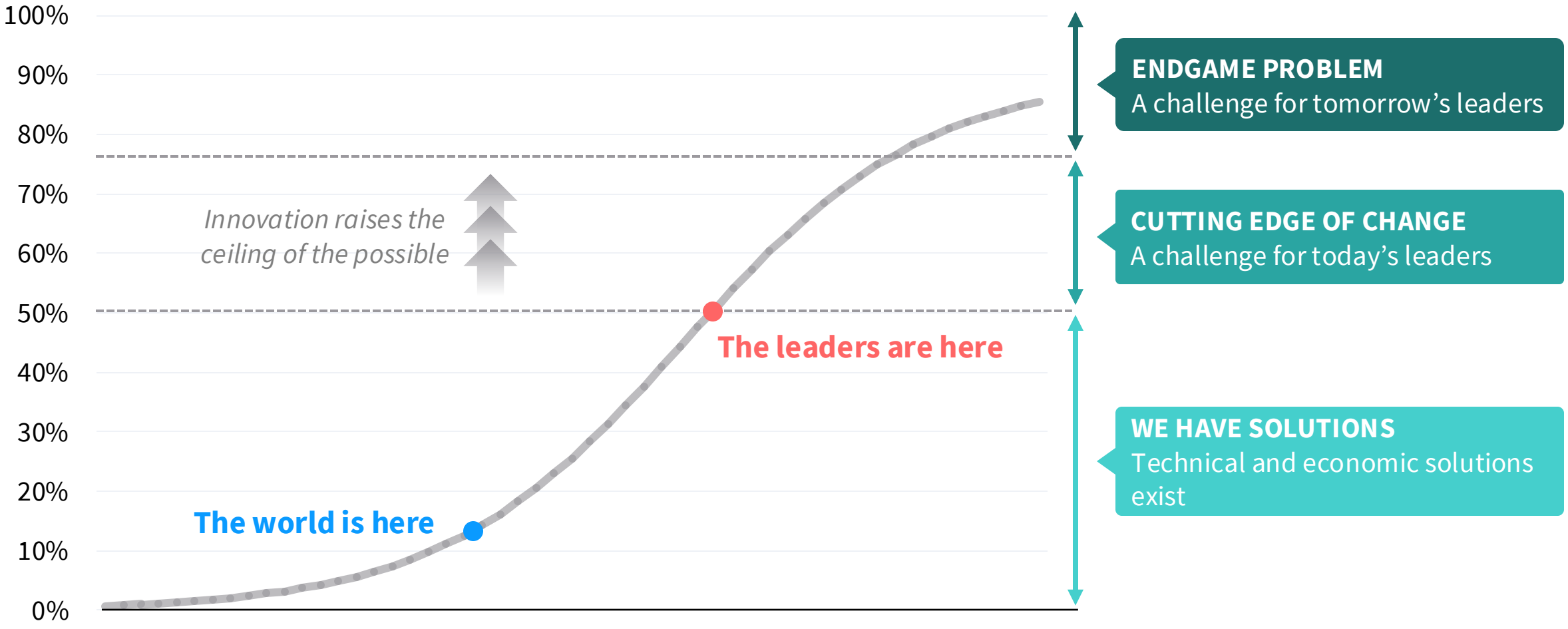


Source: Ember.

The ceiling of the possible keeps rising

Leading countries and companies keep opening up new opportunities for the rest of the world

Solar and wind as share of electricity generation

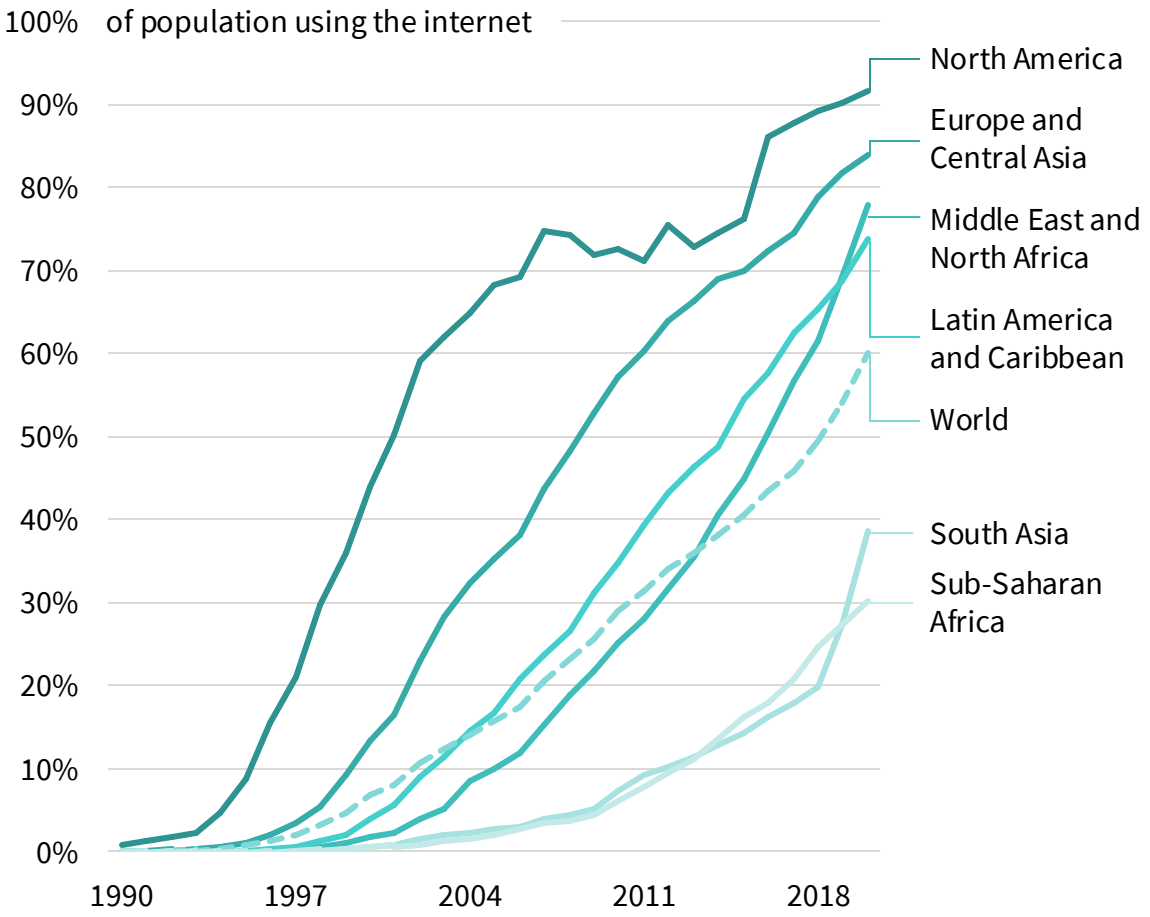


RMI Source: RMI

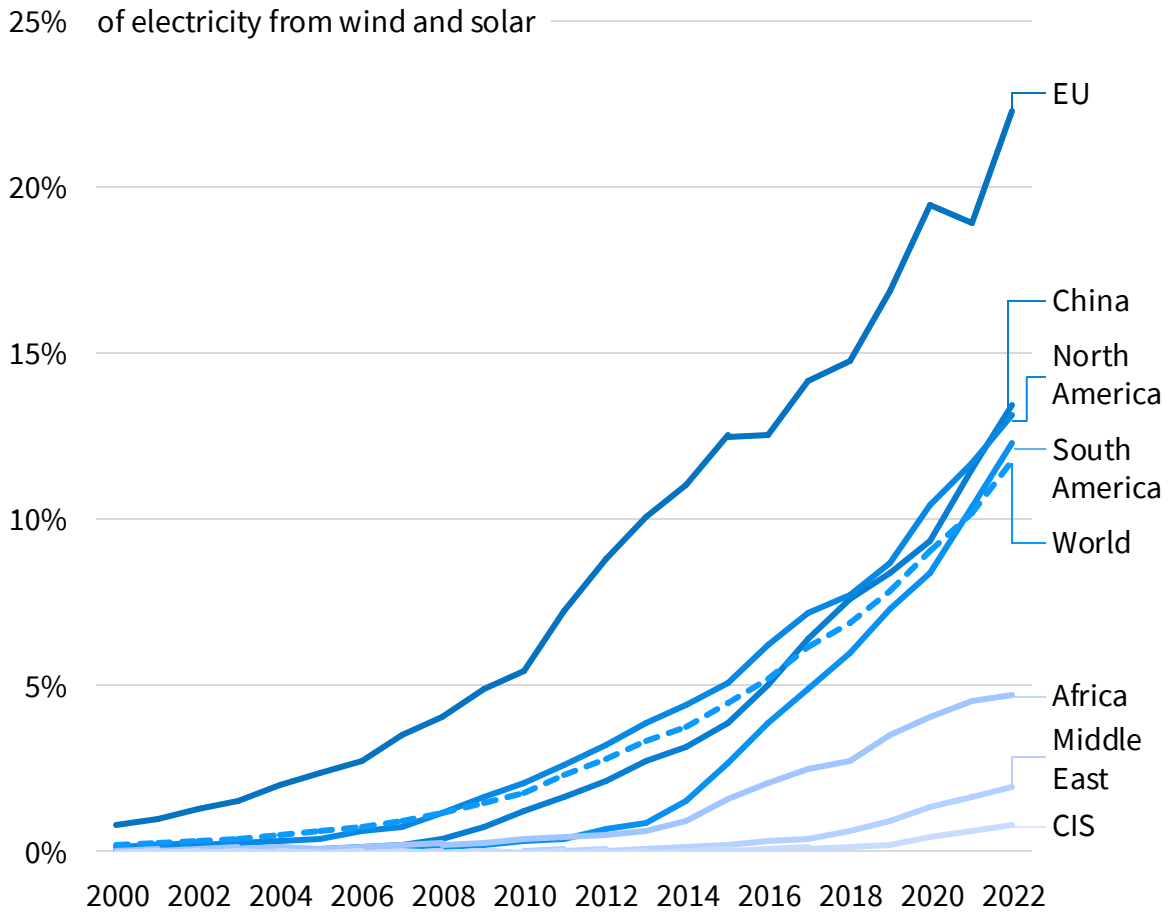
Cleantech adoption resembles that of the internet

Adoption moves from early adopters to laggards up a series of S-curves. This time anyone can be a leader

Share of population using the Internet



Solar and wind as a share of generation

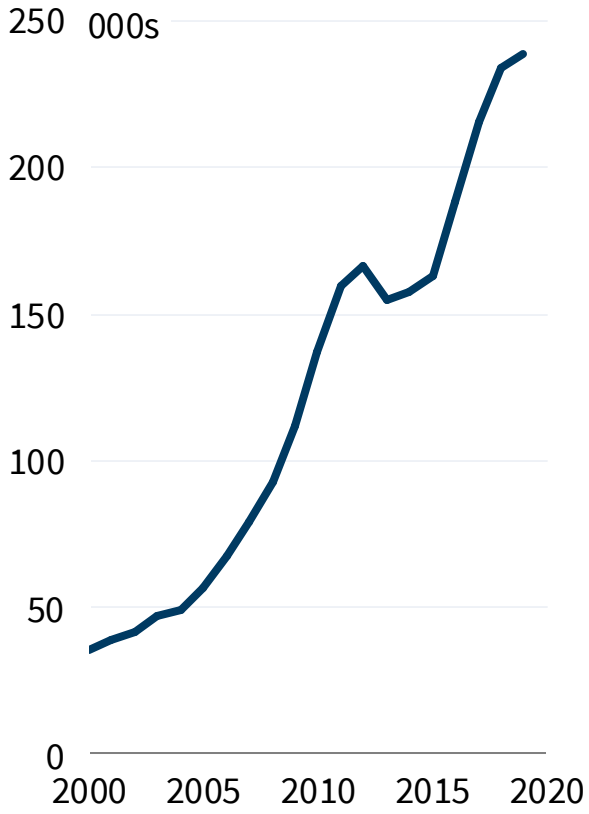


RMI *Source: OWID, Energy Institute.*

Cleantech keeps getting better

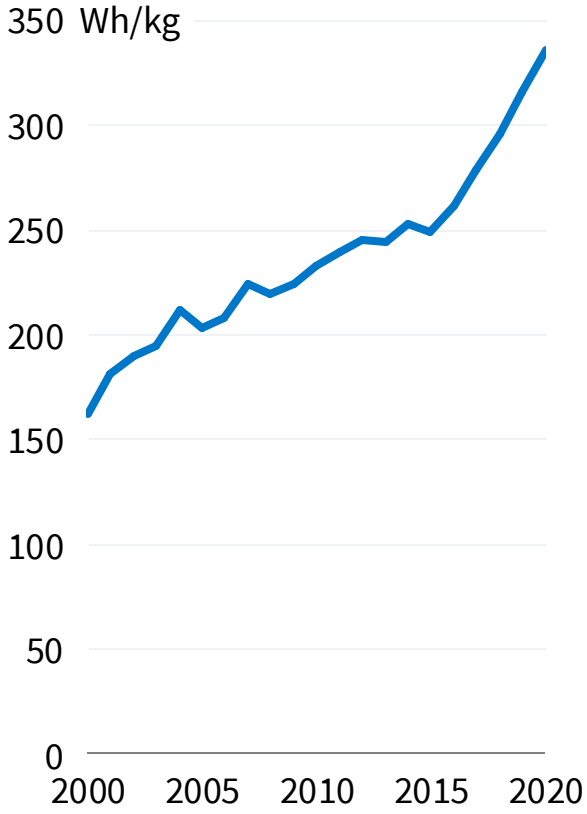
More patents, higher battery density, more solar and wind generation per unit, economies of scale, new ideas, …

Cleantech patents per year



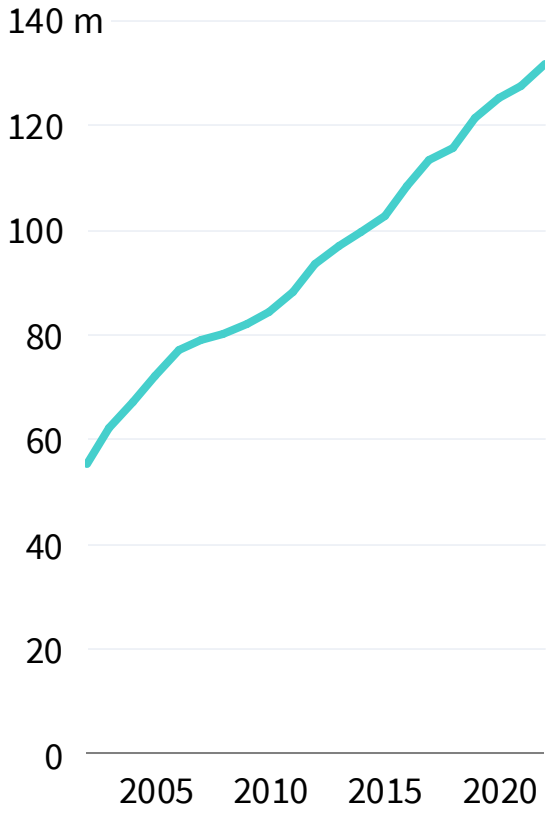
More innovation

Top-tier battery cell density



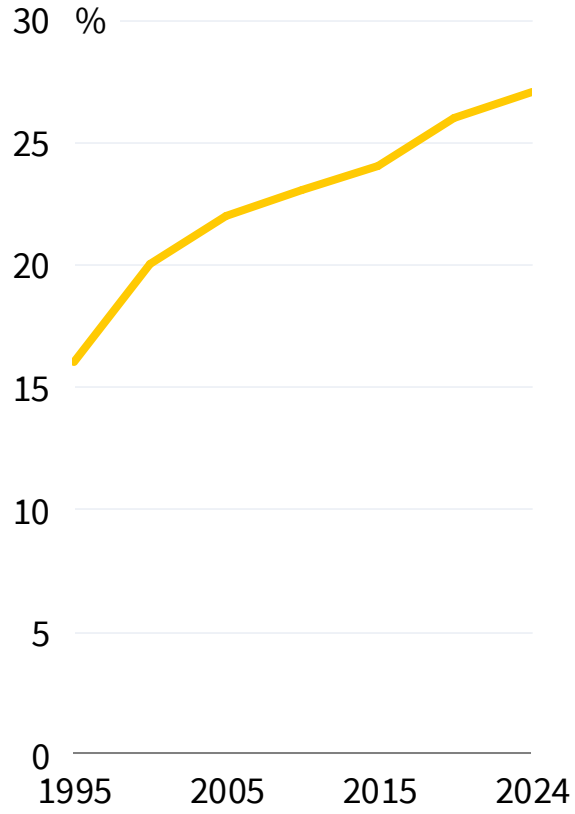
Denser batteries open up new sectors for batteries to play in

Wind rotor diameter



Bigger rotors reduce cost per MWh

Solar cell efficiency

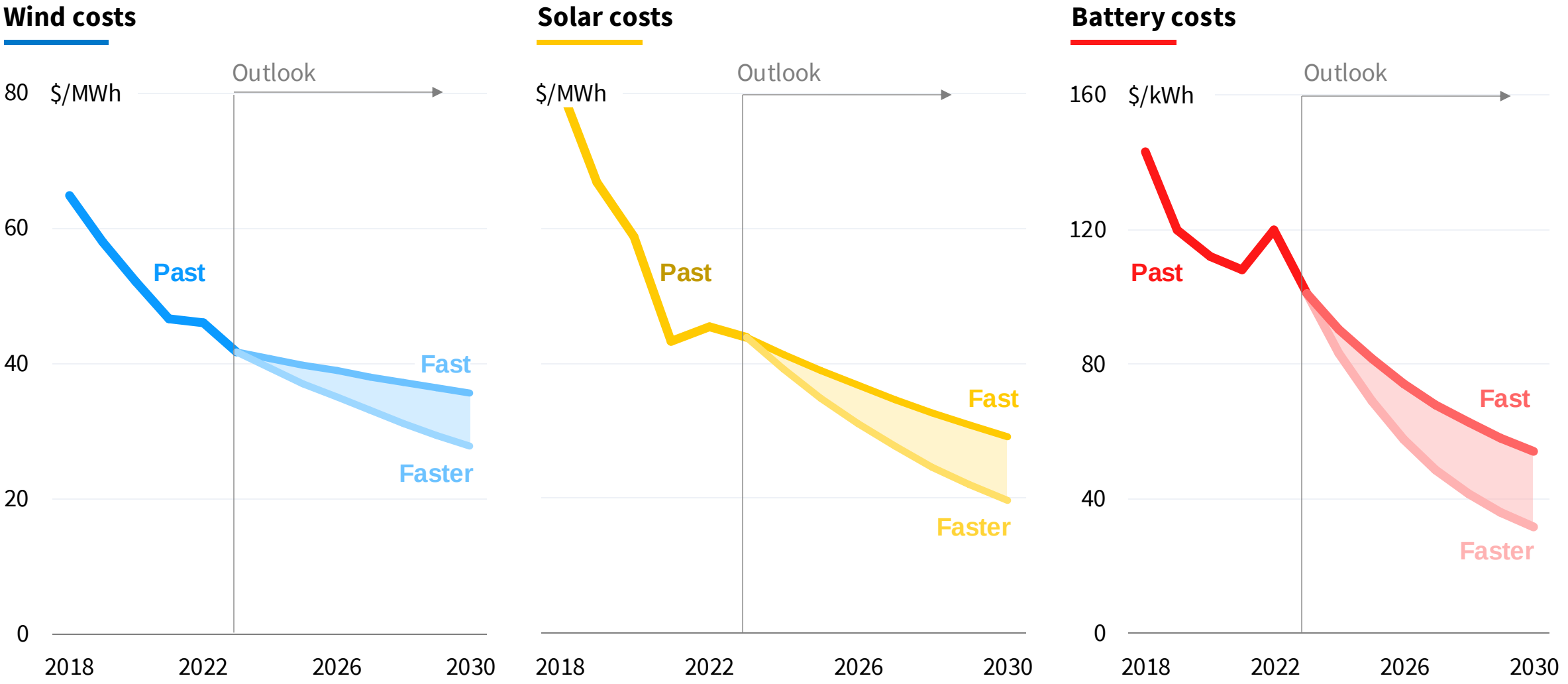


More efficient solar panels reduce cost per MWh

Sources: IRENA Patent database, RMI X-Change Batteries, US DOE, US NREL representative.

Cleantech costs will continue to fall

Solar, the cheapest energy source in history, will halve in price by the end of the decade

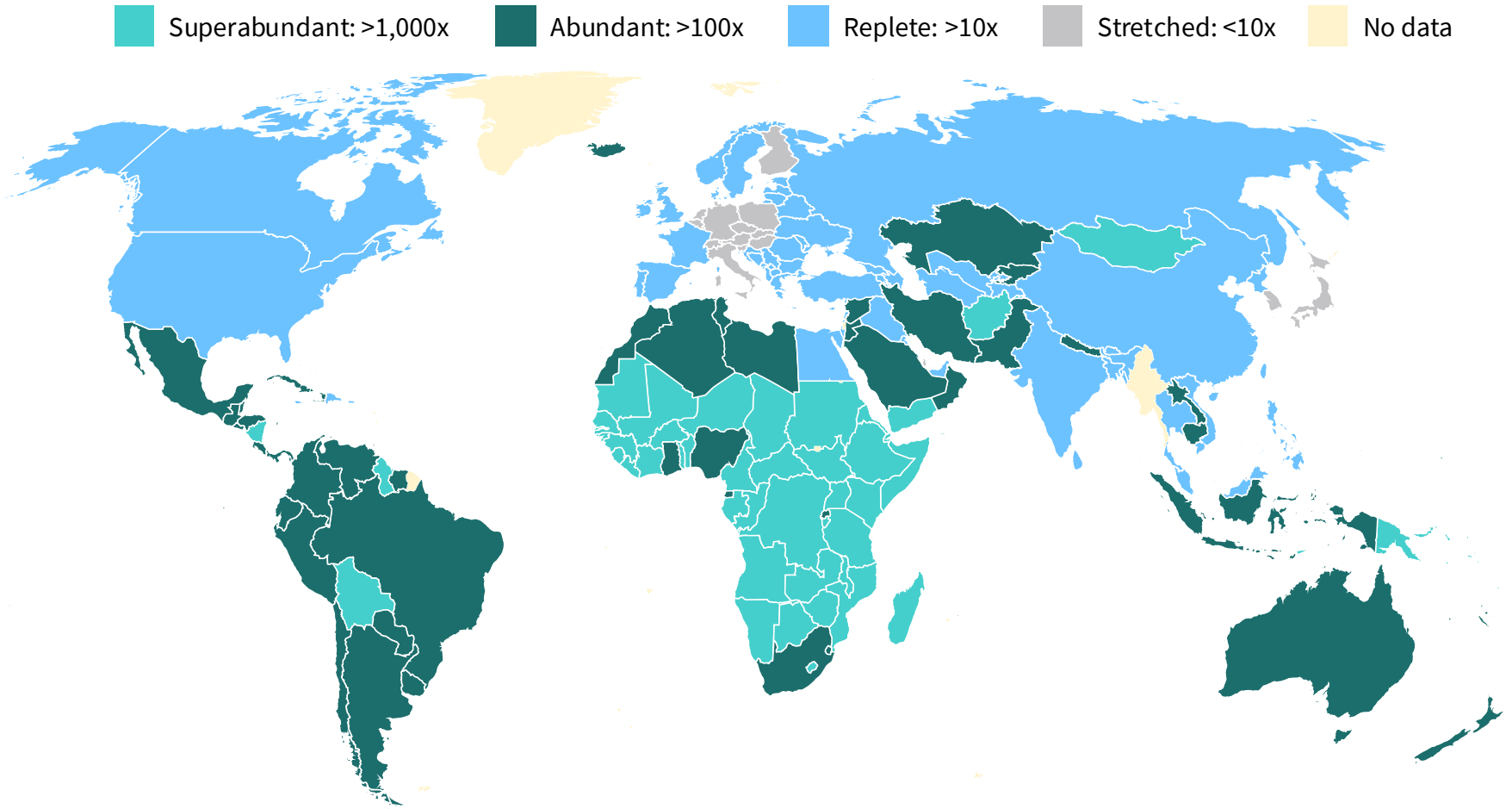


Source: BNEF, RMI analyses.

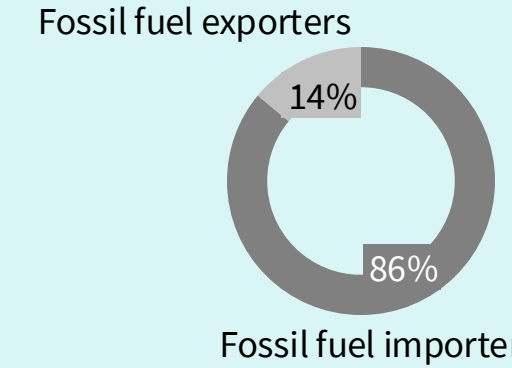
Renewables provide energy security

They are 100x bigger than fossil fuels, and every country has them

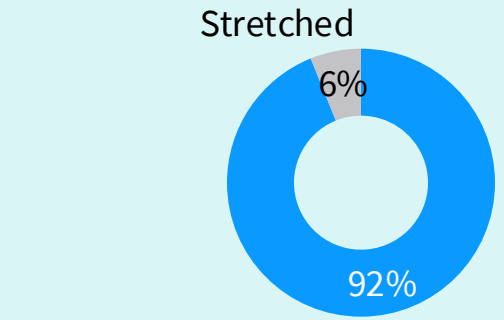
Renewable potential as a multiple of energy demand



Share of population living in countries that import fossil fuel



Share of population endowed with replete or better renewable resource



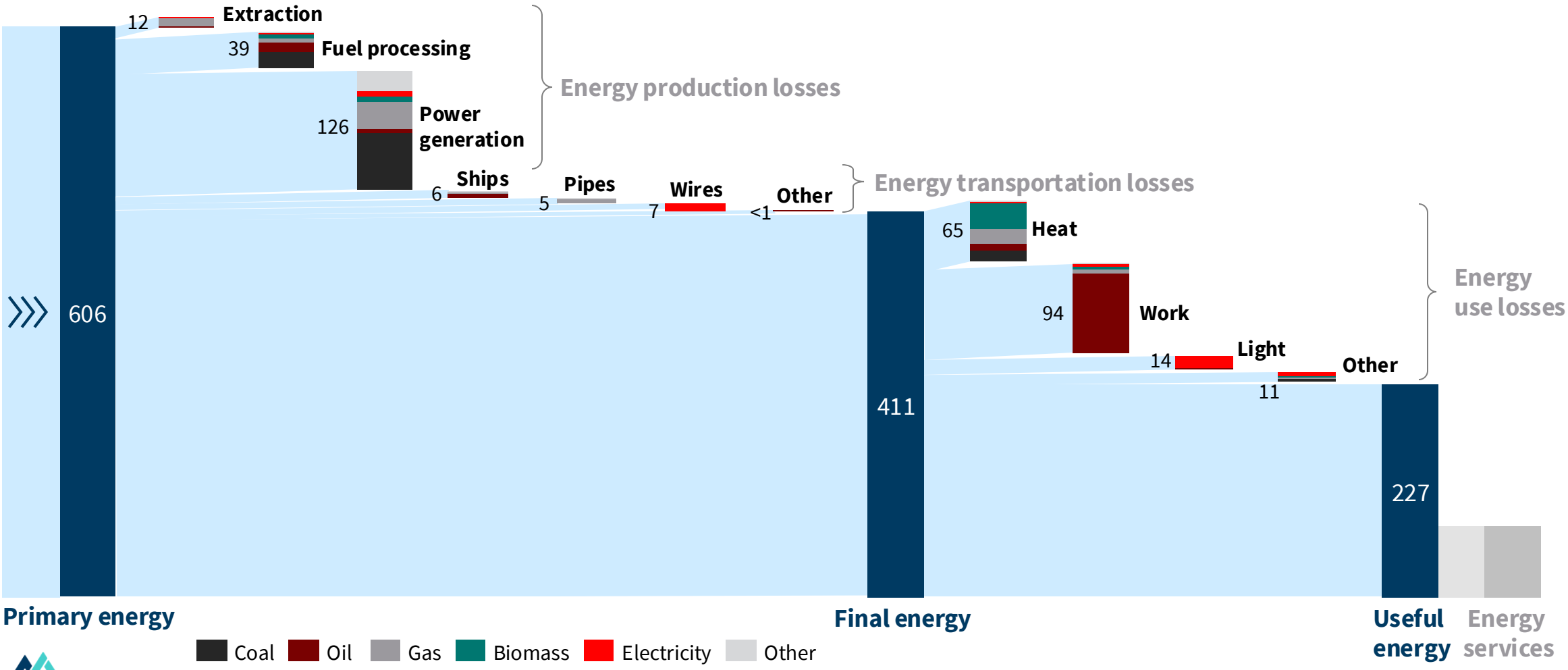
RMI

Source: Carbon Tracker, IRENA, Comtec, NREL, Solargis, RMI.

Fossil fuels are extremely inefficient

Two thirds of all fossil fuel primary energy is wasted in thermodynamic and system losses

Energy system flows, EJ, 2019



Sources: IEA, IIASA, RMI. For more see The Incredible Ineffciency of the Fossil Fuel System.

Cleantech is 3 times more efficient

Cleantech is around 3x more efficient than fossil technologies across applications

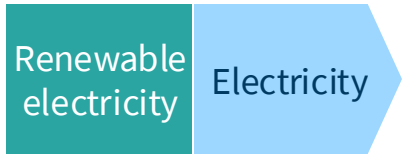
Energy production

Electricity

Fossil thermal

30%–40% efficiency

Wind and solar



100% efficiency

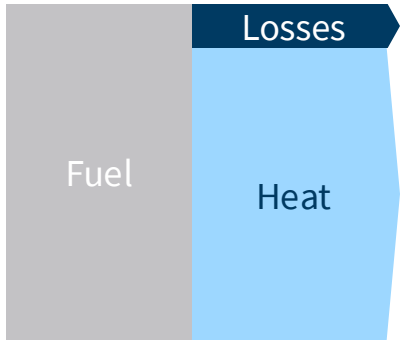
2–3x

as efficient

Energy use

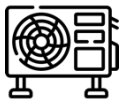
Heating

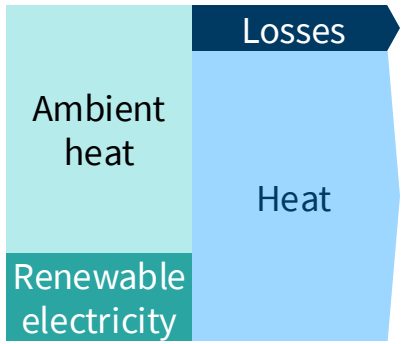
Gas boiler



85% efficiency

Heat pump





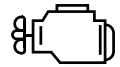
300%–400% efficiency

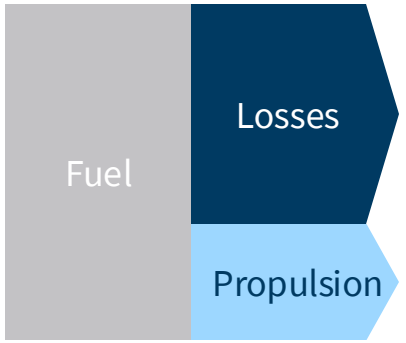
3–4x

as efficient

Transport

Internal com-bustion engine





25%–40% efficiency

Electric vehicle

80%–90% efficiency

2–4x

as efficient

Source: IEA, IIASA, RMI analysis, Adapted from Prof. Tomas Kåberger. Note: Solar and wind's 100% efficiency represents the fact that there are no conversion losses from primary to secondary energy.

The fossil fuel system is fragile

Fossil fuels impose major externalities, while collecting large rents and subsidies

$4.6 trillion In annual waste from energy efficiency losses

$2 trillion In annual fossil fuel rents

$1.3 trillion In annual explicit subsidies ($7 trillion with implicit subsidies)

86% of people live in fossil fuel-importing countries

5–6 million Annual air pollution deaths as the result of burning fossil fuels

75% Of greenhouse gases come from burning fossil fuels

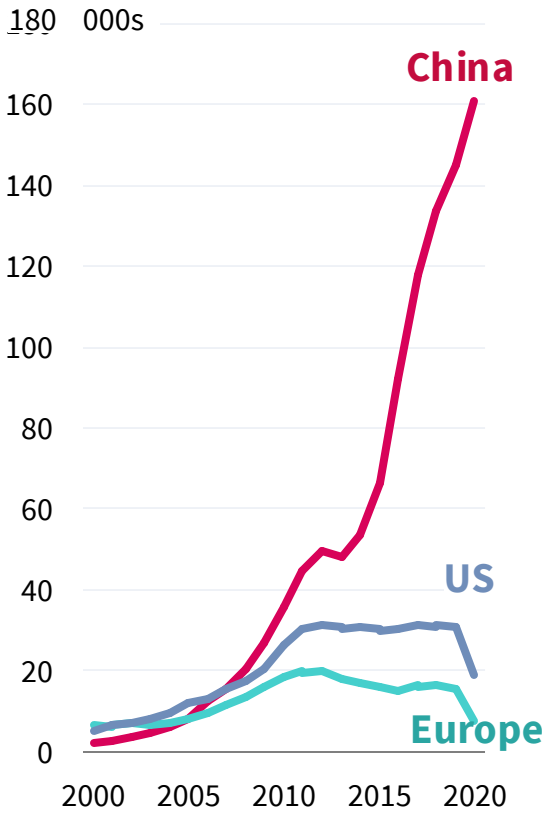
Sources: RMI, World Bank, IMF, OWID, IRENA, Lelieveld et al. (2023),BMJ, IEA, IIASA.

The world's largest energy consumer is moving fast

China is leading the way to patent, make, and deploy the energy technologies of the future

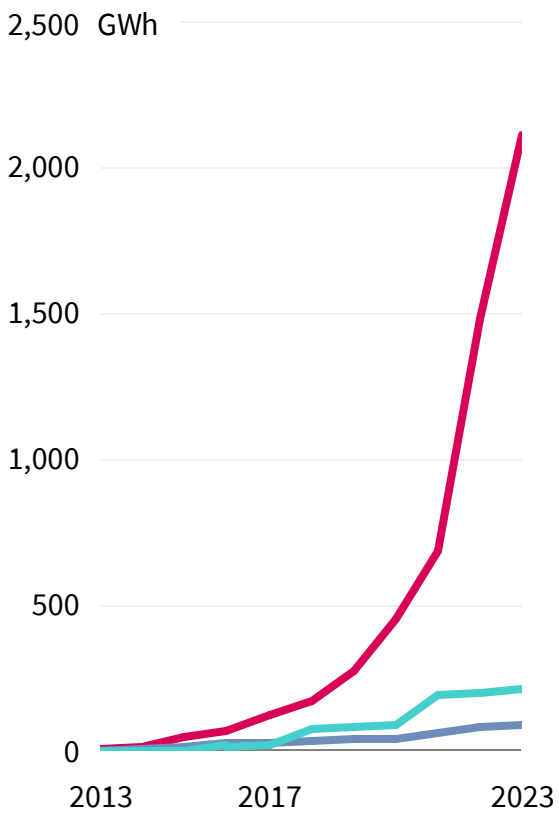
Patent

Clean energy patents



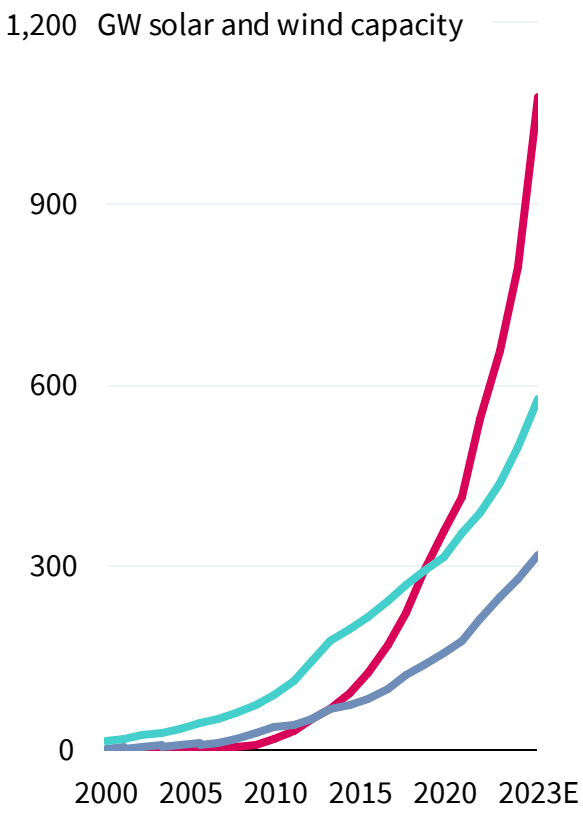
Make

Battery manufacturing capacity

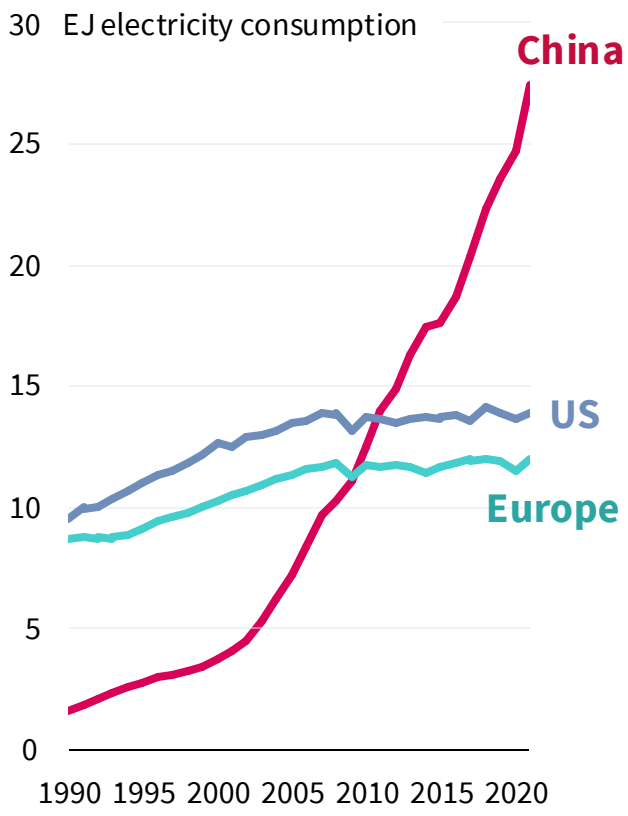


Deploy

Renewables



Electrification



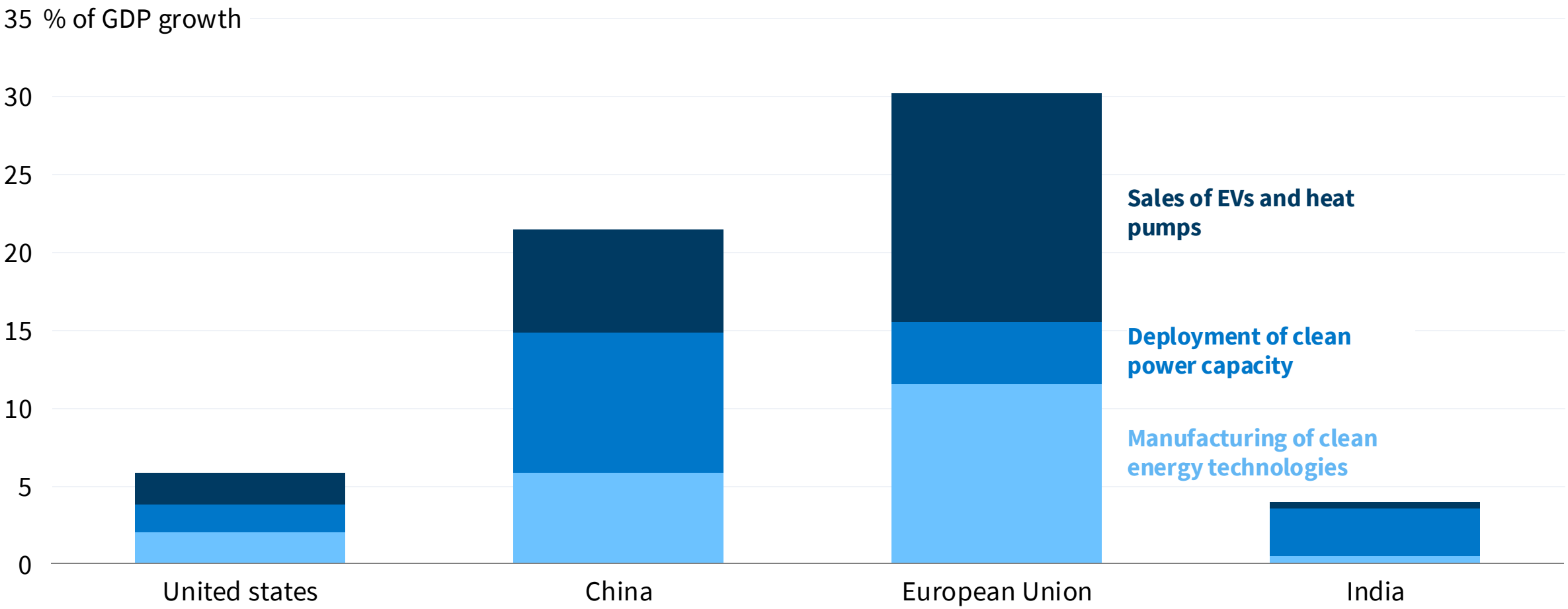
RMI

Source: IRENA, IEA, BNEF. For more see X-Change: The Race to the Top.

Everyone wants a piece of the action

Cleantech is now a key driver of GDP growth all over the world

Contribution of cleantech to GDP growth, 2023

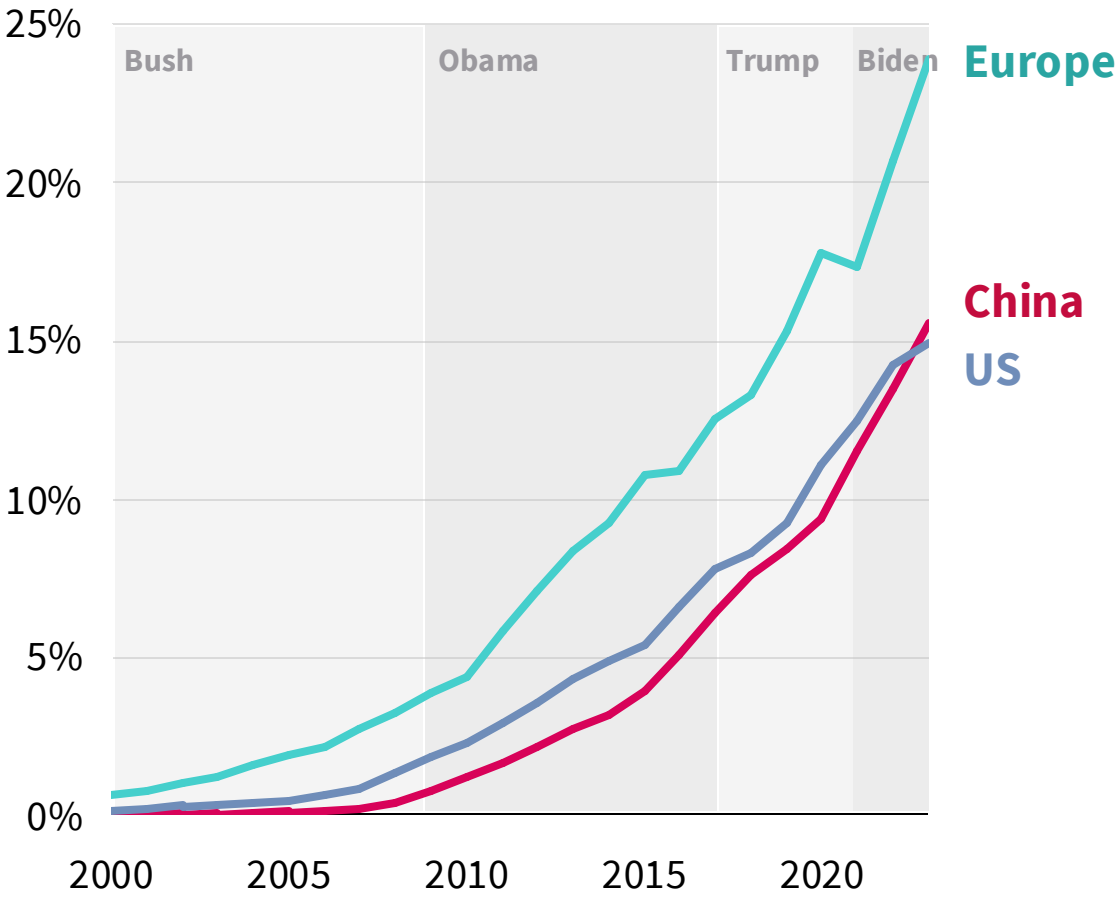


RMI Source: IEA.

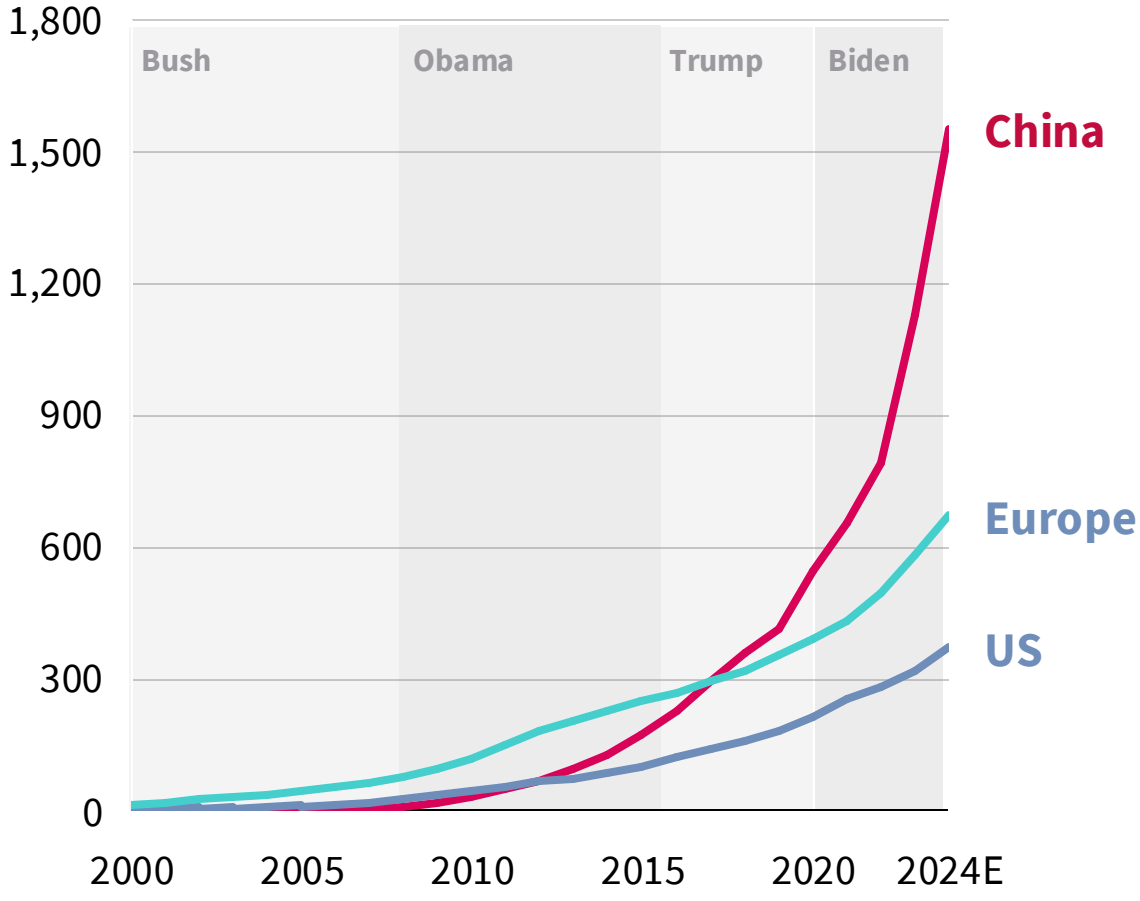
US renewables rose independent of administration

The last Trump term did not result in a significant slowdown

Solar and wind generation, %



Solar and wind capacity, GW

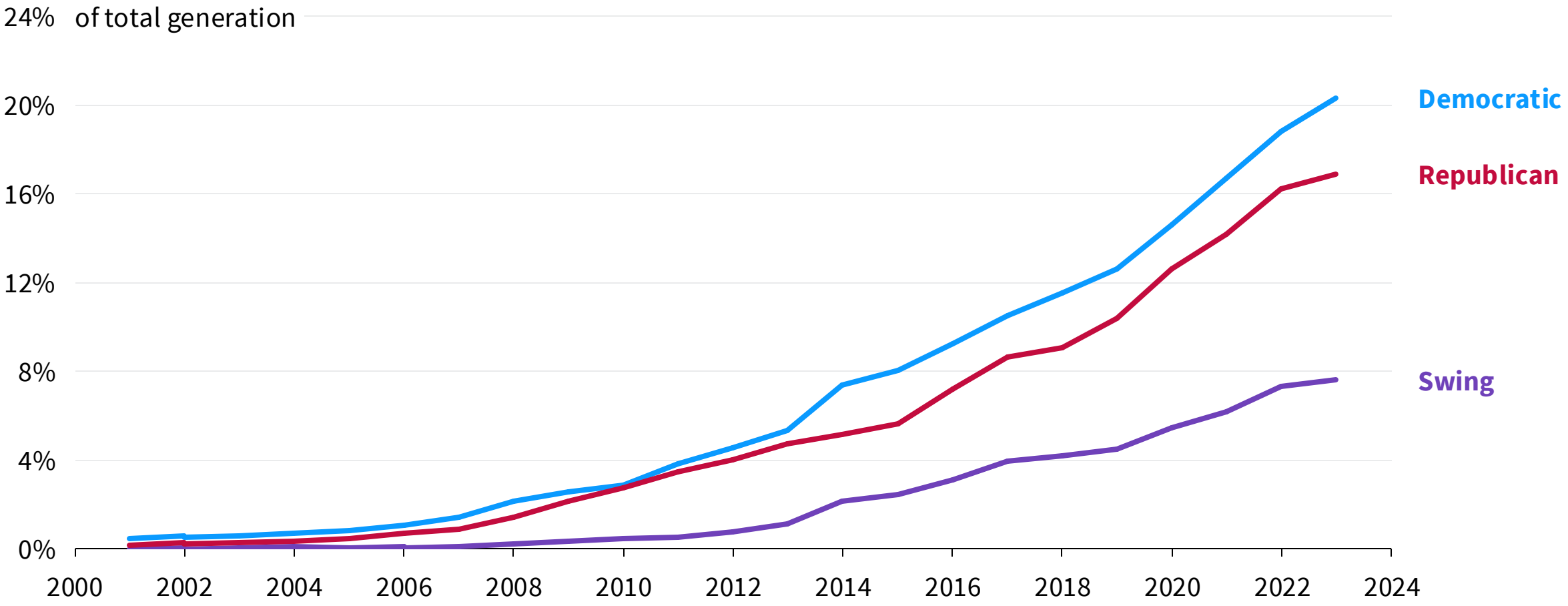


RMI *Source: Energy Institute, IEA, RMI analysis*

Wind and solar uptake has been nonpartisan

Both Democratic and Republican states have been racing up the S-curve

Solar and wind generation



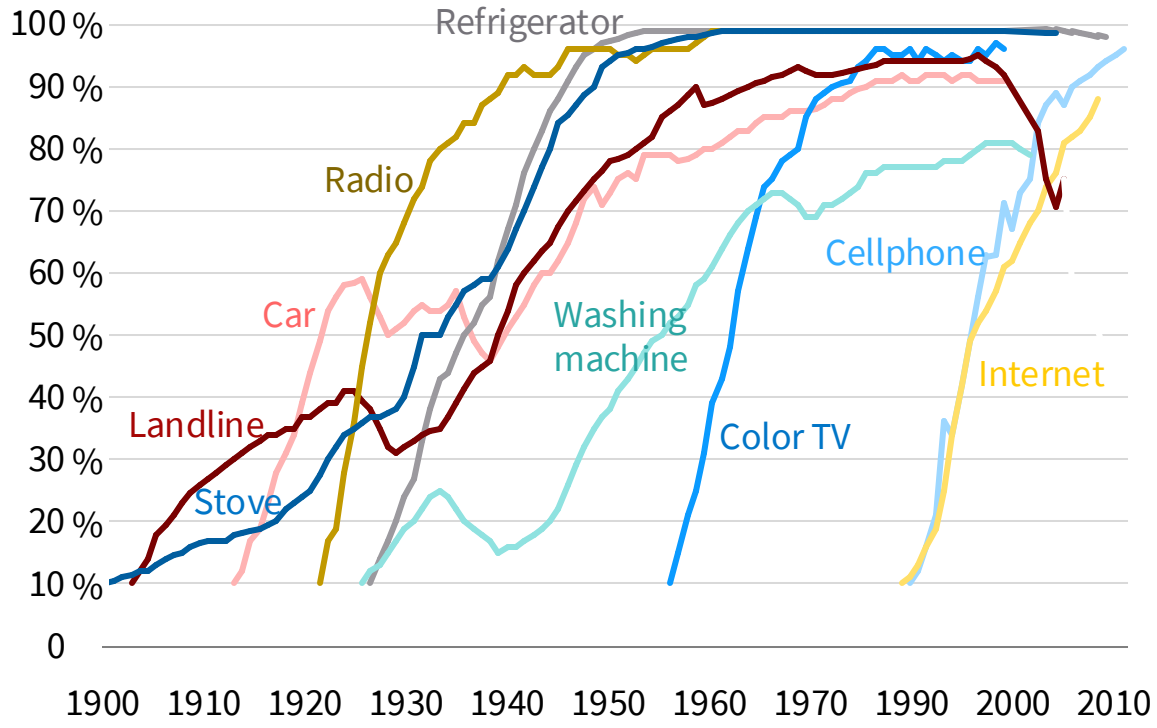
Source: EIA, RMI analysis. States' political leanings follow the widely used classifications in the lead-up to the 2024 Presidential Election.

S-curves as usual, not business as usual

We've seen this movie before. We know how technology shifts work

Individual products

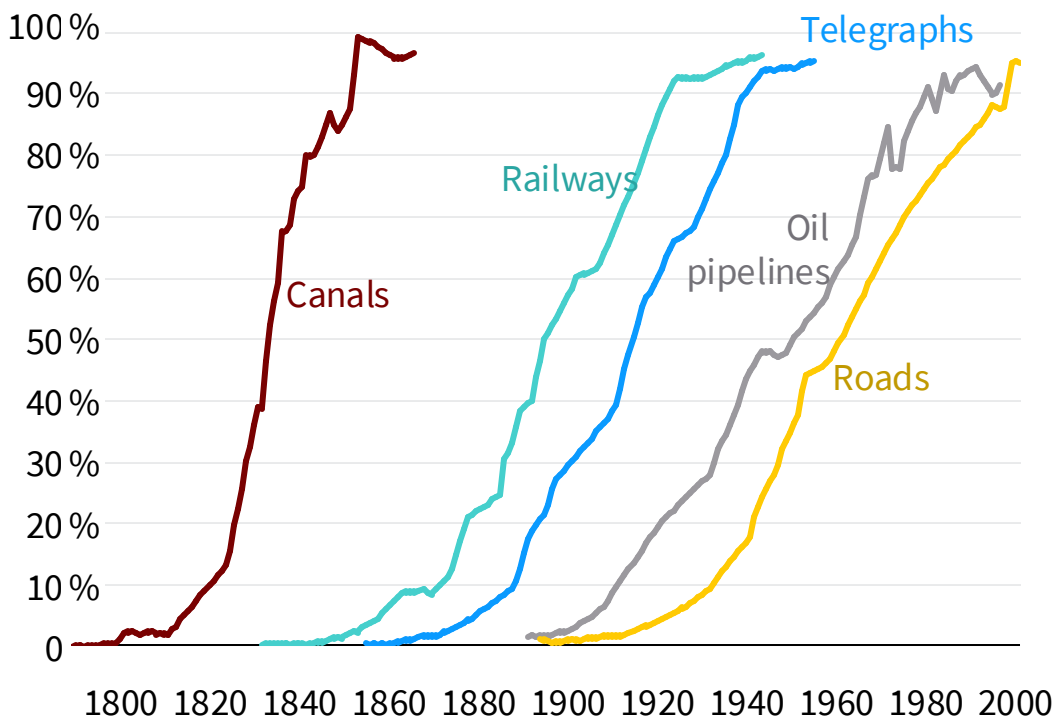
Technological adoption by household in the United States



Rapid exponential growth along S-curves is a standard characteristic of successful new technologies.

Infrastructure systems

Share of maximum size in the United States



S-curve-type growth even applies to infrastructure.

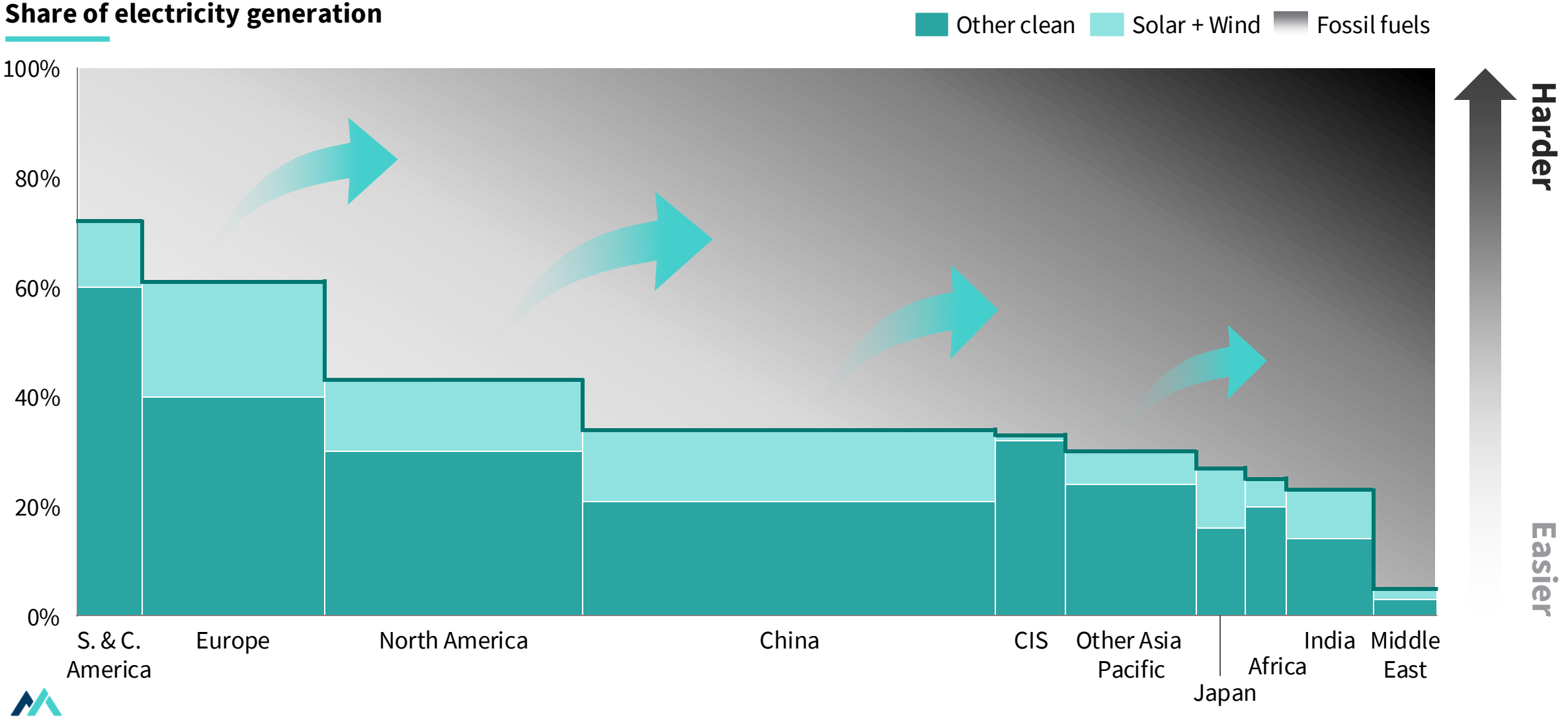
RMI

Source: Comin & Hobijn via OWID (L); Grubler (R).

Technologies cascade across geographies

We should focus on the opportunities before our very eyes, not on potential end-game barriers

Share of electricity generation



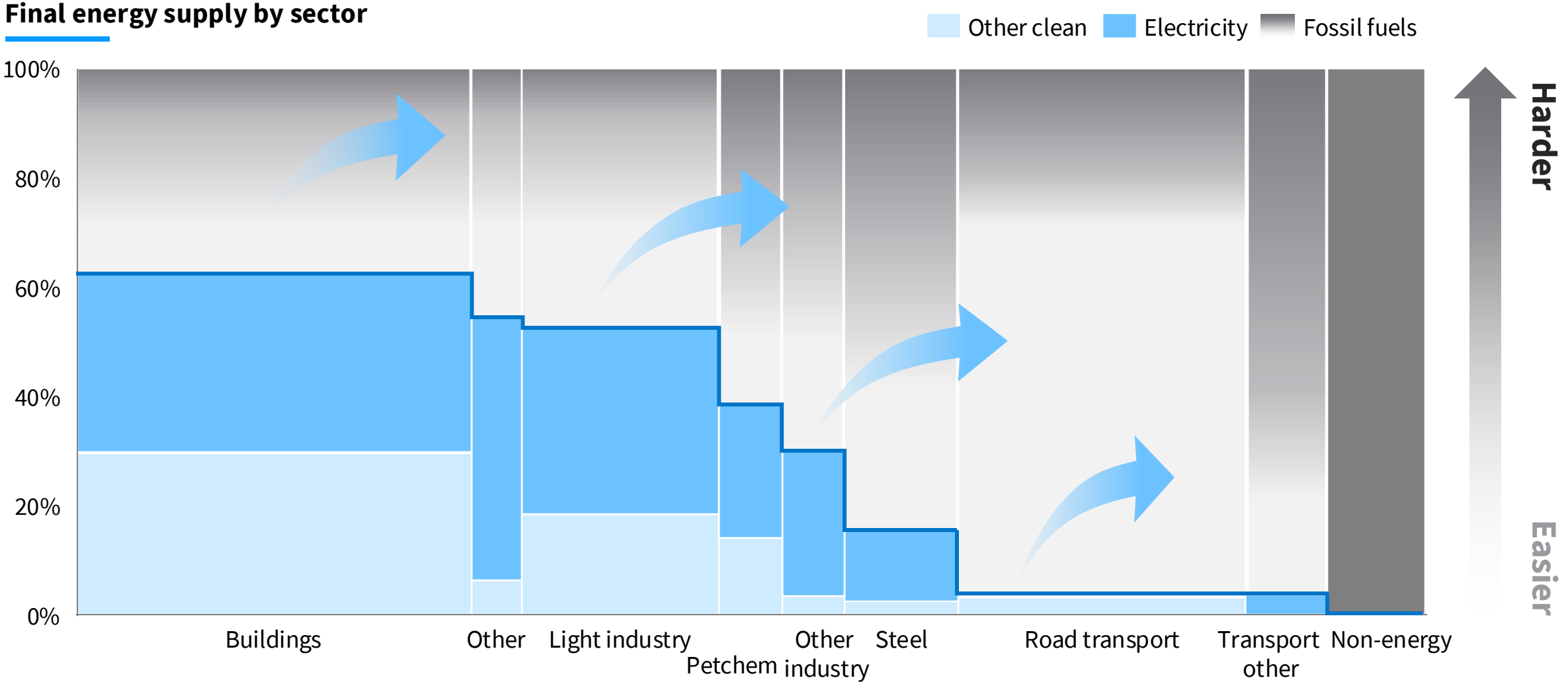
RMI

Source: Energy Institute, RMI. For more see X-Change: Electricity.

Technologies cascade across sectors

Every sector has low-hanging fruit at the frontier

Final energy supply by sector



Source: BNEF for final energy supply 2022, RMI.

Index

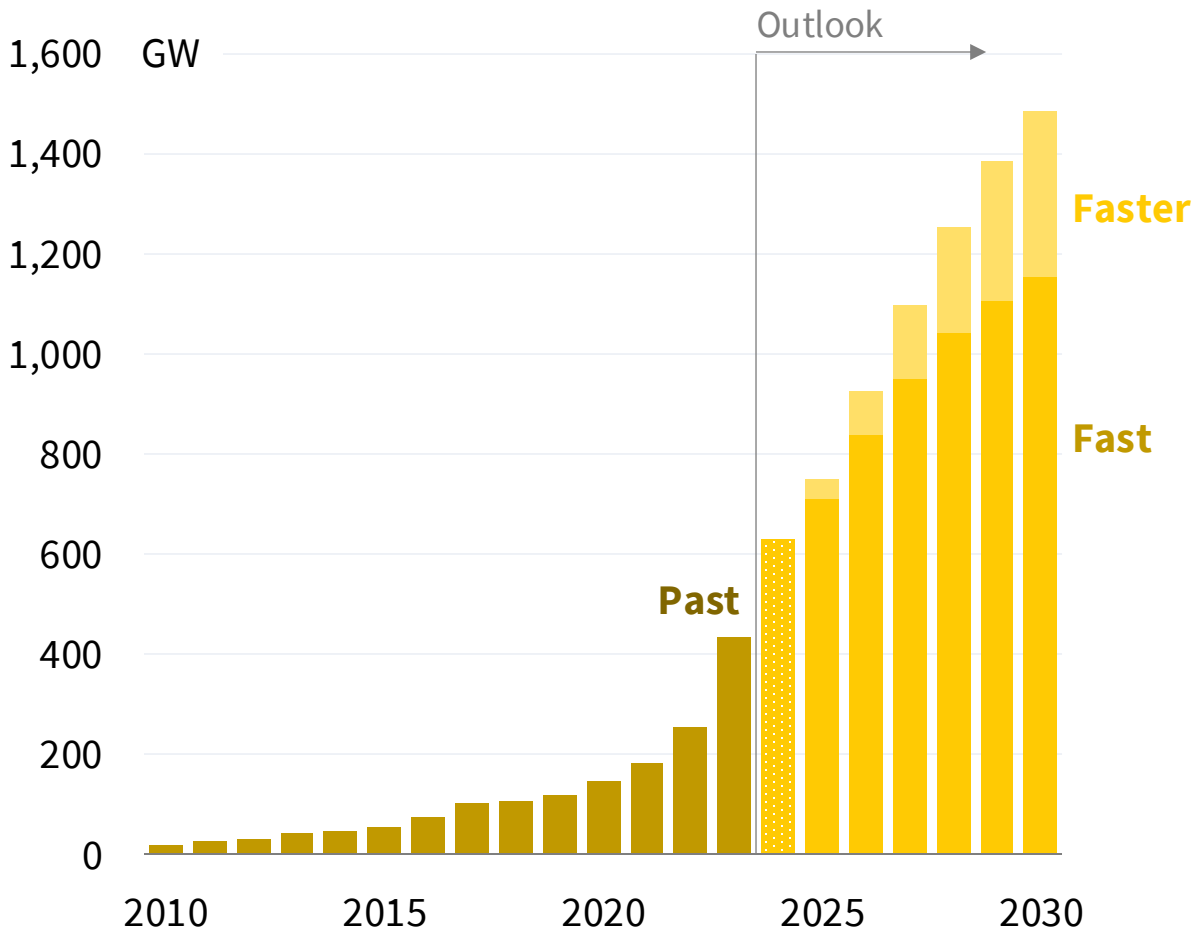
5 Implications for the energy system

- If change continues on S-curves, then by 2030 we expect solar sales of over 1,000 GW a year and battery sales of over 6,000 GWh a year.
- S-curves imply that by 2030 solar and wind generation will triple to over 12,000 TWh and EVs will be two-thirds of car sales.
- The annual electrification rate is likely to more than double to 0.5% in 2030 as transport joins the party, and success in China drags up electrification rates elsewhere.
- Annual efficiency gains are likely to double from the 1.5% average of the past two decades to at least 3% as the result of the rising share of renewables, electrification, and a greater focus on end-use efficiency.
- Renewables will push out fossil electricity, electrons will push out molecules, and efficiency will reduce waste. In a typical X shaped pattern.
- Over 75% of fossil fuel demand today is threatened by rapidly growing cleantech alternatives.
- Fossil fuel demand will be squeezed between efficiency and cleantech. The demand plateau will last until the end of the decade, and then clear decline will set in.

Super-fast growth in solar and battery sales

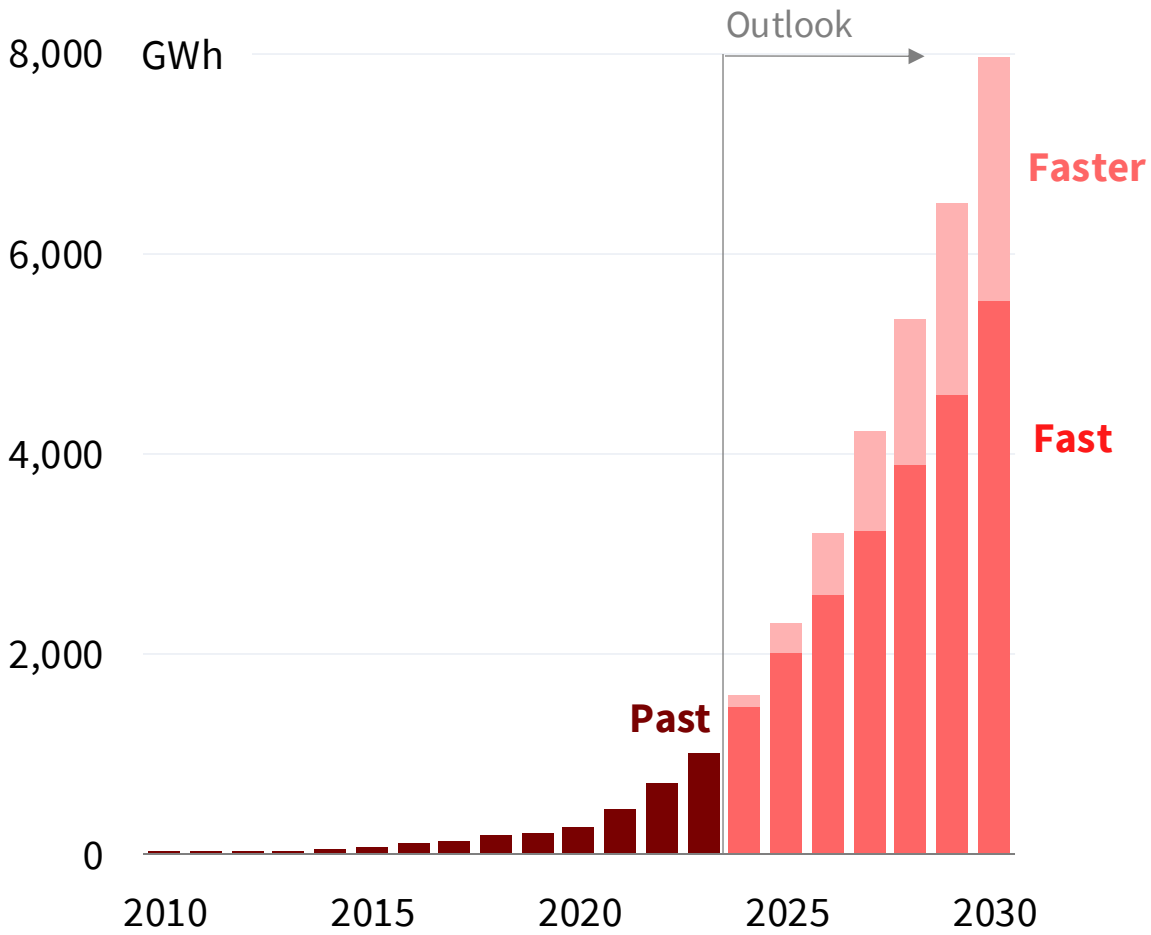
Solar sales are on track for over 1,000 GW per year by 2030

Global solar sales



Battery sales are likely to be over 6,000 GWh a year by 2030

Global battery sales

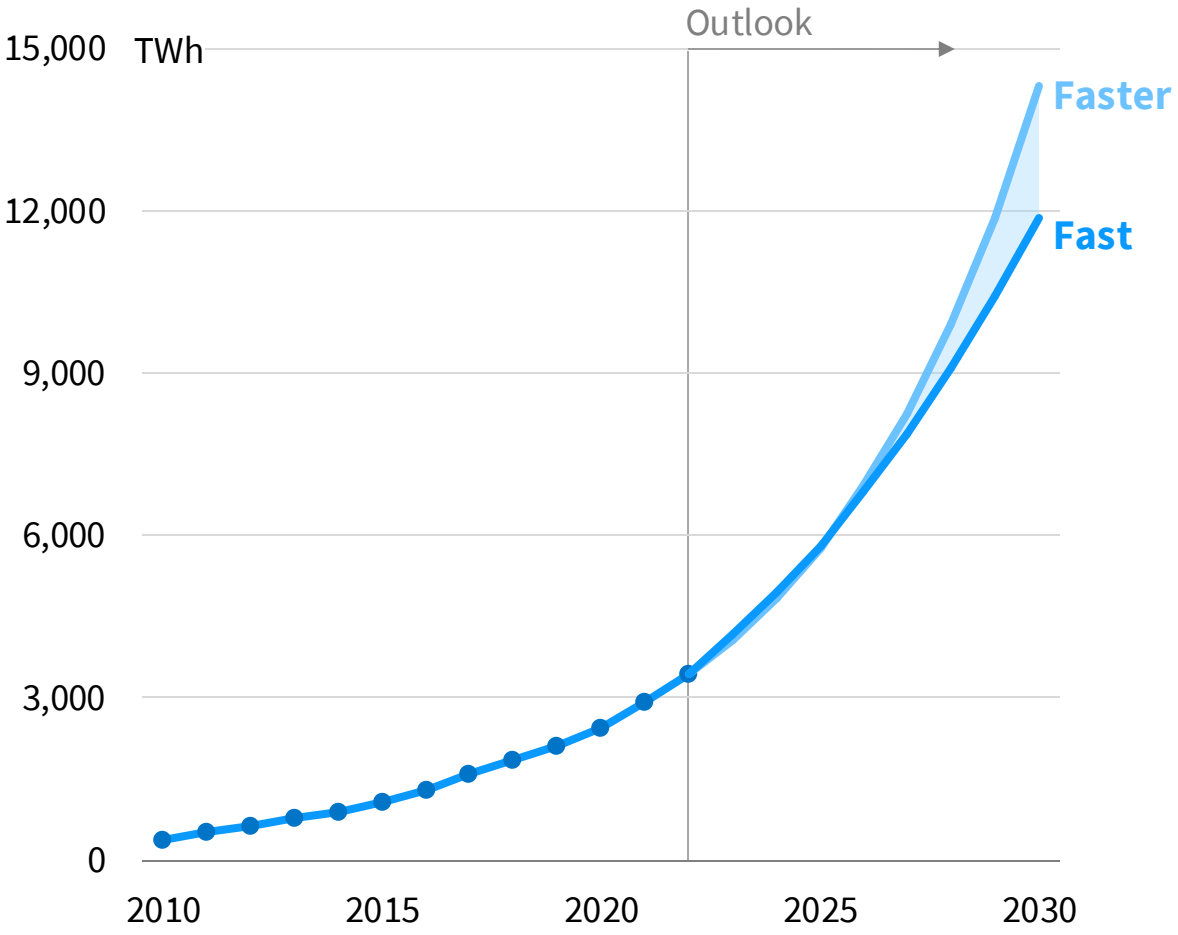


Source: BNEF historical and 2024E for solar (high), RMI S-curves. For more see X-Change: Batteries.

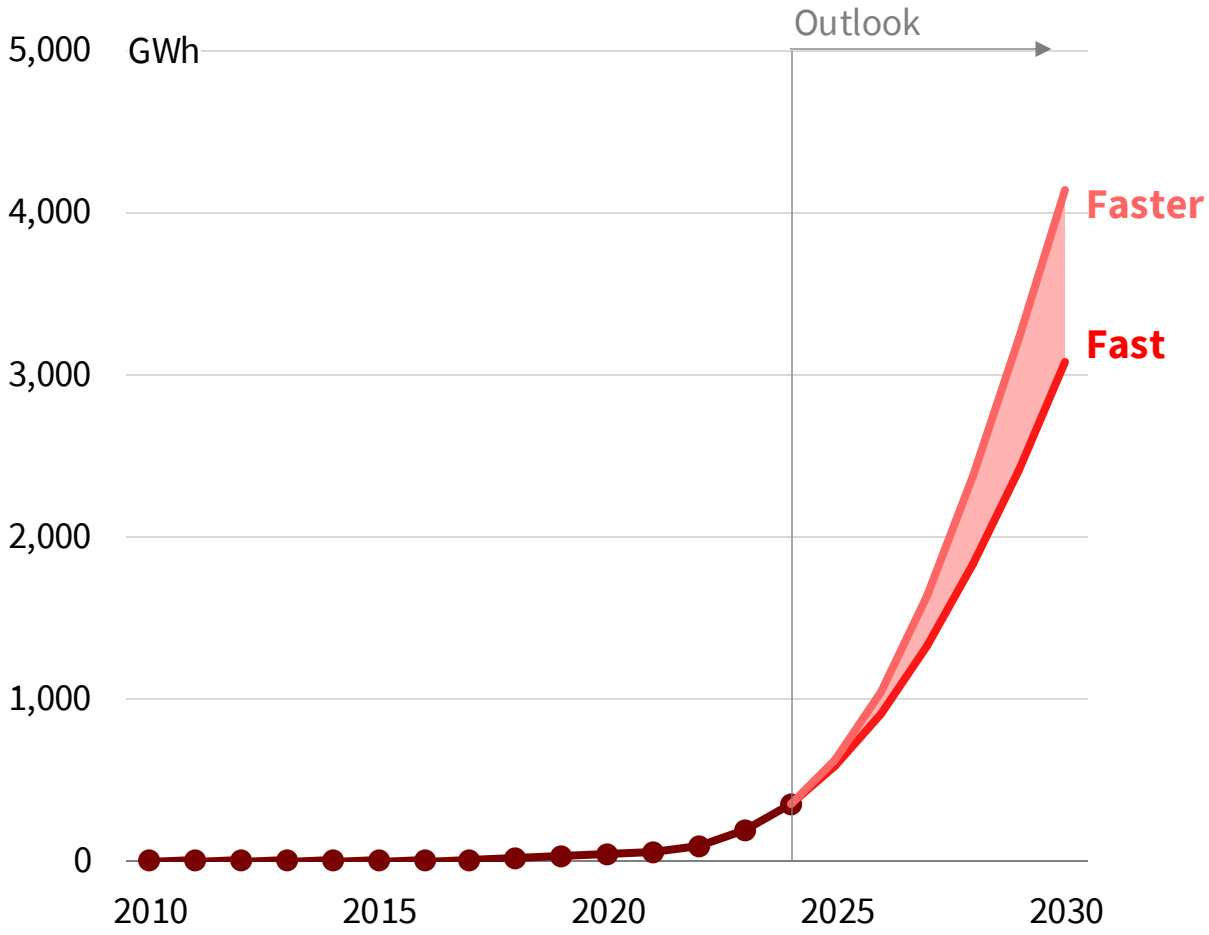
Renewables will keep rising up their S-curves

As the renewable revolution will continue to solve barriers to change

Solar and wind generation



Battery stationary storage

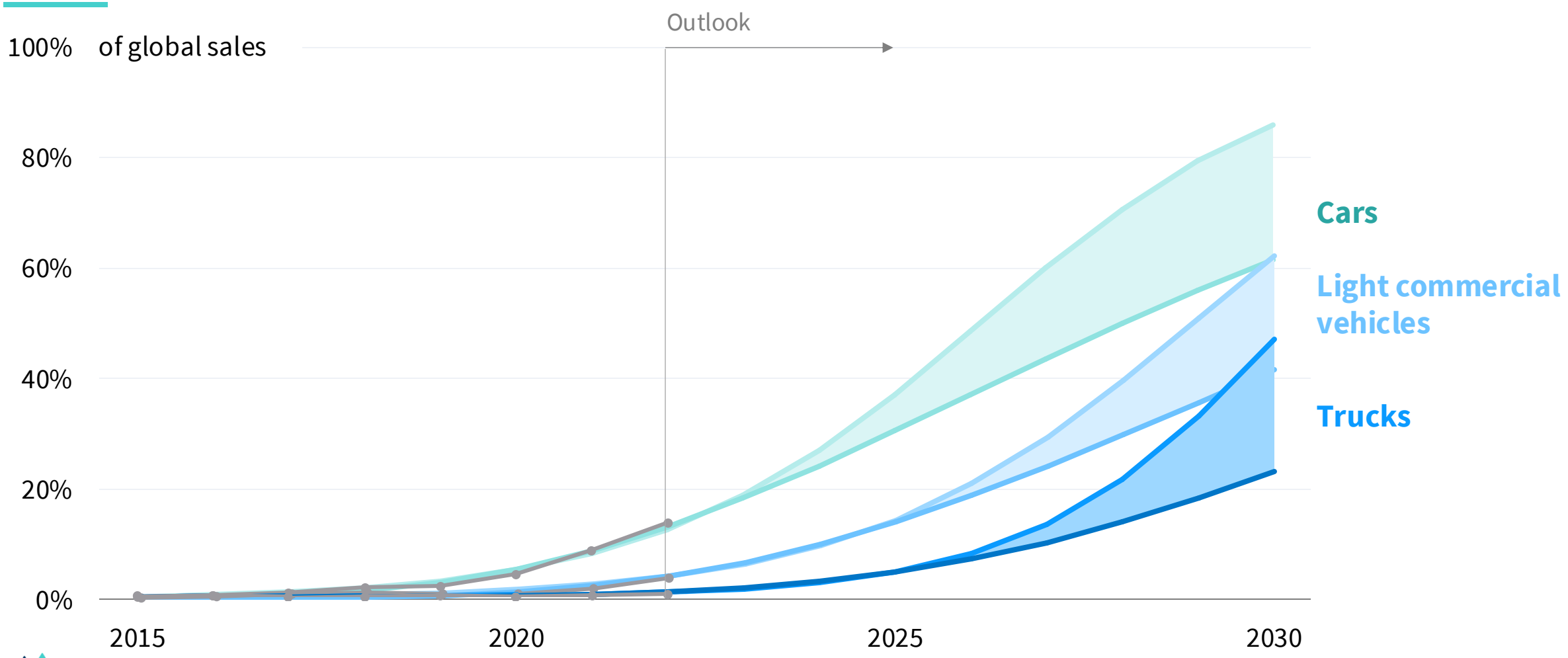


Source: Energy Institute, BNEF, RMI S-curves. For more see X-Change: Electricity.

The electric vehicle domino effect will continue

Where cars go, vans and trucks follow

The electric vehicle domino

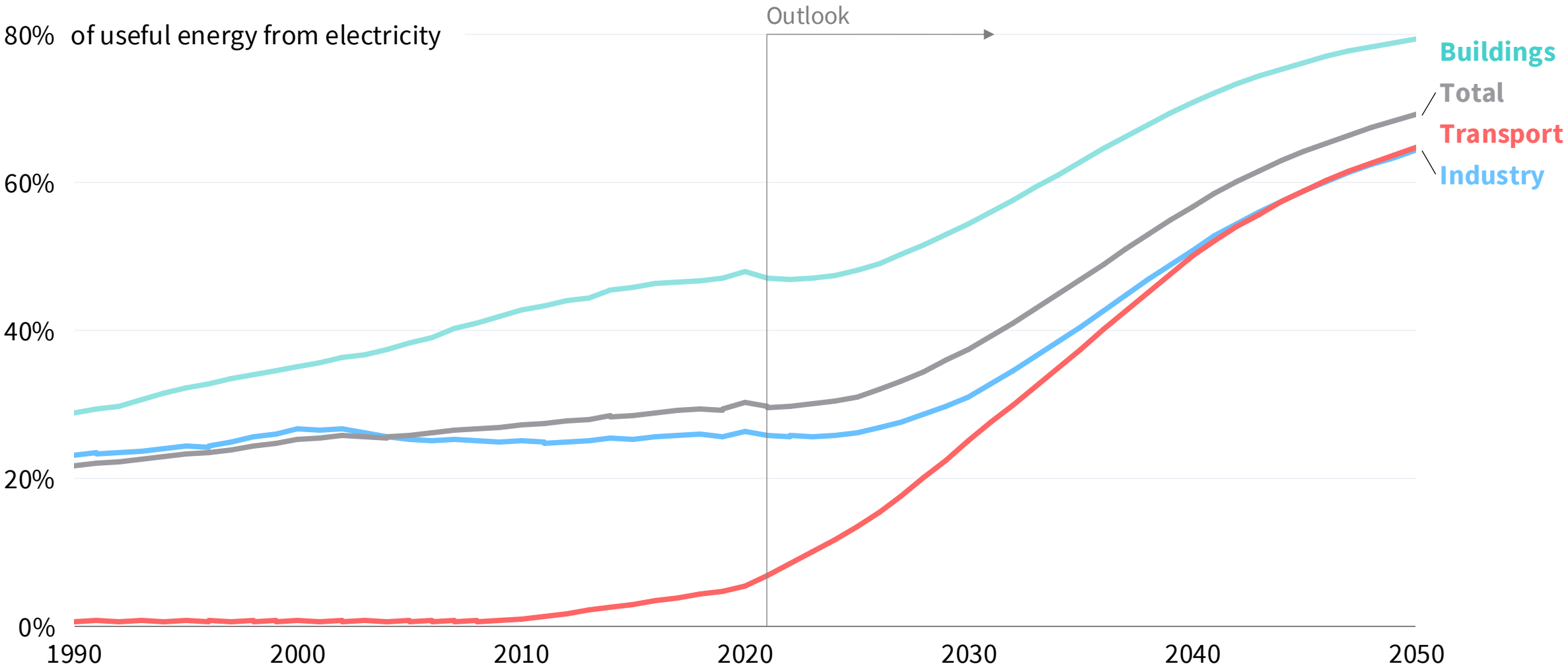


RMI

Source: BNEF, RMI S-curves. For more see X-Change: Batteries.

Electrification will pick up speed

Transport is joining the party just as electrification picks up in other sectors

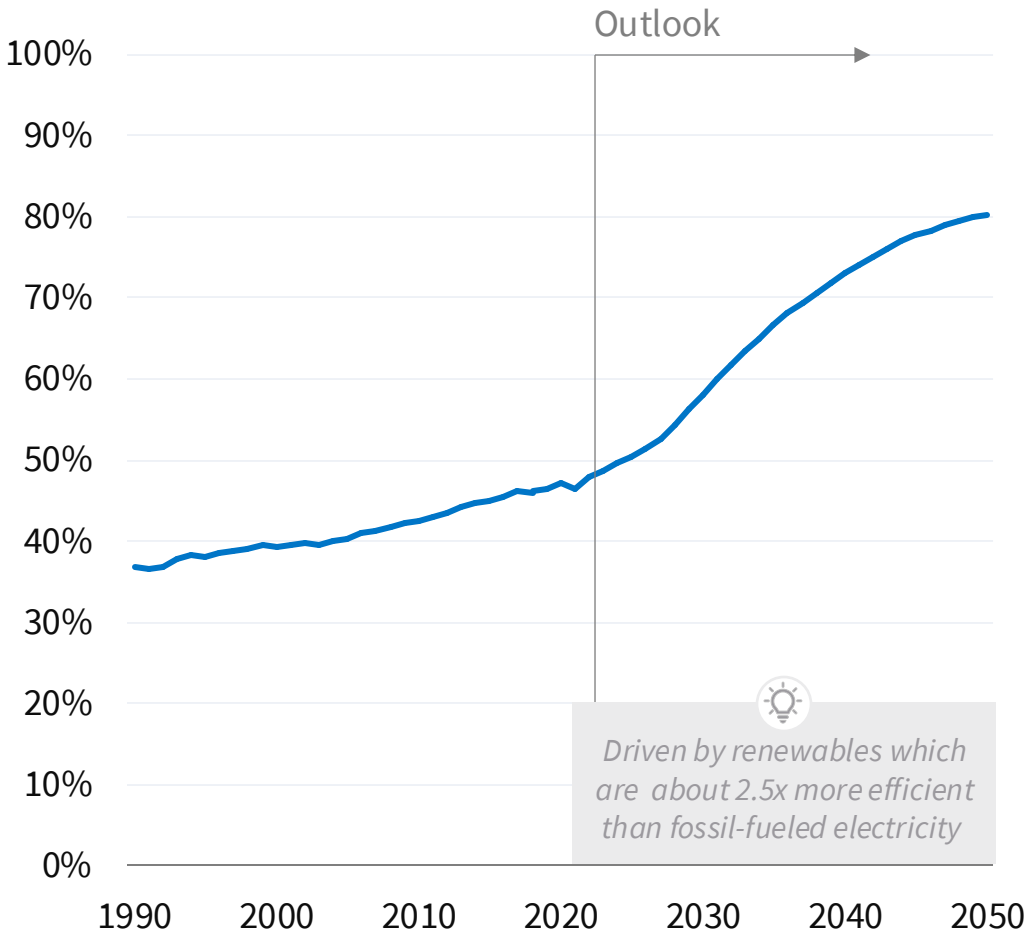


Source: Rystad Energy 1.6°C.

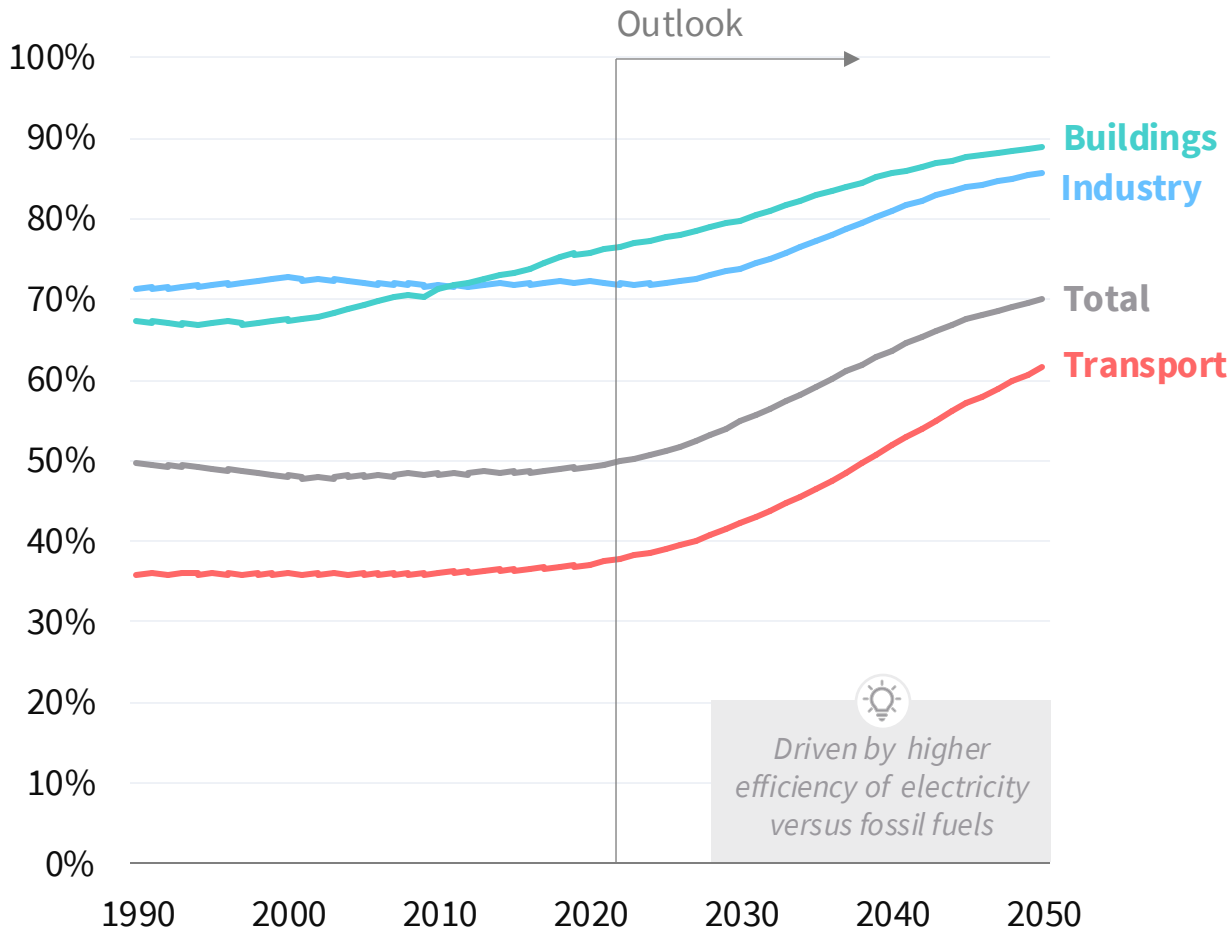
Efficiency will be pulled up the S-curve

Faster cleantech deployment will speed up efficiency improvements

Electricity generation efficiency



End-sector efficiency

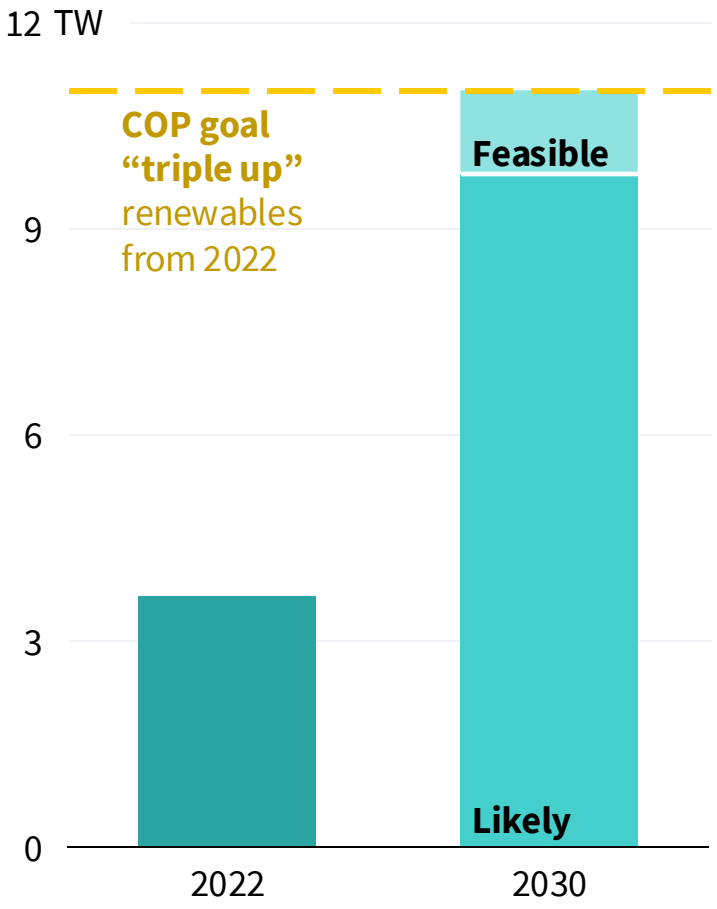


Source: Rystad Energy 1.6 °C. Electricity efficiency is final as a share of primary. Sector efficiency is useful as a share of secondary.

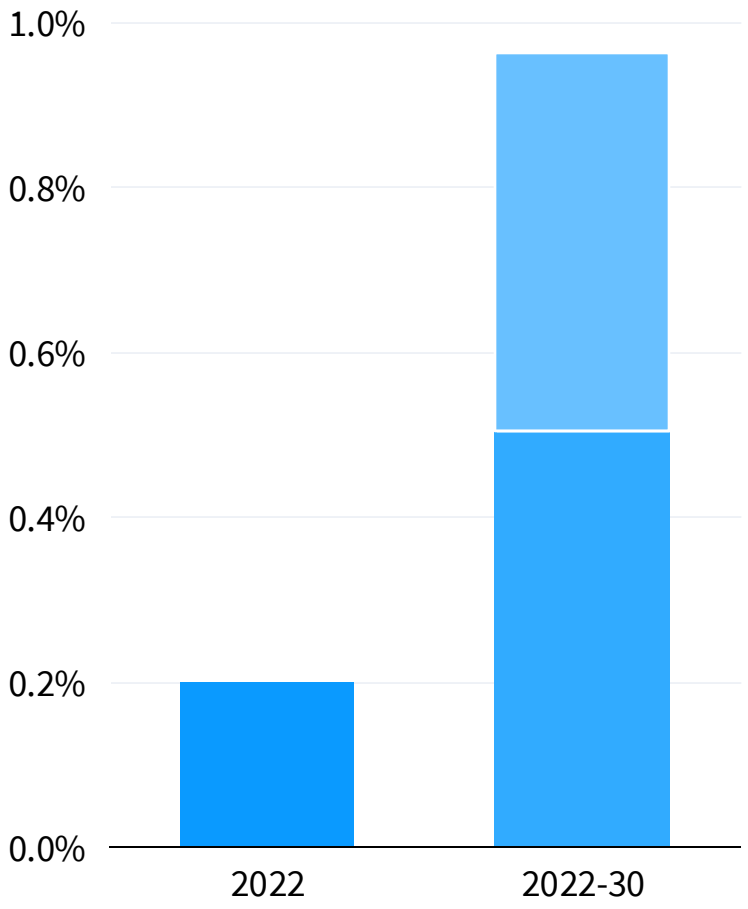
Tripling renewables by 2030

S-curves suggest we will triple renewables, and more than double electrification and efficiency rates

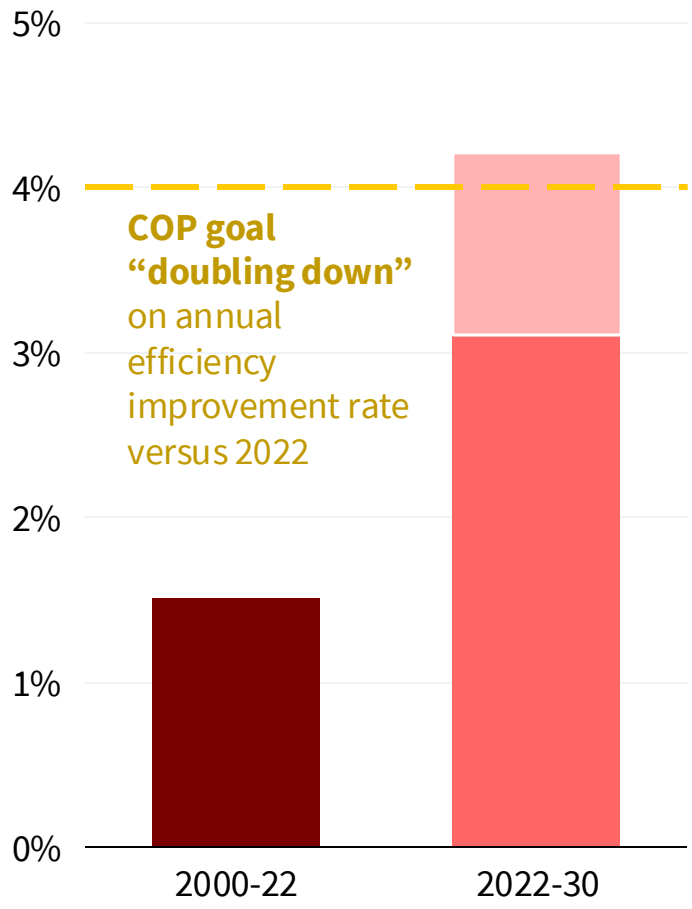
Renewable capacity



Annual rate of electrification



Annual primary efficiency gains



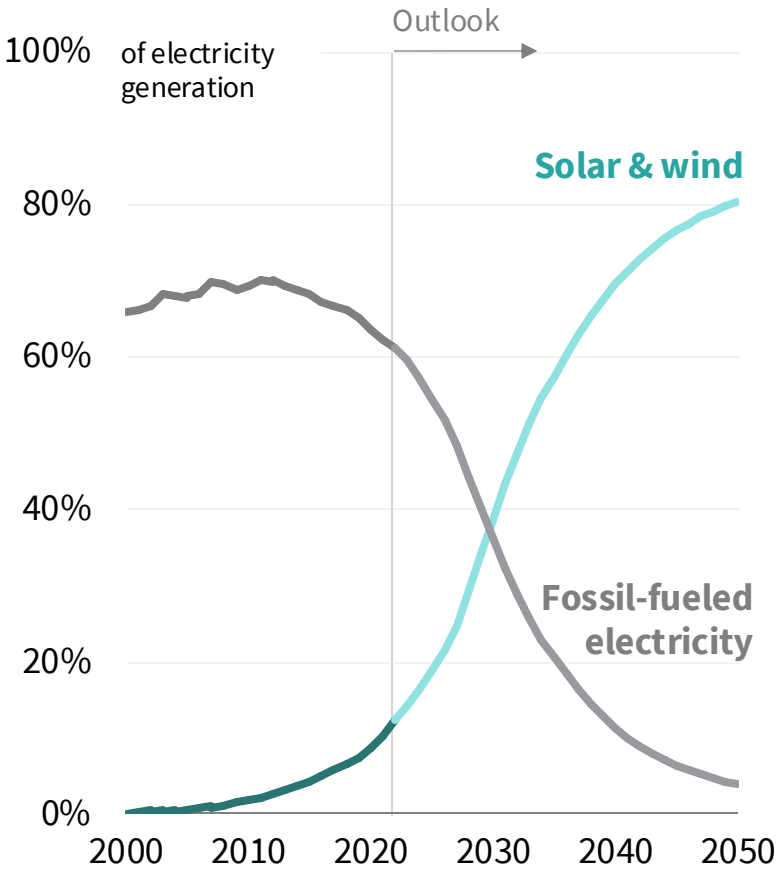
Source: IEA APS scenario as likely (Announced Pledges Scenario); NZE as feasible (net zero emissions).

In with the new, out with the old

Renewables push out fossil electricity, electrons push out molecules, and efficiency reduces waste

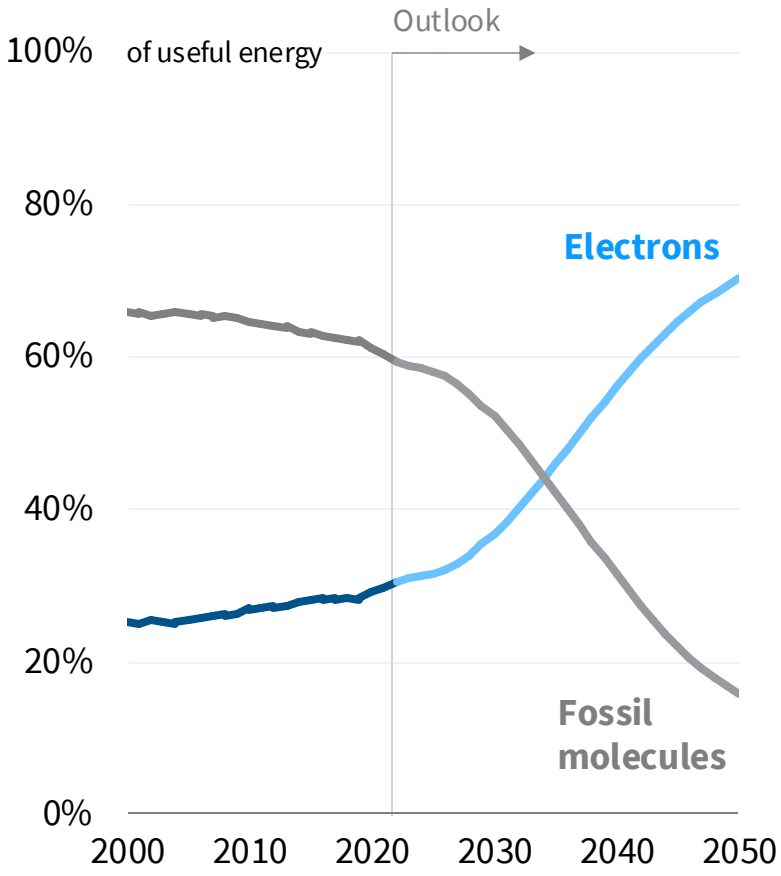
Renewables

Renewables beat fossil-fueled electricity



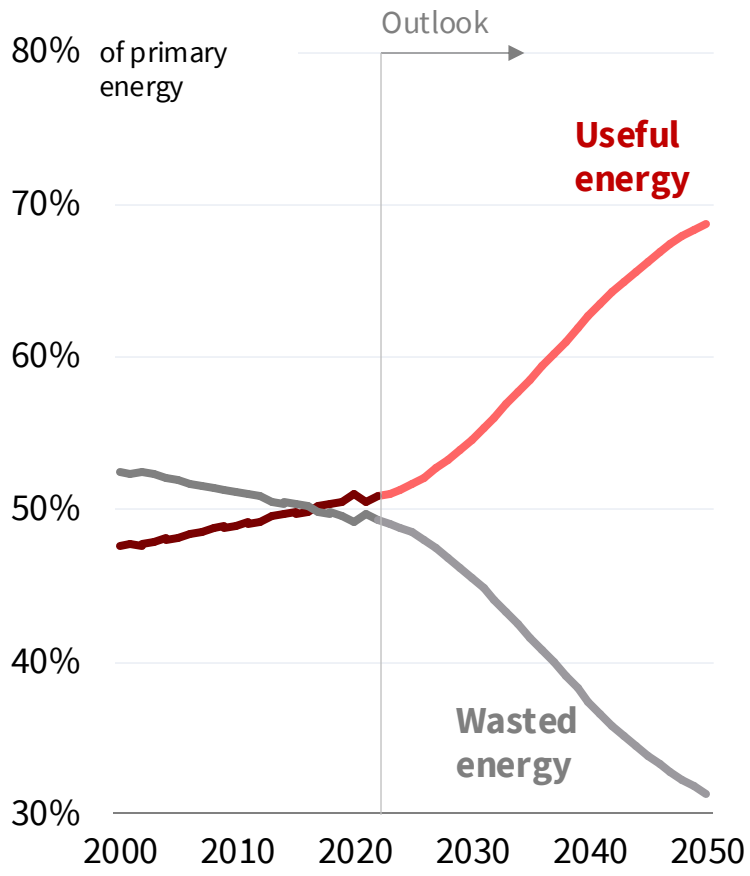
Electrification

Obedient electrons beat fiery molecules



Efficiency

Efficiency beats waste



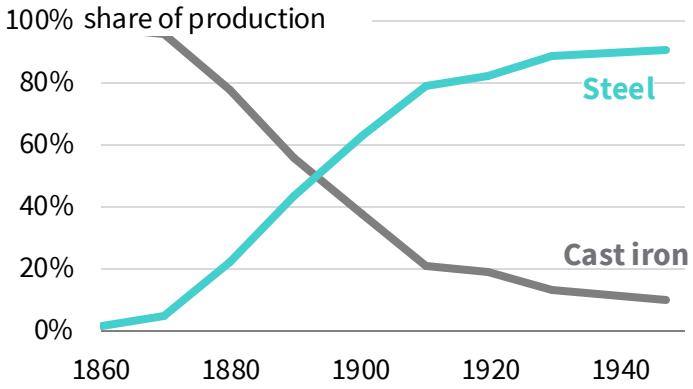
RMI

Source: Rystad Energy 1.6°C scenario.

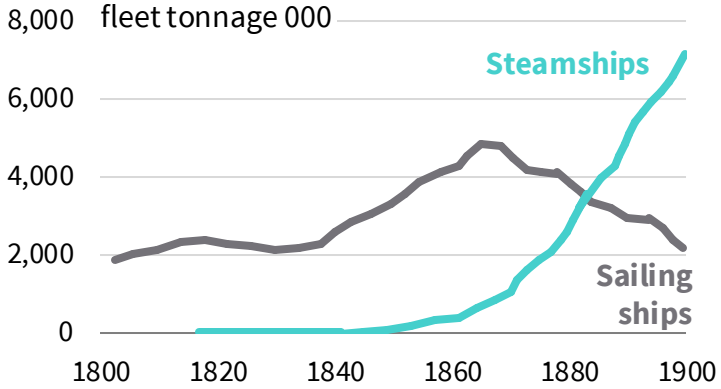
We have seen this X shaped pattern before

An X shaped technology transition is standard so we should not be surprised

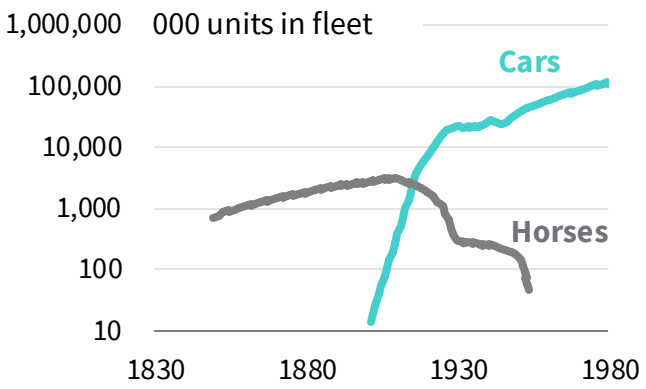
Industry: Cast iron to steel



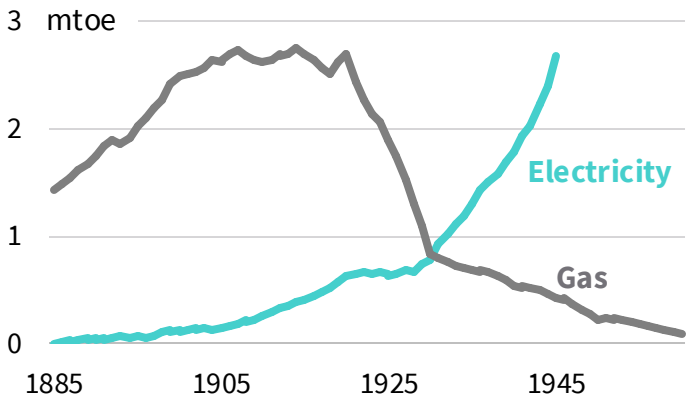
Ships: Sailing ships to steamships



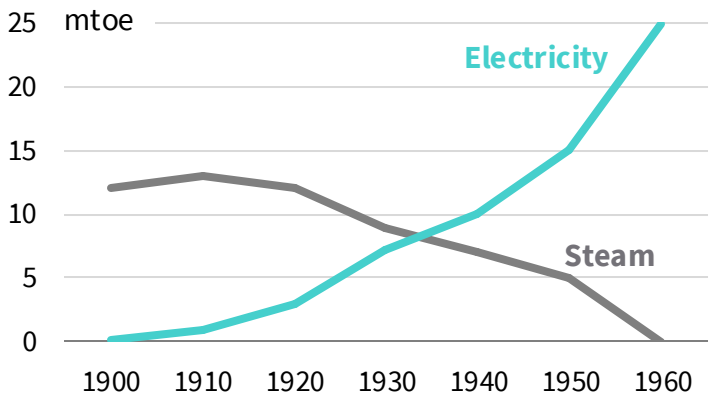
Land transport: Horses to cars



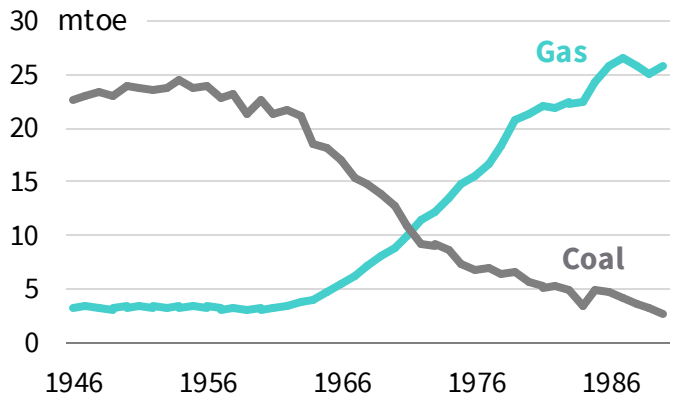
Lighting: Gas to electricity



Power: Steam to electricity



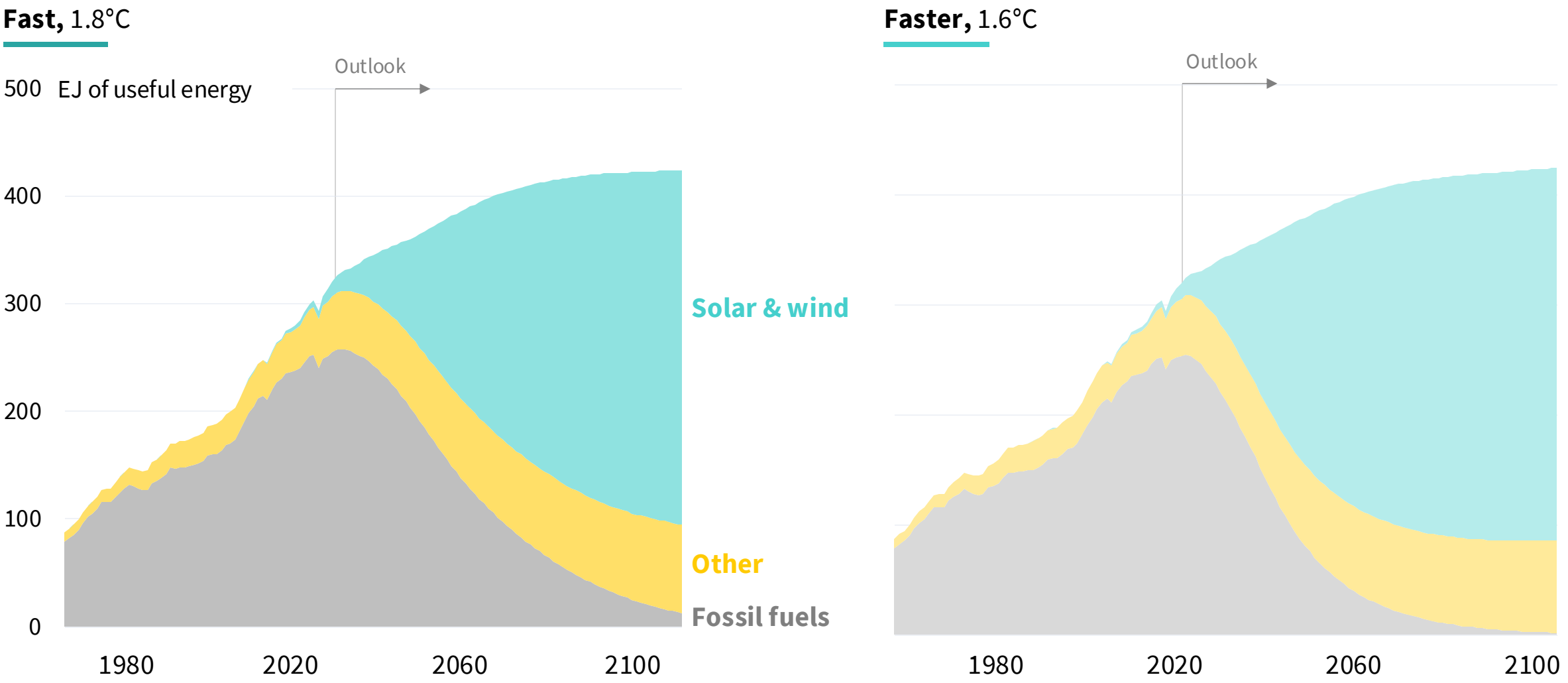
Heat: Coal to gas



Source: Perez, Fouquet, Nakicenovic, Mitchell; Note: all UK charts except horses to cars (US).

A new energy system is coming

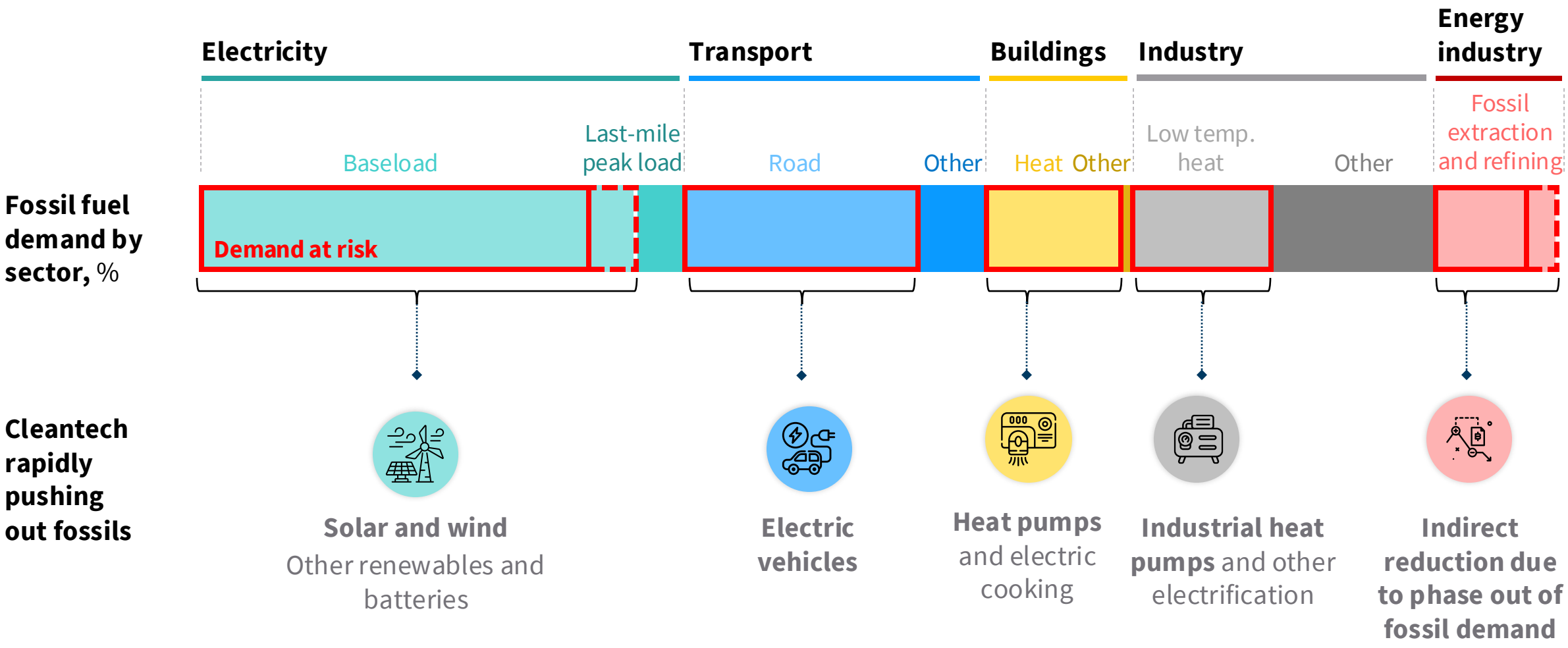
Fast or faster; either we are off the fossil plateau by the late 2020s or by the early 2030s



Source: Rystad 1.6° & 1.8°C degree scenario.

The largest areas of fossil fuel demand are most at risk

Over 75% of fossil demand today is under direct threat by exponentially growing cleantech

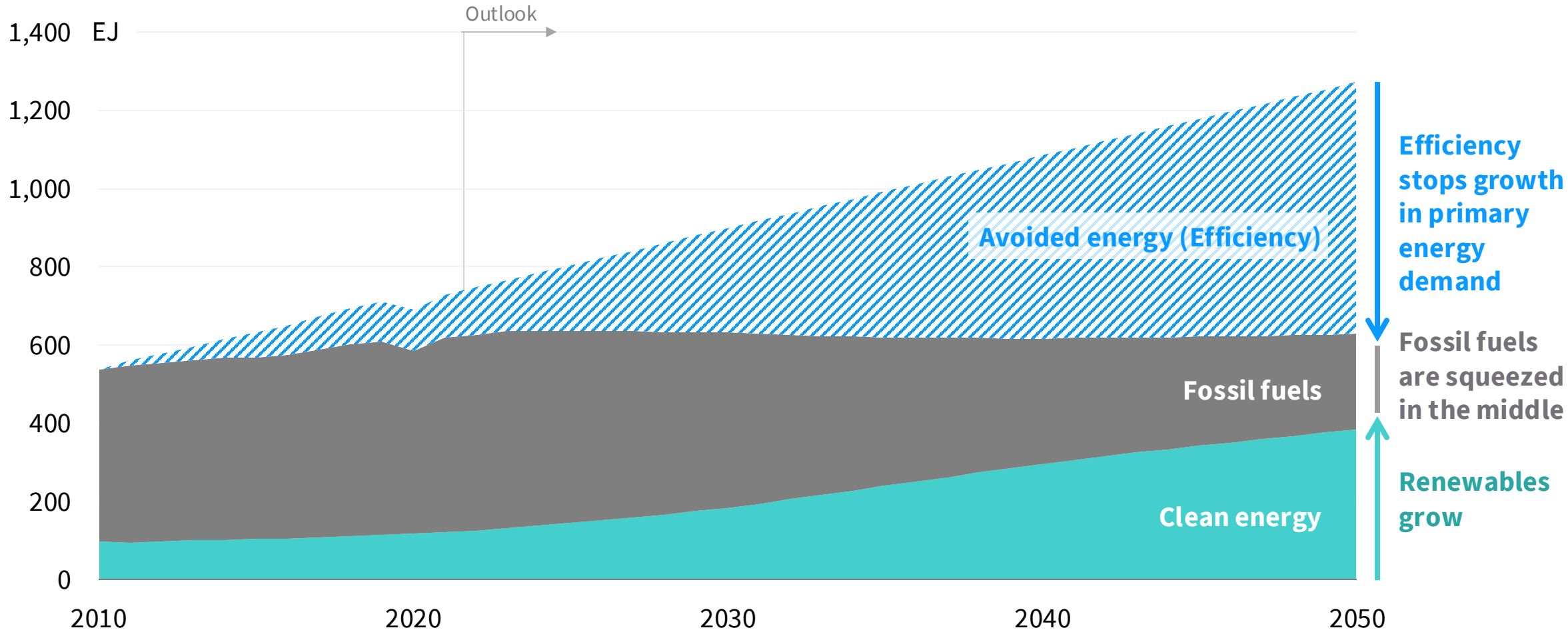


Source: IEA, IIASA, RMI.

Fossil fuel demand gets squeezed

The growth of cleantech and rising efficiency will squeeze out fossil fuel demand

Primary energy supply

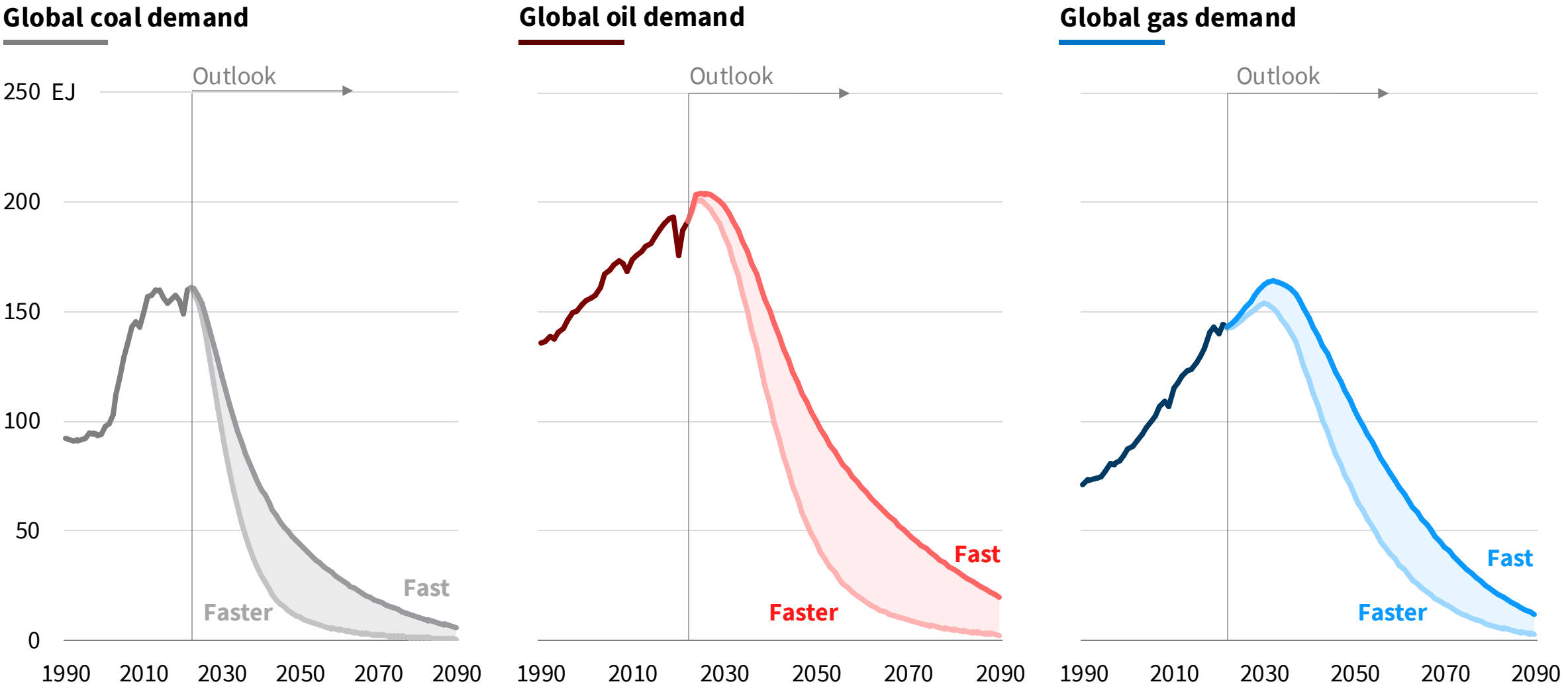


RMI

Source: IEA WEB, IEA APS scenario, RMI.

So fossil fuel demand is on the brink of rapid decline

Fossil fuel demand faces a cliff edge. The key variable is the length of the plateau — short or very short



Source: Rystad Energy (Fast 1.8°C, Faster 1.6 °C).

Index

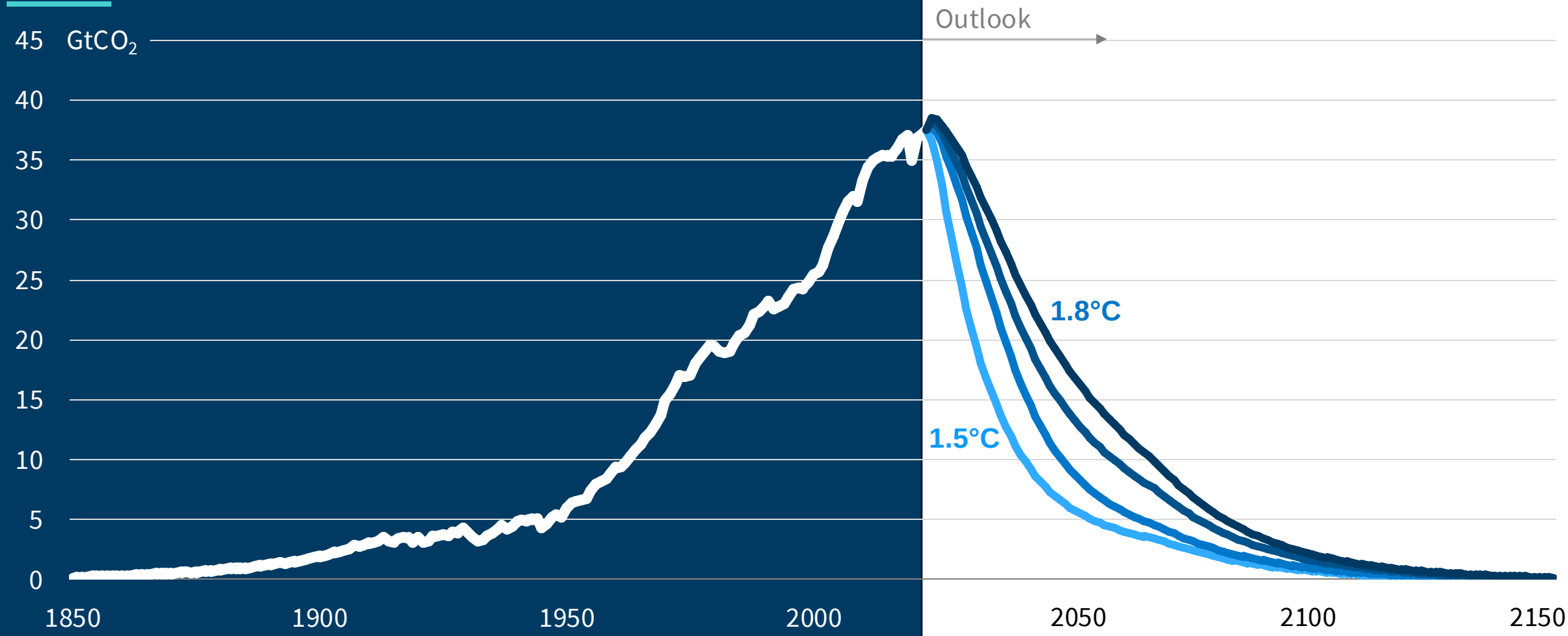
6 Wider implications of the transition

- Paris is achievable because we are at the pivot point in the 300-year history of fossil fuel use.
- The race for the top is on fire. A battle for leadership is taking place in every area of energy supply and demand. Competition will drive change.
- The Global South can continue to leapfrog to cleantech. Witness the success of Kenya, Barbados, Morocco, Vietnam or Bangladesh.
- We are at peak waste, so we can reduce the pressure on nature.
- The great capital reallocation will continue. Capital will shift into areas of growth and out of those in decline.
- Stranded fossil fuel assets will result from the gap between the expectations of incumbents for business-as-usual and the reality of exponential change.
- Since the fossil fuel system is huge ($50 trillion of fixed assets), this asset stranding has profound implications for the financial system.
- As China is leading this transition, we need to benchmark to China.
- The debate will be very different by 2030 and the transition will be priced into markets.

Paris is feasible

This is the pivot decade from growth to decline

Global CO_2 emissions from energy

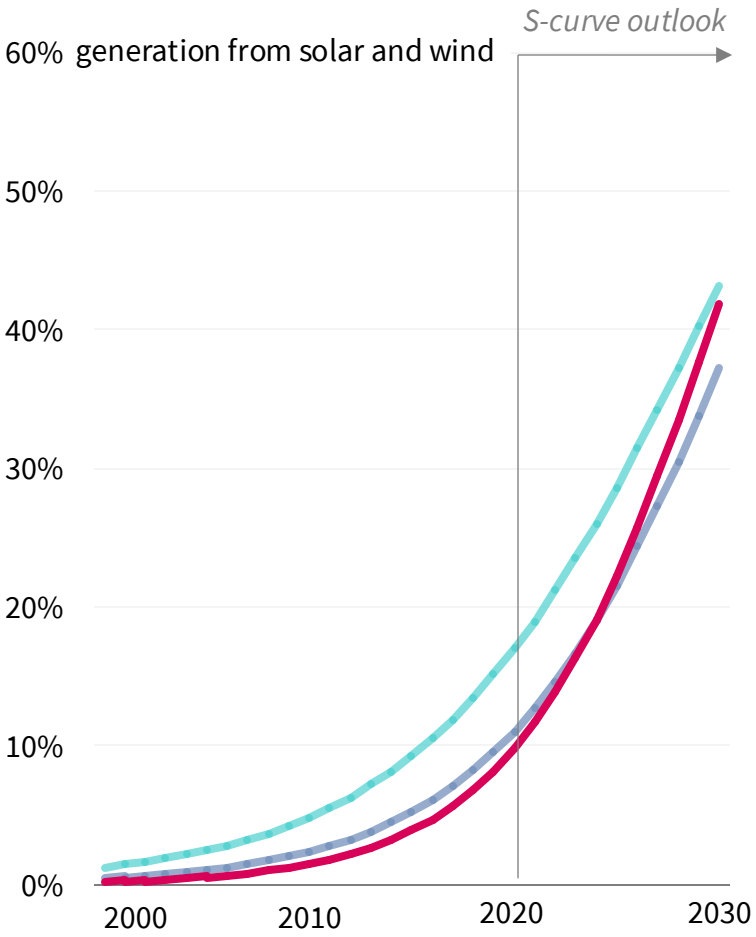


Source: Global Carbon Project, OWID (1850-2023), Rystad Energy to 2023-2070; RMI illustrative onwards. Paris here means the goal of the 2015 Paris Agreement to keep global warming well below 2°C .

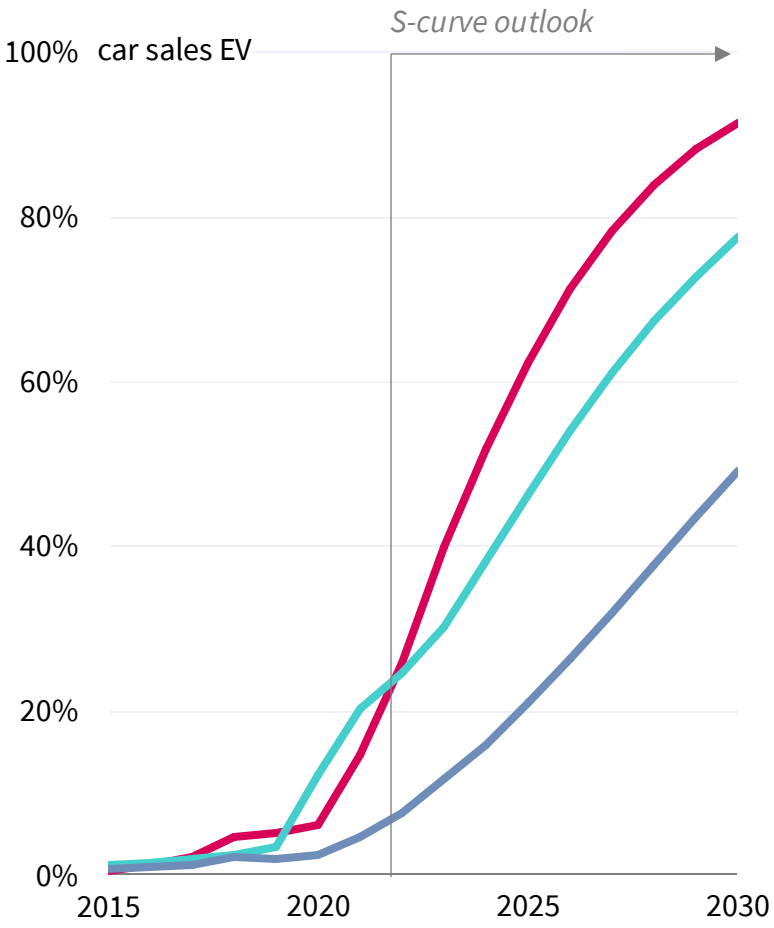
The race for the top is on fire

Nobody wants to miss out on the technologies of the future

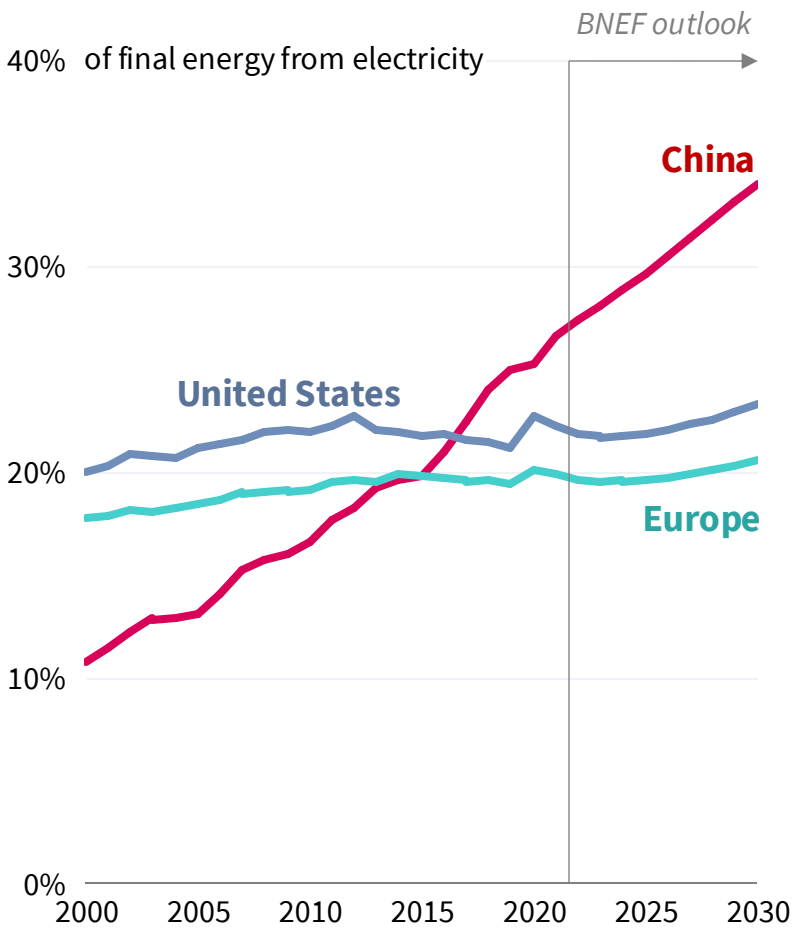
Renewables



Electric vehicles



Electrification

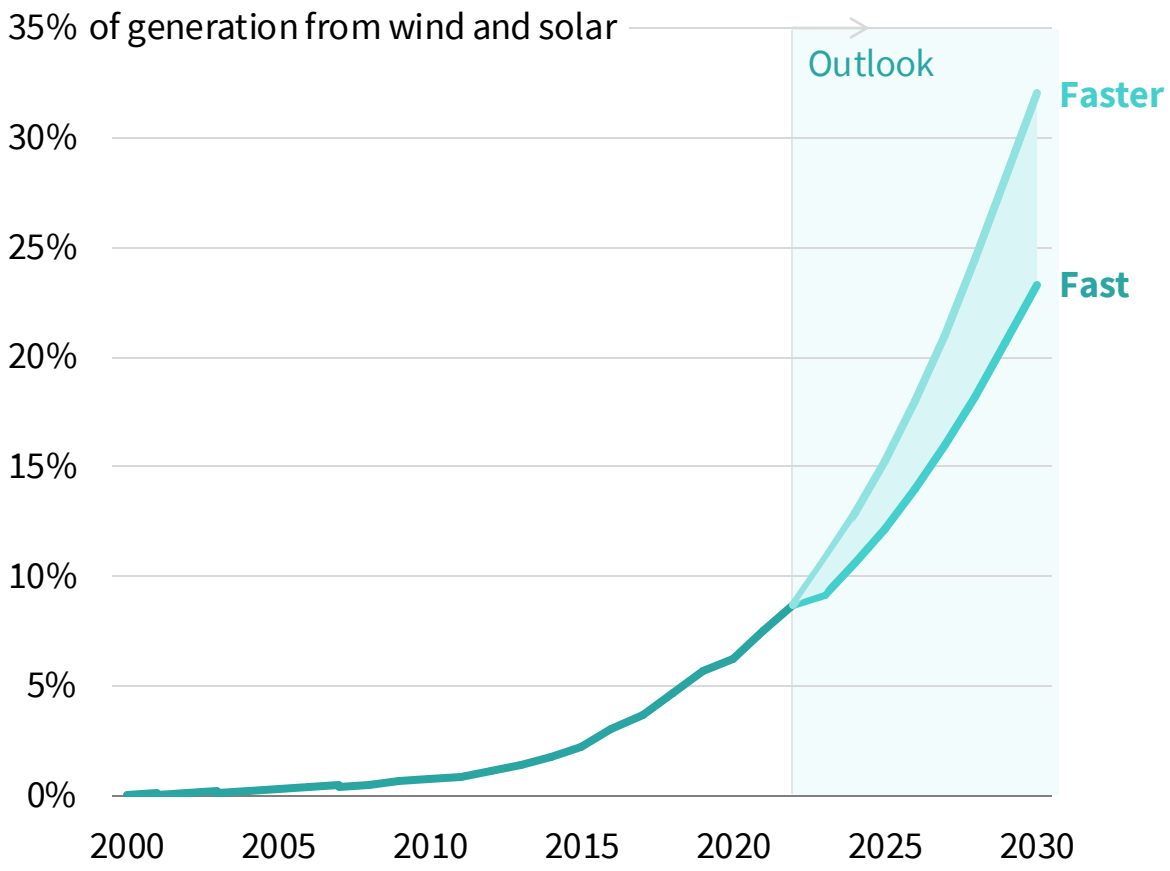


Note: Solar, wind, and EVs in an S-curve outlook based on RMI modeling; electrification is from BNEF's ETS.
Source: Energy Institute, IEA, BNEF, RMI analyses. For more see X-Change: The Race to the Top.

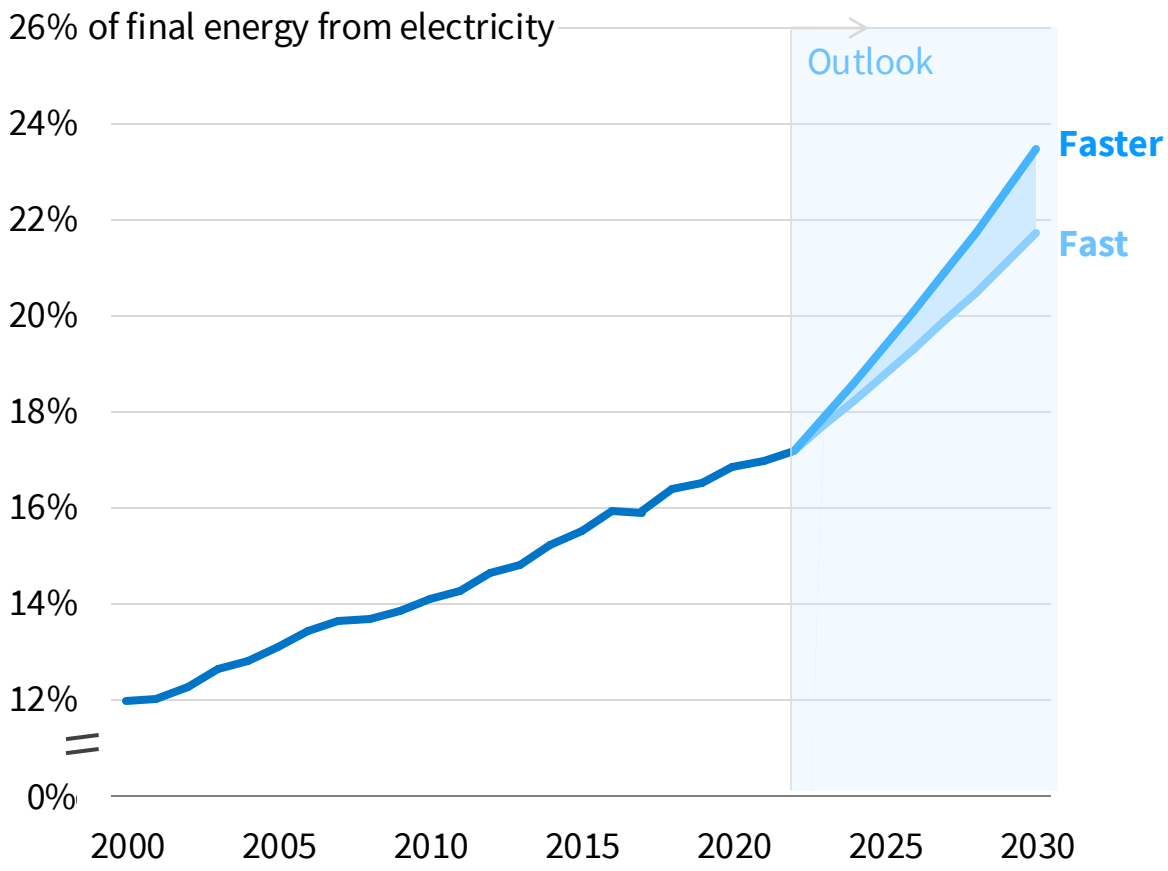
The Global South will continue to leapfrog

The Global South is likely to follow the standard S-curve of technology deployment

Solar & wind generation



Electrification

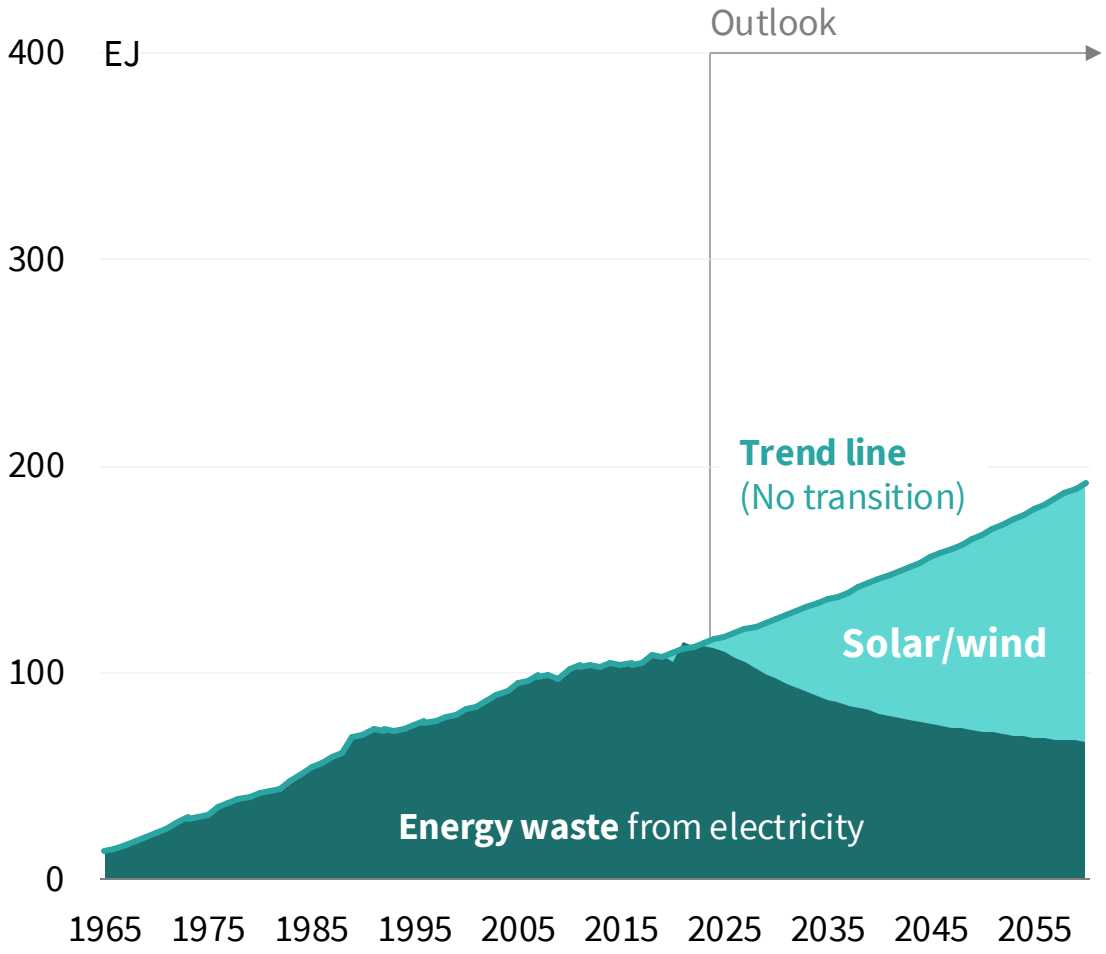


Note: Solar and wind as a share of electricity generation assumes that the Global South either follows the S-curve of the Global North (fast) or follows a standard S-curve (faster). Electrification S-curves are centered around assumptions in the IEA APS scenario. Source: IEA, RMI forecasts.

We are at peak waste

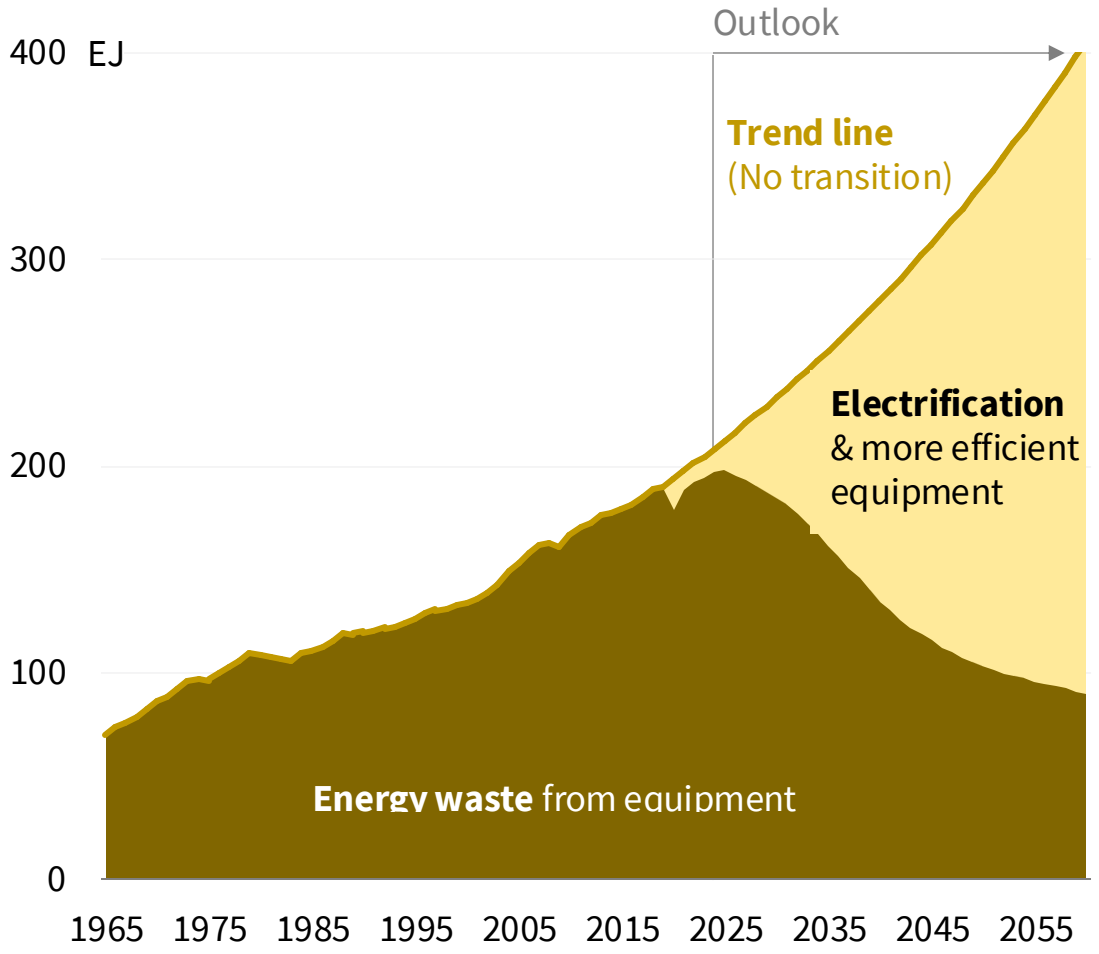
So we can massively reduce the strains of the energy system on nature

Solar & wind reduces losses from generation



Electrification reduces end-use losses

ILLUSTRATIVE



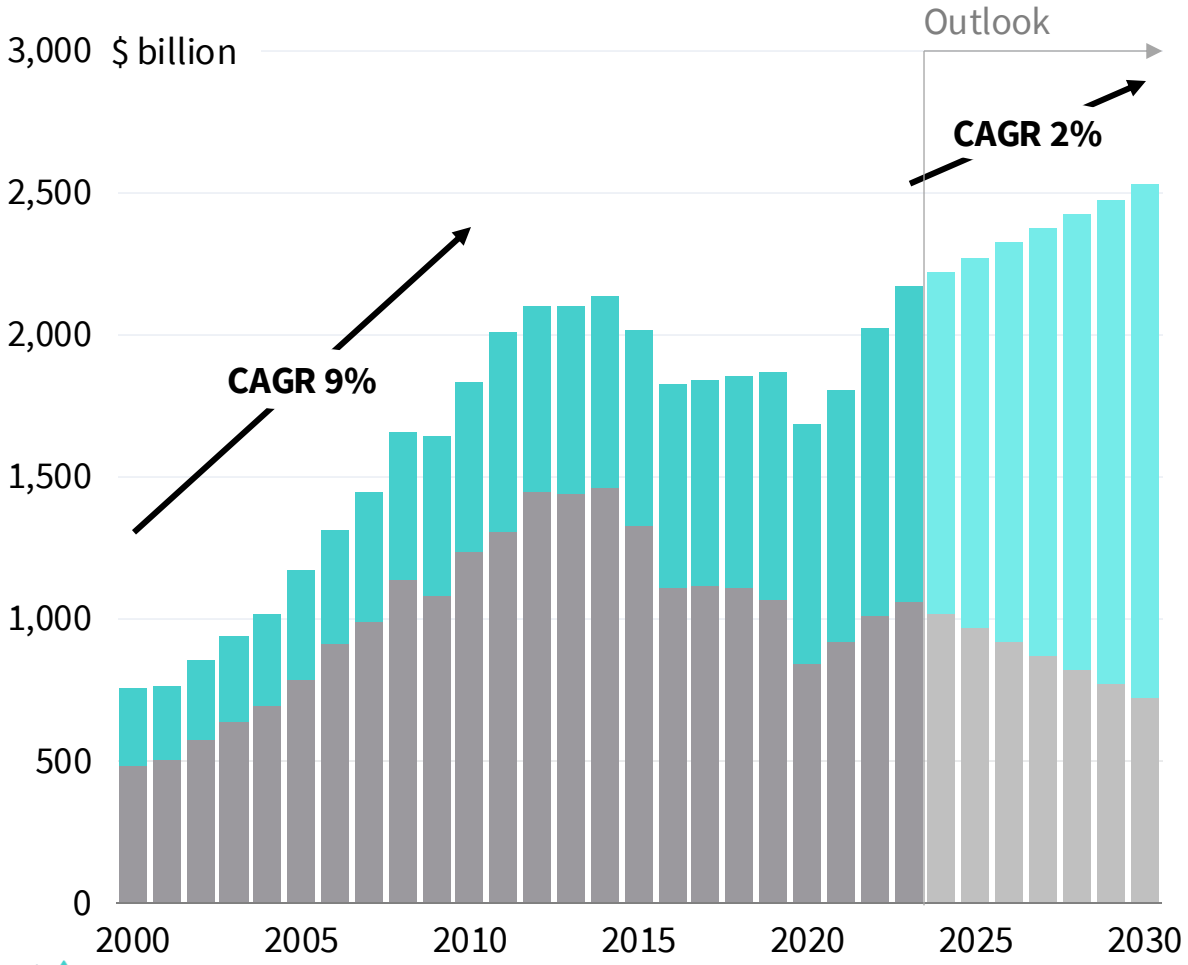
RMI

Source: Rystad Energy 1.6 °C Scenario.

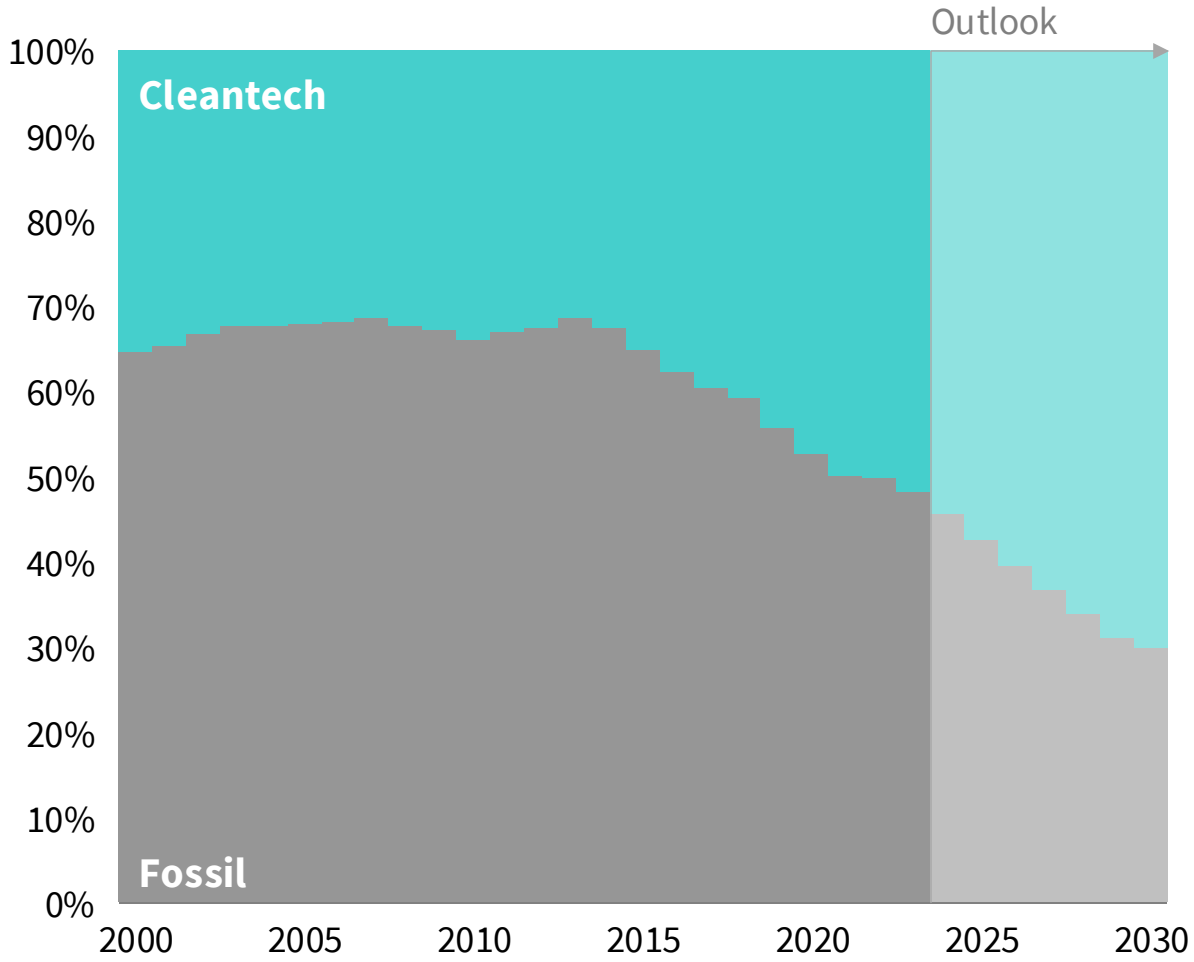
We are halfway through a Great Capital Reallocation

The required growth in investment is achievable, and reallocation from fossil to cleantech is well underway

Total investment in primary energy supply



Share of total investment

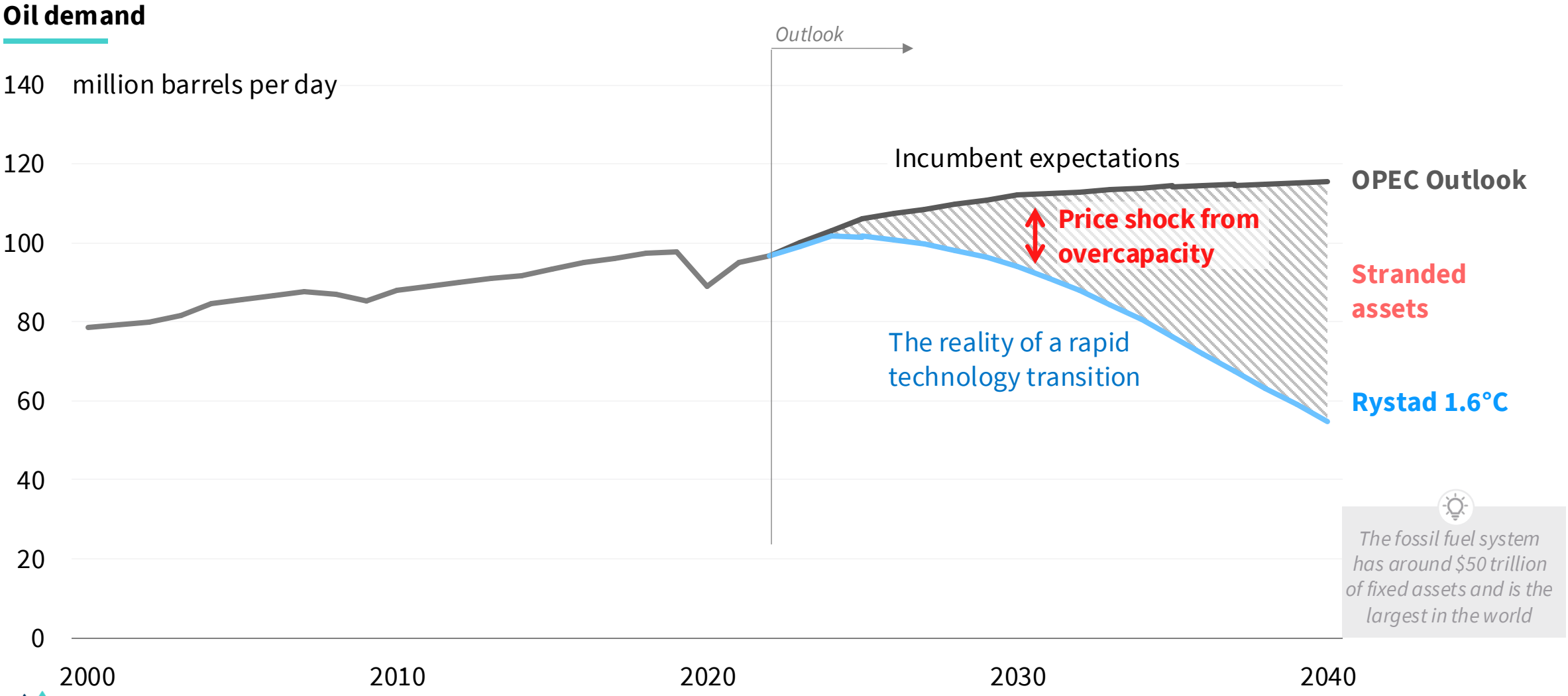


RMI

Source: IEA, RMI. For more see The Great Reallocation: Capital expenditure on energy production.

The fossil fuel system faces trillions in stranded assets

Assets get stranded at the top of the market, and disruption is driven by price changes

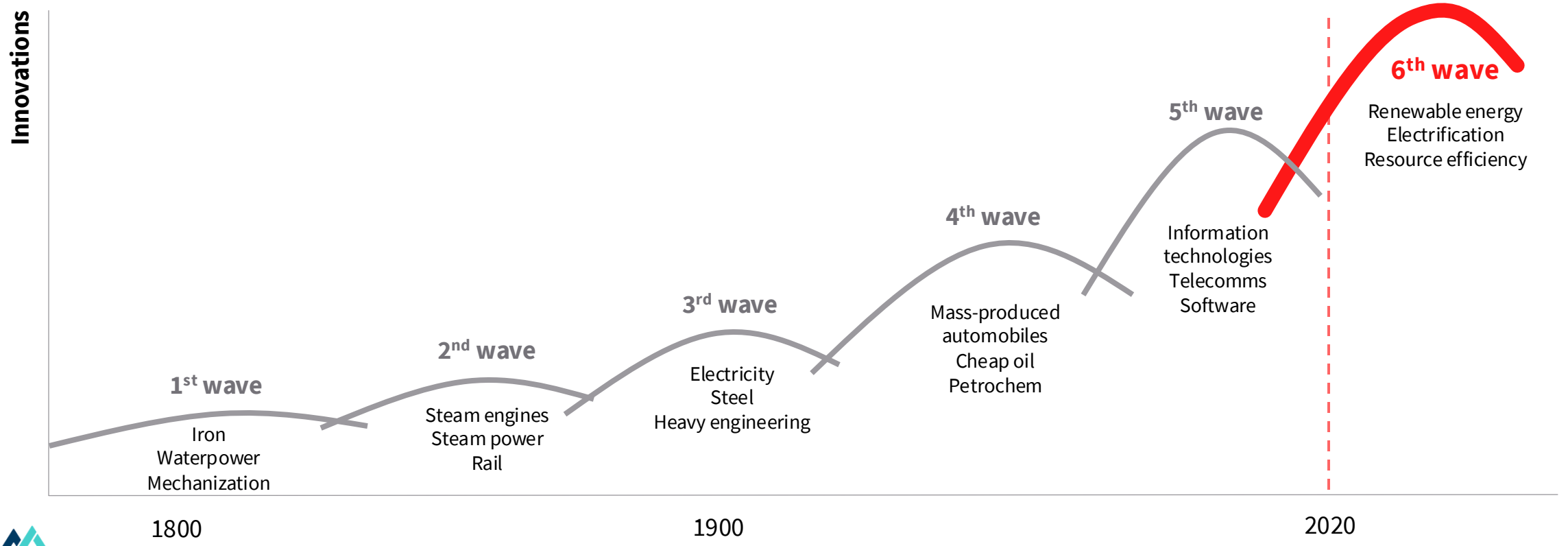


Source: Rystad Energy, OPEC, RMI.

We need to change our framework of reference to China

China is leading this technology revolution, and others need to catch up or fall behind

Transition	Industrial Revolution	Age of Steam & Rail	Age of Steel & Electricity	Age of Oil & Mass production	Information Age	**The Renewable Age**
Led by						



Source: Carlota Perez (first five), RMI (renewable age).

The debate will be very different in 2030

When the facts change, people change their minds. Repricing follows.

Area	2015	2024	2030
Cost of renewables	Expensive	Cheap	Super cheap
Societal pressure for change	Niche	Moderate	Intense
EVs	Toy for the rich	A second car for the rich	A cheaper car for all
Renewables	Grid can’t take 20%	Grid can’t take 70%	Leaders enjoy cheap energy
Net zero	<1% of world has targets	90% of world has targets	90% of world has plans
Global fossil fuel demand	Growth	Plateau	Decline
Hard-to-solve areas	CCS	Lots of technological solutions	Lots of commercial solutions
Geopolitics	Climate makes good speeches	Renewables nice to have	Renewables a key tool of power
United States vs. China	China pollutes too much	China makes too many climate solutions	China and United States compete
Financial markets	ESG	Carbon offsetting	Minsky Moment
Corporations	Greenwash	Green premium	Green prize

RMI *Source: RMI.*

Index

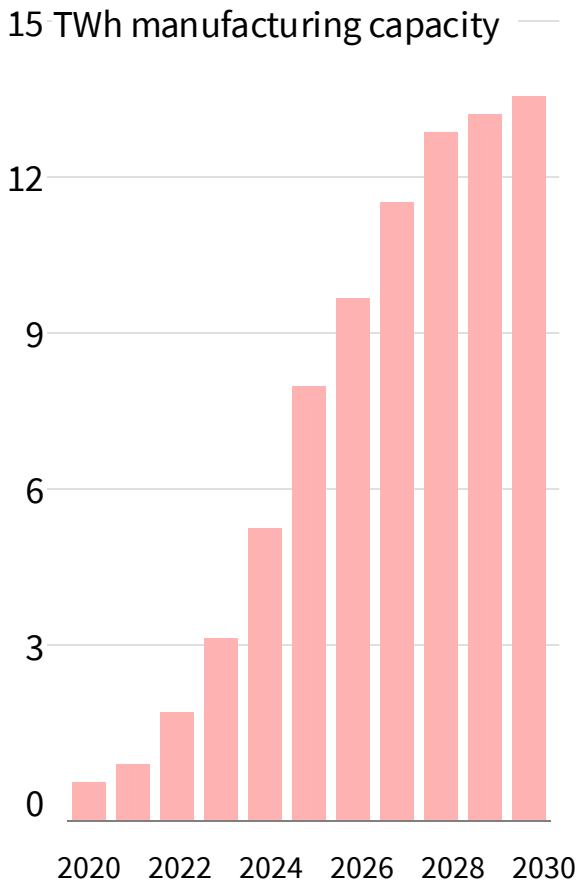
7 What we need to do now

- This is the pivot decade when cleantech manufacturing capacity is built, renewables get too cheap to resist, and fossil fuel demand reaches the end of its plateau.
- Focus on the signal not the noise. We need to prepare for change, not hide behind denial.
- We need to continue building out the renewable system, speed up electrification in the OECD, and increase focus on efficiency.
- We should make good bets on solutions that work: small modular technologies and efficiency measures. Equally, we need to avoid high-cost, inefficient, and unproven bets.
- Companies need to move from tactics to strategy.
- Investors should retool for the megatheme of the energy transition.
- Energy modelers need to change their approach or become stranded experts.
- And we need to get on with it. We are in a race between climate and economic tipping points. The direction is inevitable, but speed is up to us.

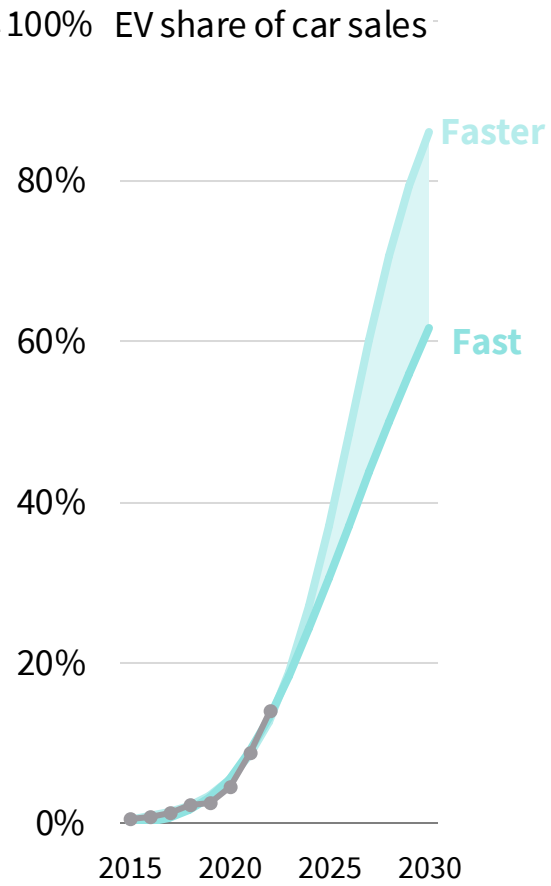
The 2020s are the pivot decade

You snooze, you lose

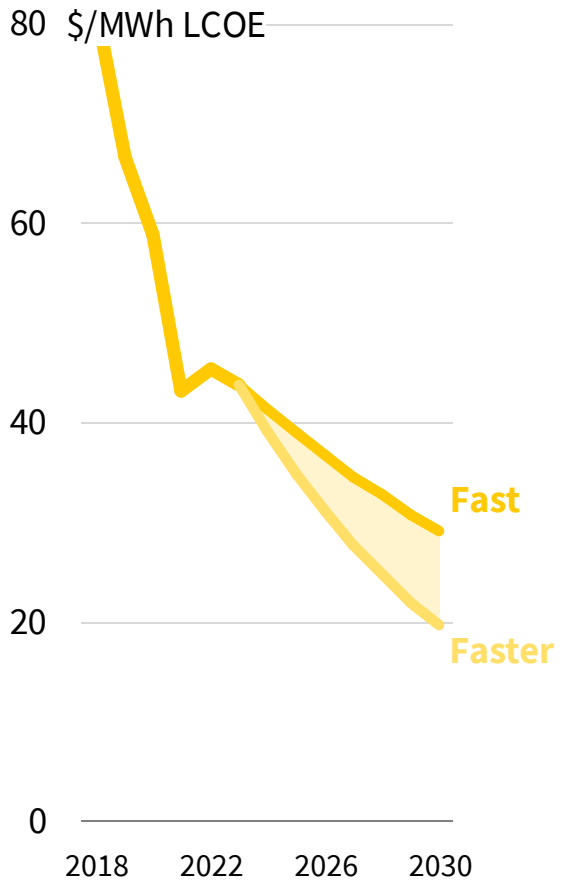
Manufacturing capacity is built: Batteries



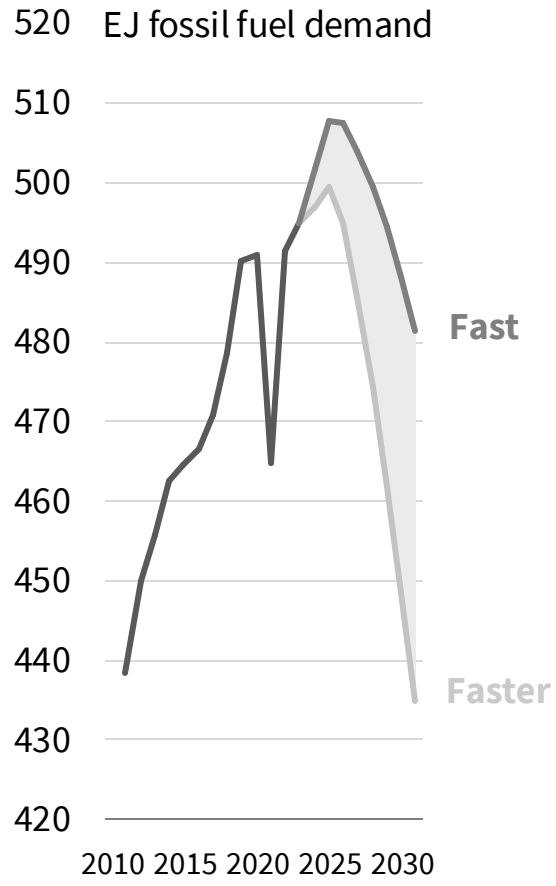
Cleantech goes up the steep part of the S-curve: EV



Renewables get too cheap to resist: Solar



Fossil fuel demand enters terminal decline

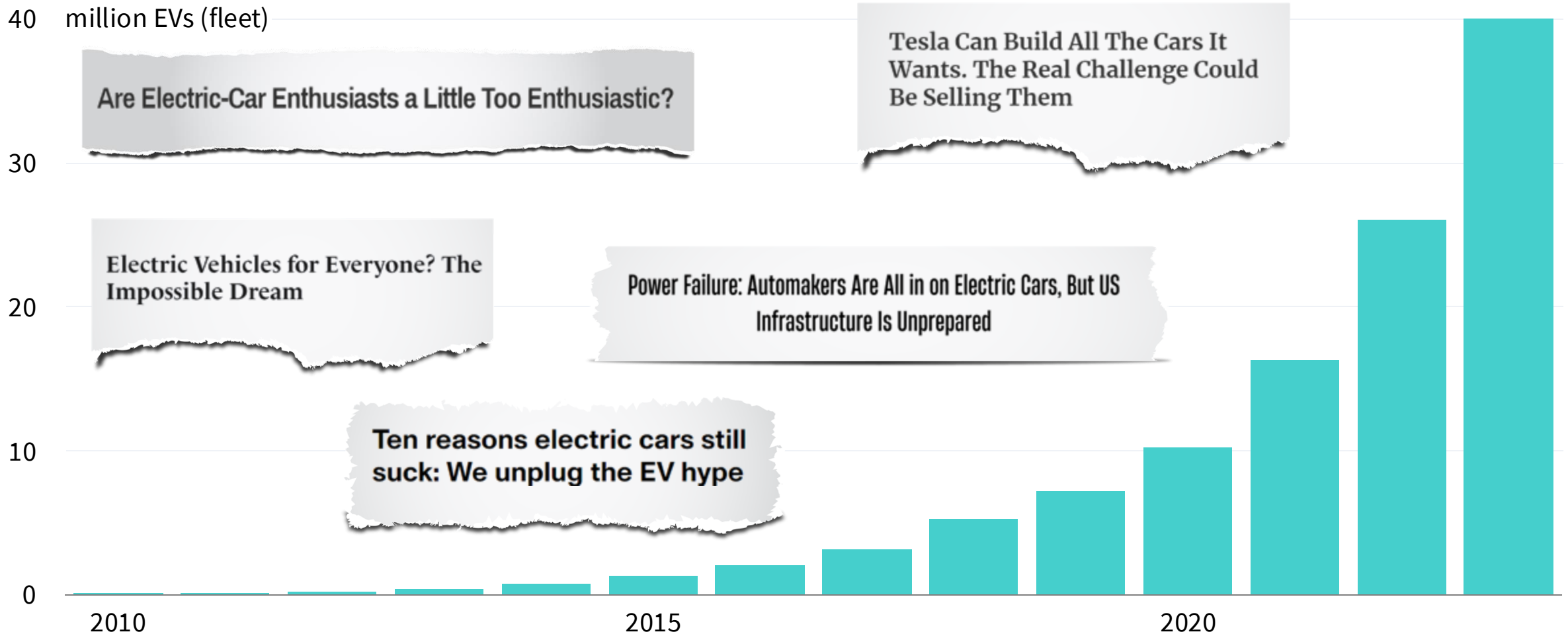


RMI *Sources: BNEF, RMI, Rystad Energy.*

Focus on the signal not the noise

There are always barriers to change. Those who solve them get rich.

EV adoption versus headlines

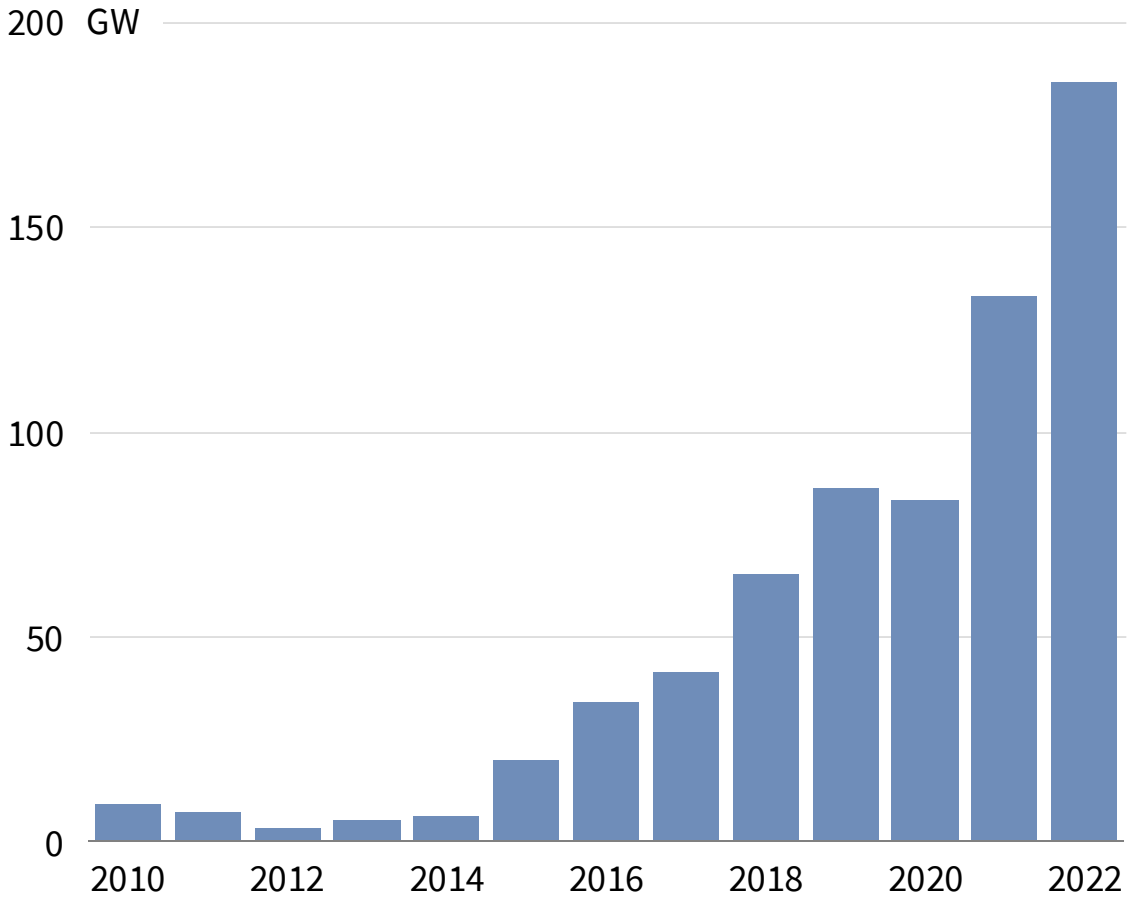


Media headlines are centered around their year of publication.
Sources: IEA ,CNET, Time, Forbes, InsideHook, Manhattan Institute.

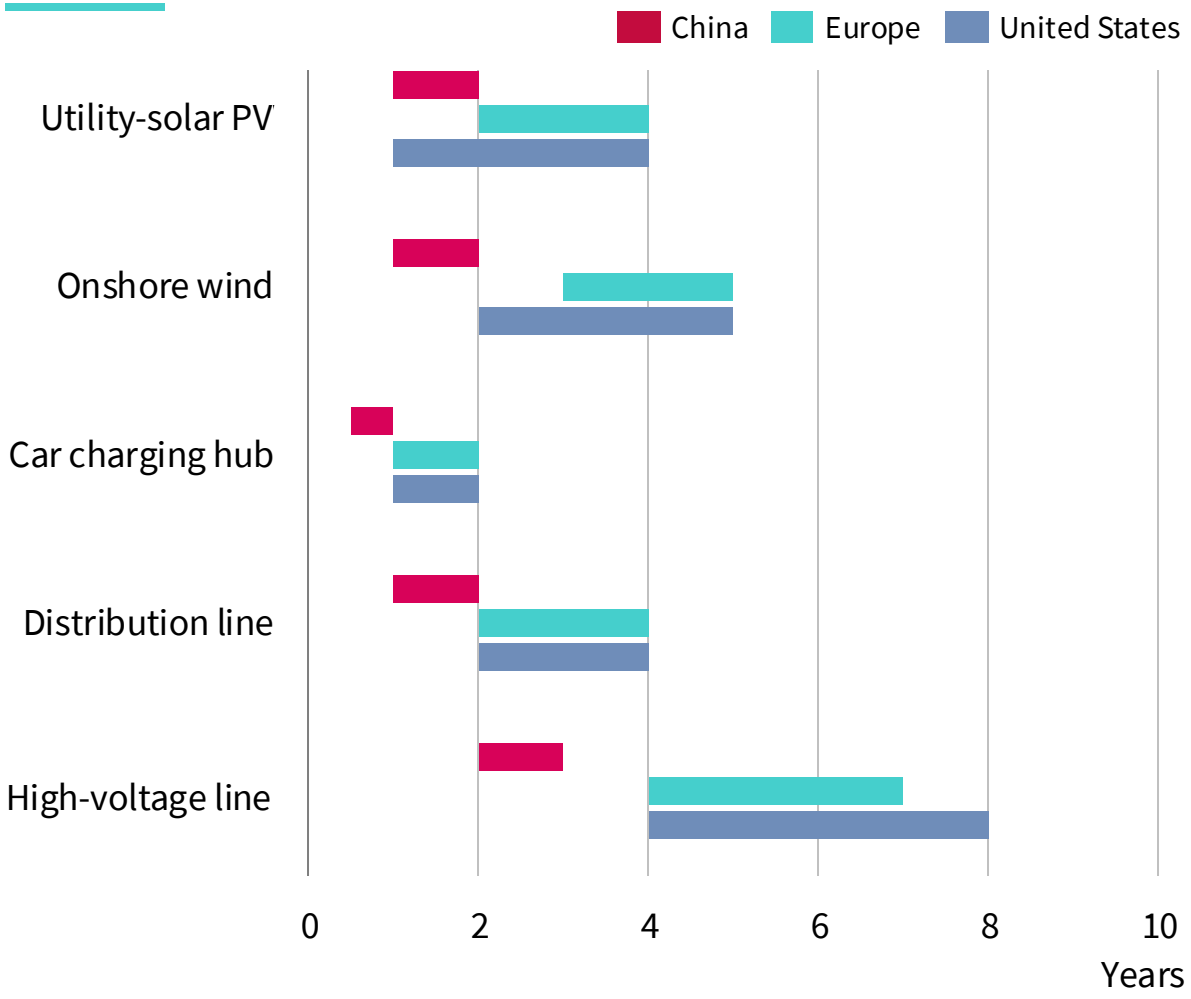
Build, baby, build…

If you want to stay in the game, you need to deploy renewables and electrify end-use demand, and fast

Connection queue growth in United States



Typical deployment time

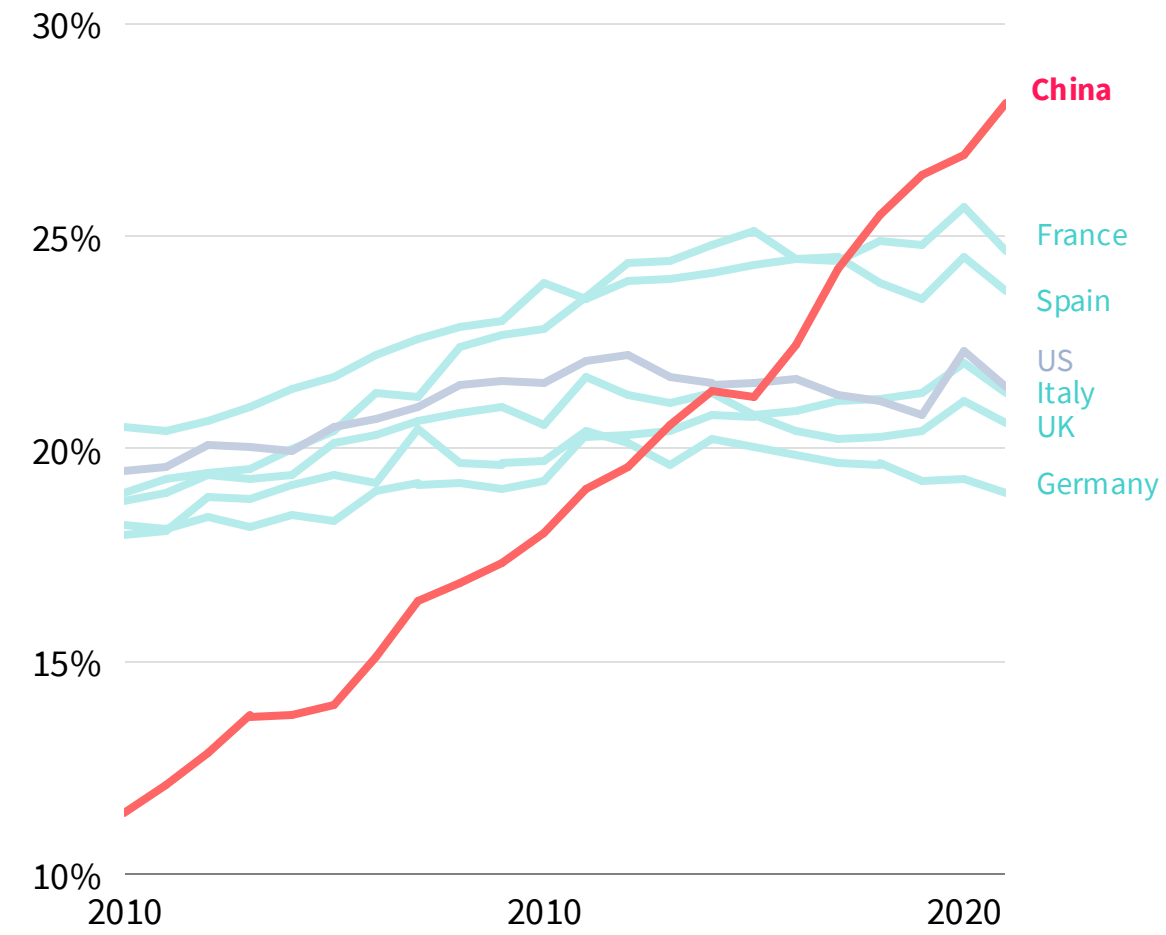


RMI *Source: IEA.*

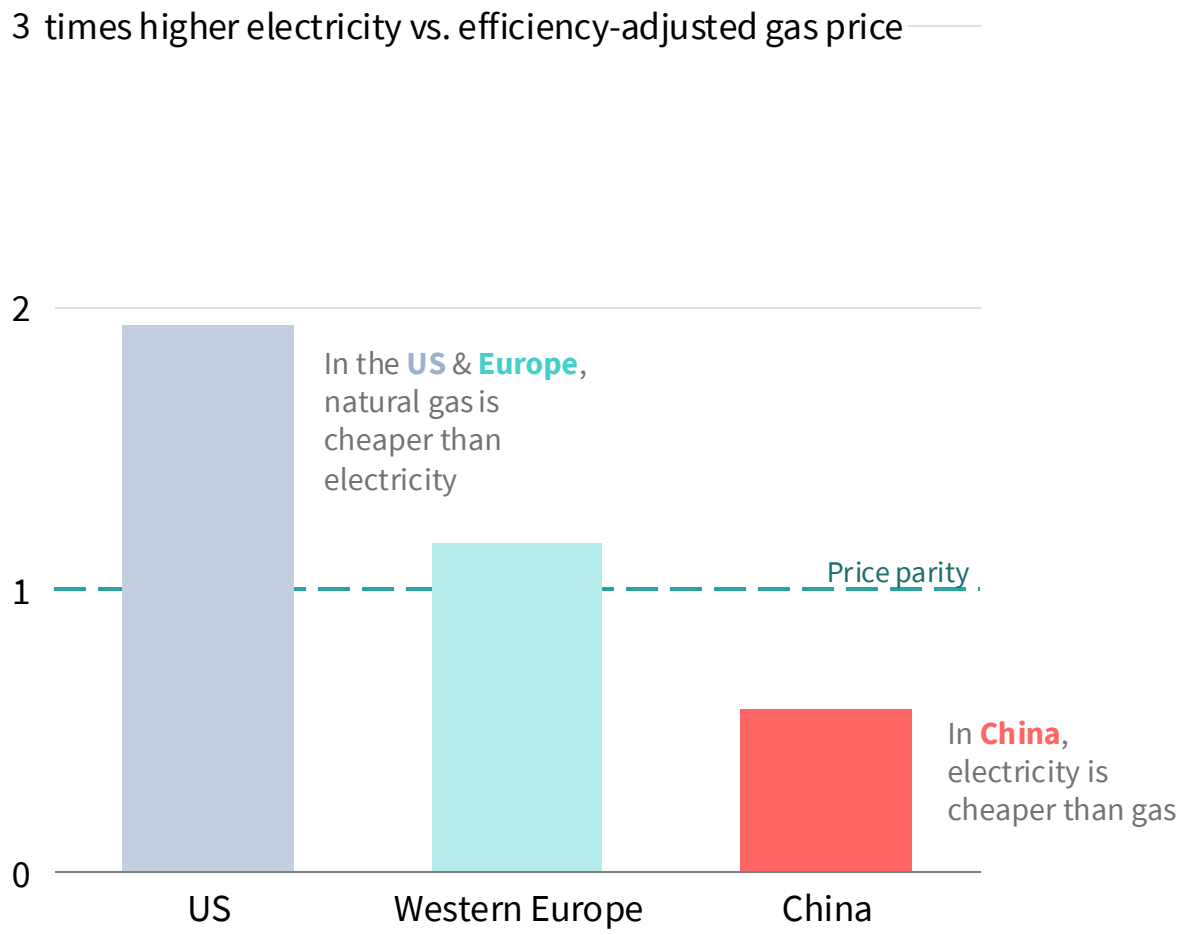
Speed up electrification in the OECD

Redesign electricity markets to pass the low cost of renewables onto industry and households

Electricity share of final energy



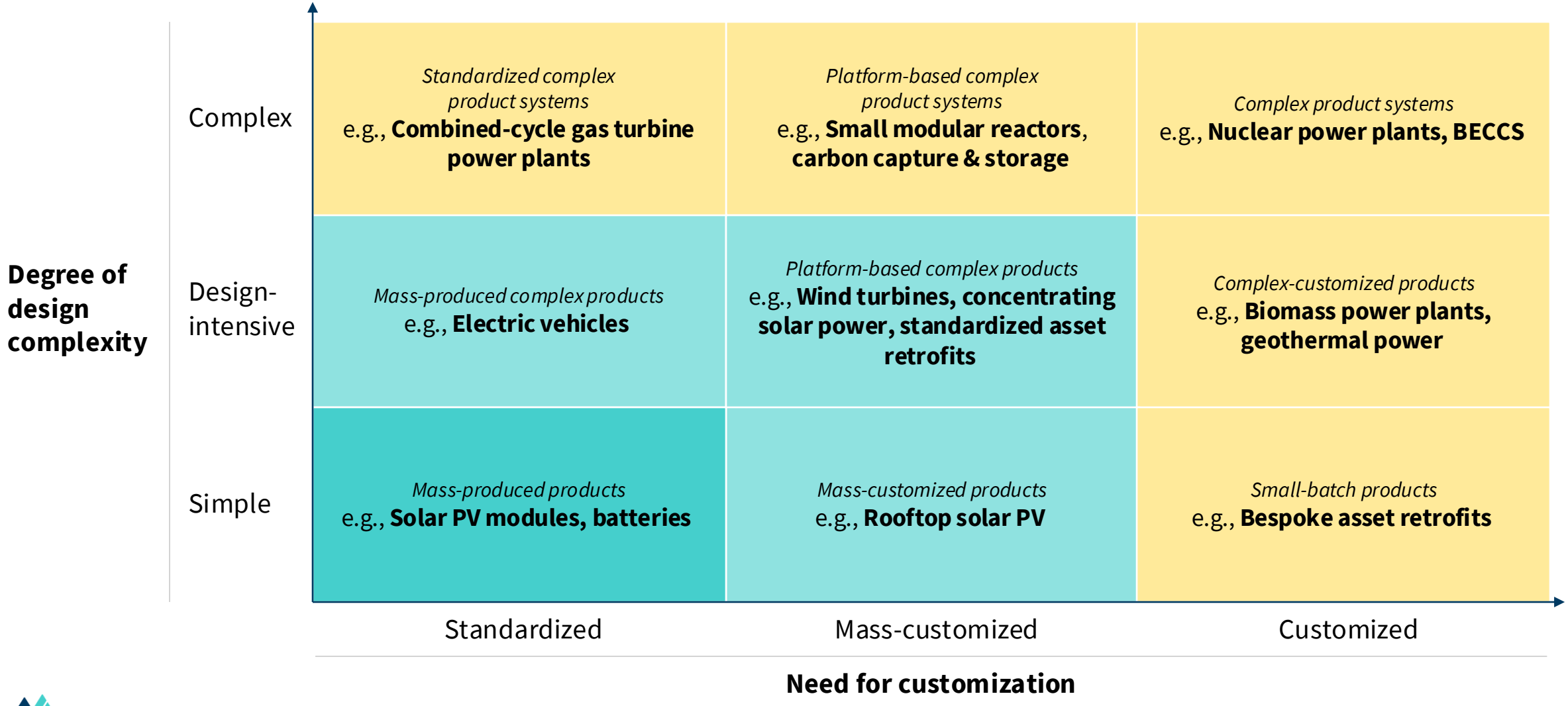
Electricity multiple of natural gas prices in 2023



Source: IEA WEB, IEA, RMI. Note: assuming a 40% efficiency of natural gas for a fairer comparison between the two energy carriers.

Make good bets on the technologies of the future

Focus on modular technologies with steep learning curves; avoid expensive and hard-to-deploy technologies

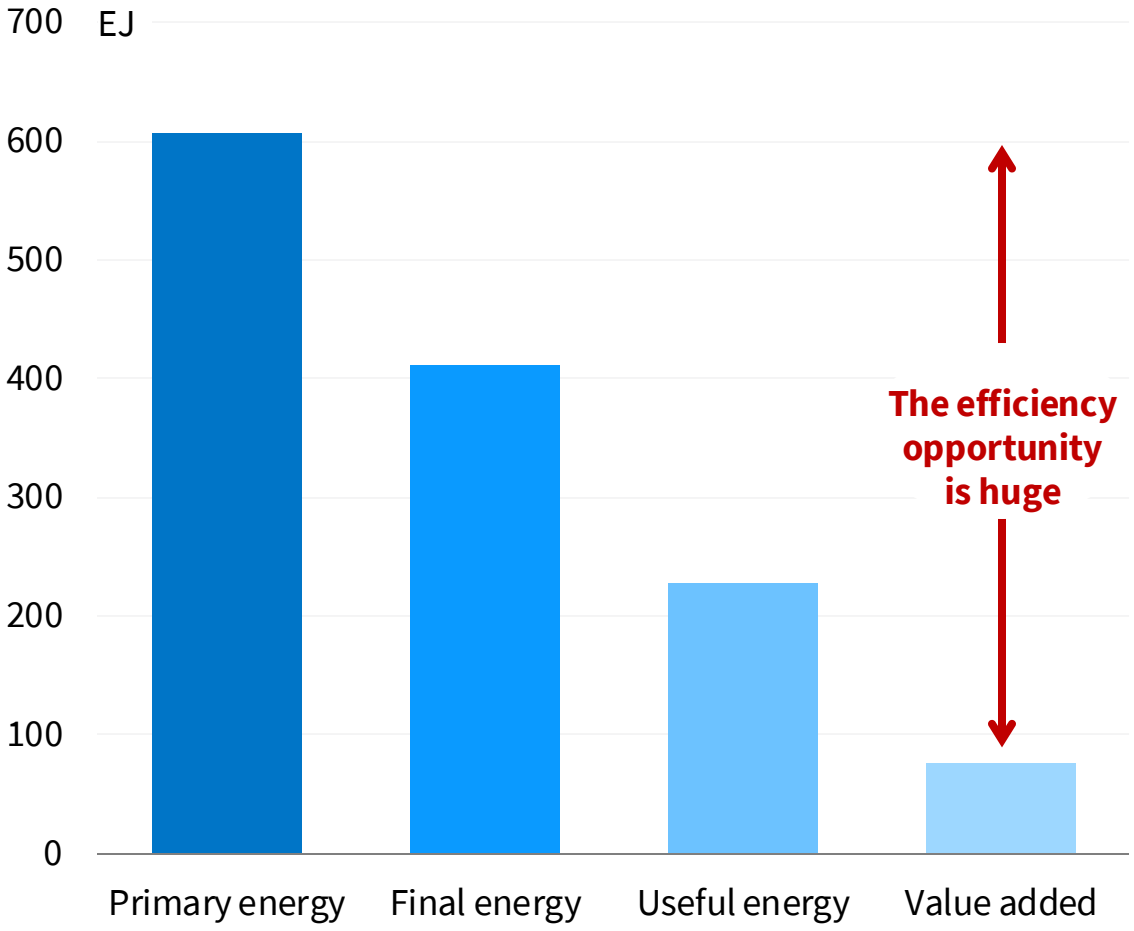


Source: Adapted from Malhotra and Schmidt, "Accelerating Low-Carbon Innovation."

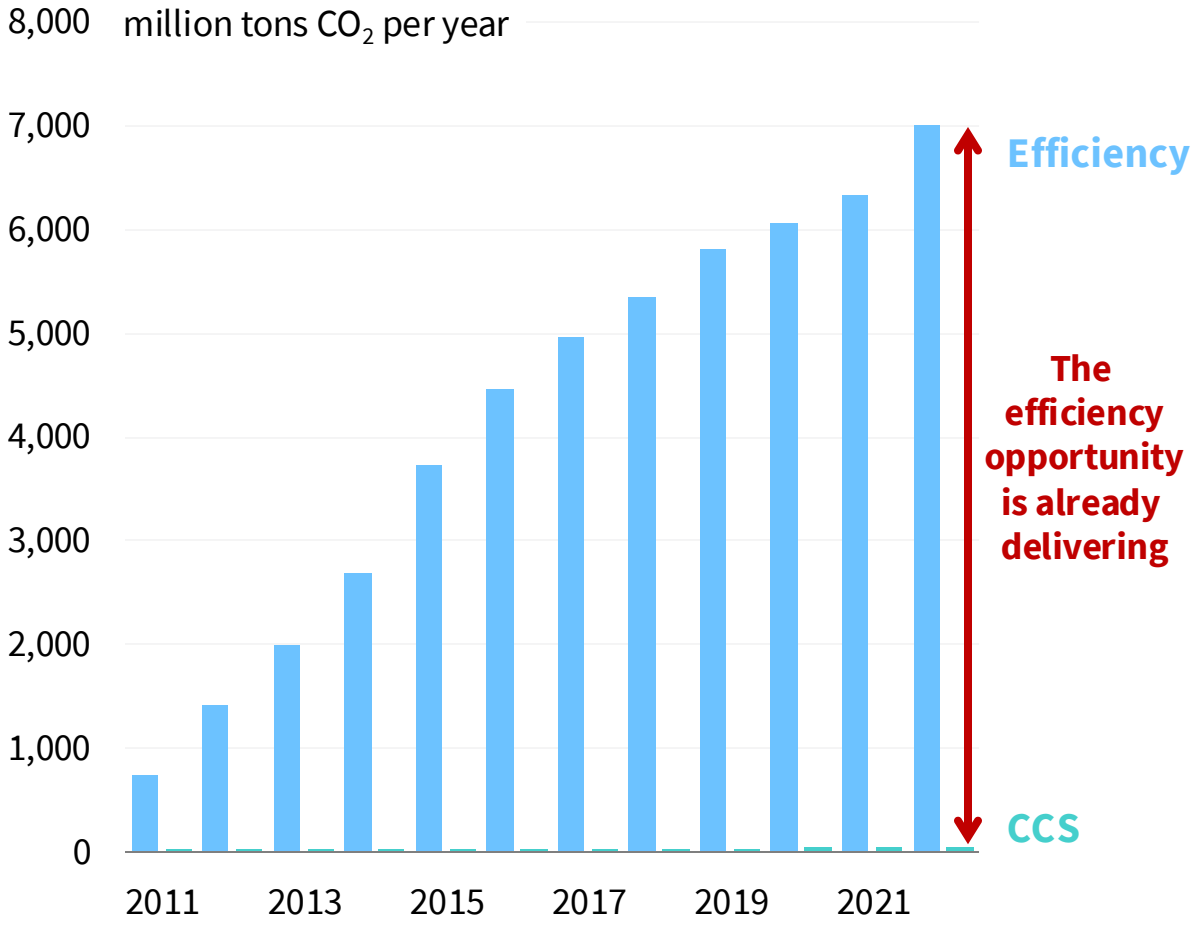
Harvest the vast fields of efficiency

The efficiency potential is huge, and proven

Energy demand from primary energy to value added 2019



Emissions avoided by efficiency, in context



RMI *Source: IEA, IIASA, RMI assumptions, Amory Lovins.*

Companies: time to move from tactics to strategy

The energy transition is not a box-ticking exercise

Company types and actions

Type	Future	What to do
Fossil fuel producers	Decline of core products	Reinvention; rundown
Heavy fossil fuel users	Need to find a new energy source	Retool for the new energy source
Renewable companies	Rapid growth, rapid innovation	Innovate and expand
Entrepreneurs	A brave new world of opportunities	Solve barriers and get rich
Others	A new environment	Rethink areas of focus

RMI *Source: RMI.*

Finance: Retool investment strategies

The energy transition is a megatheme, like the industrialization of China or the growth of the internet

Allocate capital to sectors with growth

Exit sectors in decline. Or trade the volatility on the way down

Go long-short winners and losers from change. Disruption is coming, so separate reality from lip service

Pick winners. The Gartner hype curve is the standard tool

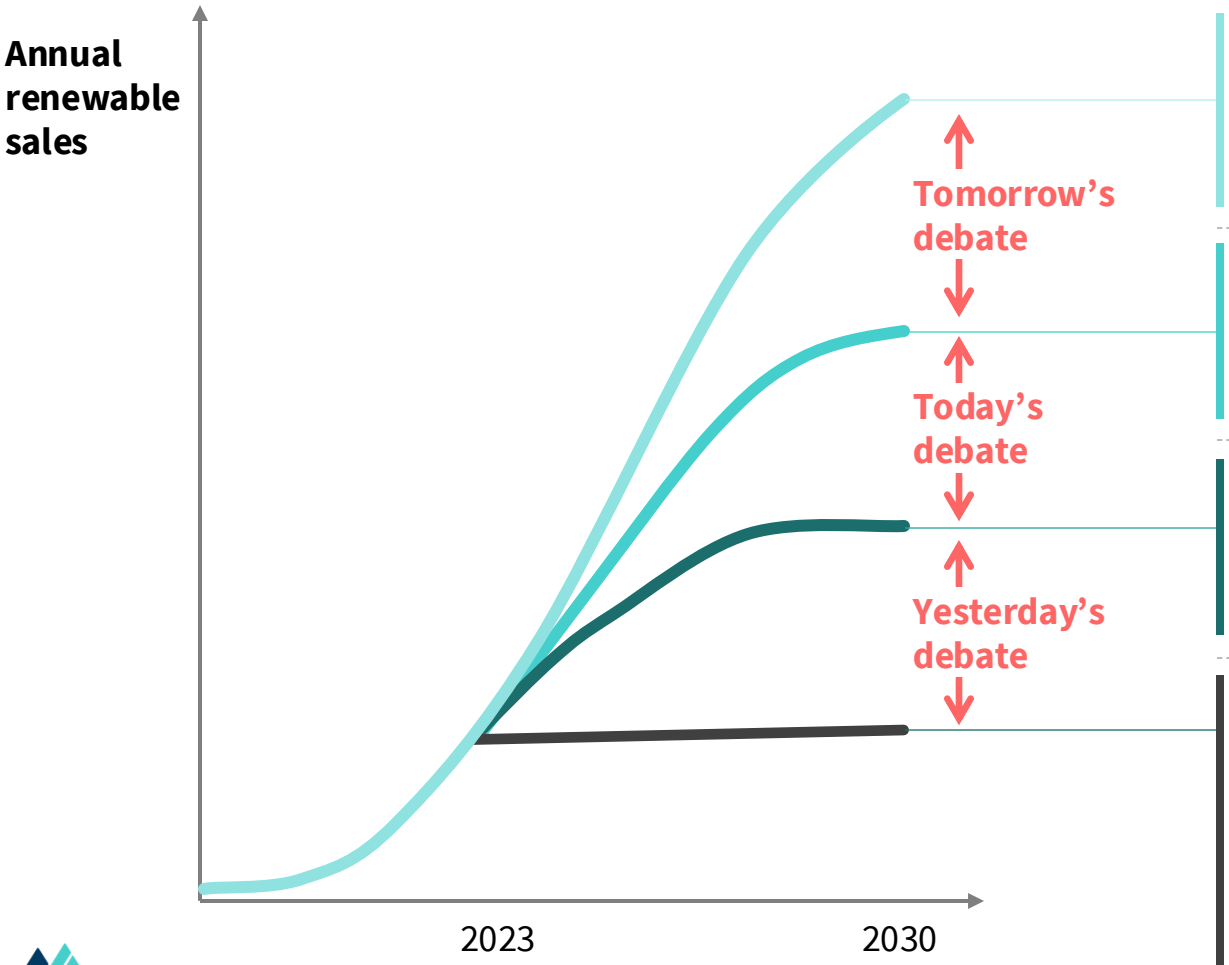
Beware of fossil Minsky moments the coming decade

RMI *Source: RMI.*

Adjust energy models to capture reality

Incumbent modelers need to up their game or become stranded experts

Annual renewable deployment concept chart



Who is where?

Illustrative

RethinkX, RMI, INET Oxford, CATL, Tesla

RystadEnergy, IEA, Bloomberg New Energy Finance, EMBER

Princeton University Net-Zero America, NGFS, S&P Global, IPCC

Organization of the Petroleum Exporting Countries, Exxon, eia

..and the many tied banks and consultants

The group

"A new energy paradigm"

"Renewables are the future"

"Change is difficult, but we should try and do this"

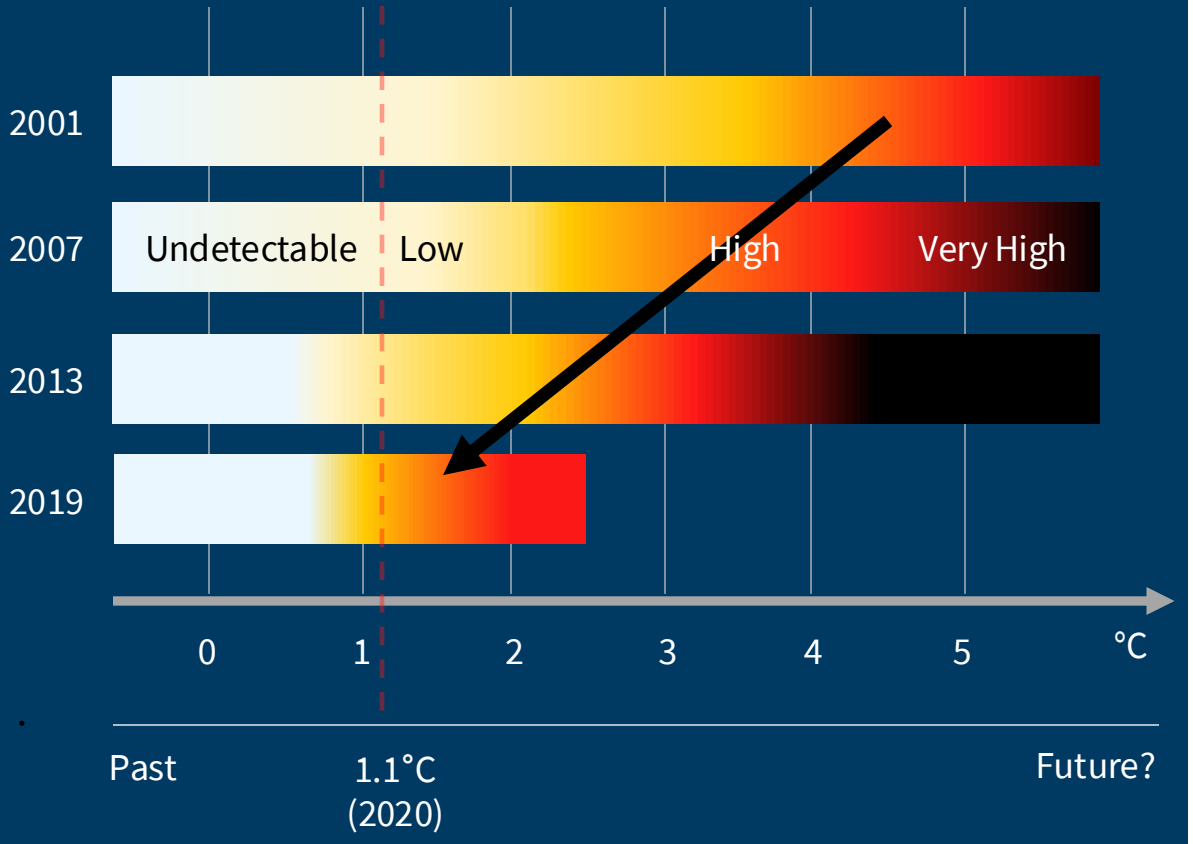
"Green idealists are naïve; the world needs our fossils"

RMI *Source: RMI.*

We are in a race between climate and economic tipping points

On the one hand, **climate** tipping points are coming faster than expected…

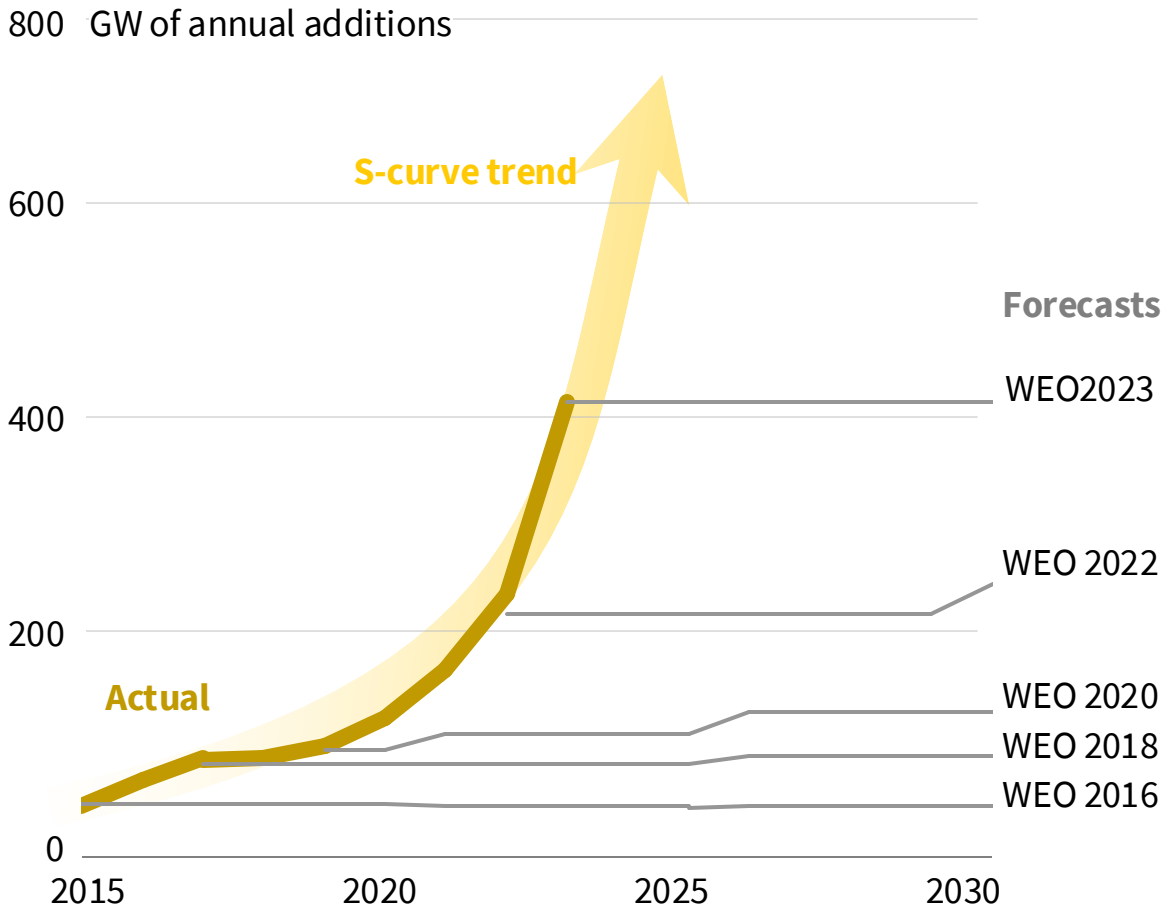
Climate tipping points



Source: Lenton et al based on IPCC reports

…on the other hand, **climate solutions are scaling faster** than most analysts thought possible.

Actual solar additions *vs.* consensus outlooks

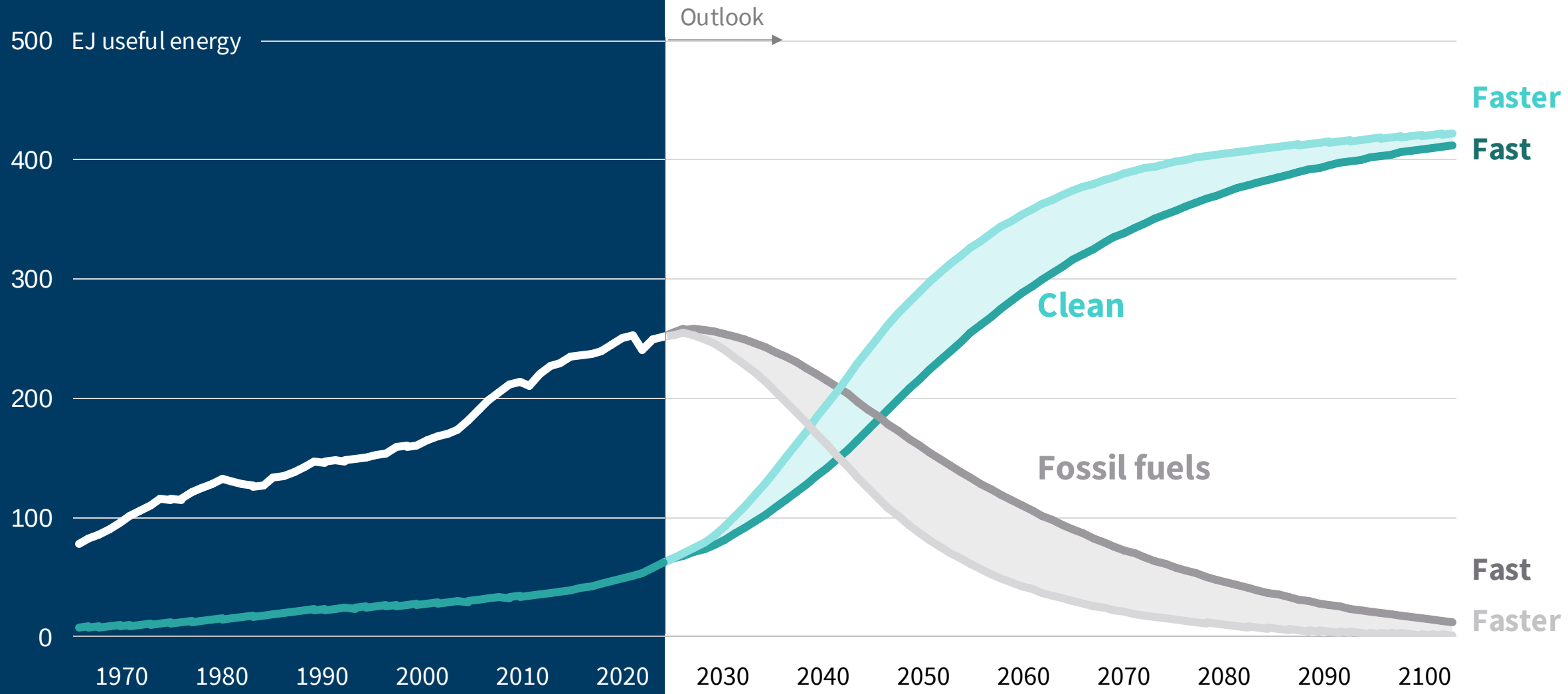


Source: IEA STEPS, BNEF actuals.

Direction is inevitable, but speed is up to us

There is both inevitability and agency.

As time is short there is every reason to act.



Source: Rystad Energy scenarios (1.6°C Faster, 1.8°C Fast).

About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut climate pollution at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing.

Authors

Kingsmill Bond, kbond@rmi.org
Sam Butler-Sloss, sbutlersloss@rmi.org
Daan Walter, daan.walter@rmi.org

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