Understanding *Stellar* Energy

How SWB Superpower will create clean energy superabundance

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Understanding Stellar Energy

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Who we are

RethinkX is an independent not-for-profit research organization that analyzes and forecasts technology-driven disruptions and their implications. We produce impartial, data-driven analyses that identify pivotal choices to be made by investors, policymakers, civic leaders, and other decision-makers. Our research team uses the Seba Technology Disruption Framework™ to understand the dynamics of disruption and their associated interactions among technology, business models, and market forces. We then leverage this understanding to forecast the scope, speed, and scale of a disruption's impacts across social, economic, geopolitical, environmental, and other dimensions, and their implications for market sectors, industries, and geographic regions.

Our mission

RethinkX aims to facilitate a robust global conversation about the threats and opportunities of technology-driven disruptions, and highlight choices that could lead to a more equitable, healthy, resilient, and stable future for all of humanity.

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Contents

Introduction

Part 1 / Solar, wind, and batteries are different

Part 2 / SWB Superpower is the answer

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Part 3 / Findings

Introduction

Understanding ***Stellar*** **Energy**

***Stellar* Energy system** *(n)*: A system in which a critical mass of solar power, wind power, and battery energy storage assets enables society to become energetically self-sustaining via clean energy superabundance.

Today's gigantic extractive flows – including fossil fuels, ongoing material inputs, and the enormous global infrastructure and logistics to support them – become unnecessary.

Like the sun, once a Stellar Energy system passes the ignition point, it enters a stable state of radiance in which clean energy is available in such abundance that we not only meet today's needs without causing damage but actively heal and restore past harms to people and the planet.

To learn more about Stellar and the journey to a Stellar World see: ***STELLAR*: *A World Beyond Limits and How to Get There*** by James Arbib and Tony Seba. stellarworld.com

We are in the midst of the fastest, deepest, most transformative disruption of the energy sector in over a century. The final outcome will be a ***Stellar* Energy™ System** based overwhelmingly on solar power, wind power, and batteries.

Solar and wind power both ultimately originate as energy from the sun.

Unlike terrestrial fire, whose combustion must be maintained by a perpetual inflow of carbon-based fuels (which are themselves a store of sunlight), the stellar furnace at the heart of the sun that fuses millions of tons of hydrogen into helium every second is a vastly larger, more stable, and non-depletable source of energy. Moreover, stars ignite by gathering a critical mass of resources together, after which they shine without the need for any further external inputs. So too will humanity's future energy system produce a superabundance of clean energy from long-lived stocks of solar power, wind power, and batteries – in stark contrast to our energy system today that depends on costly flows of oil, natural gas and coal.

Stellar Energy is an essential pillar of humanity's superabundant future that RethinkX founders Tony Seba and James Arbib describe in their new book *STELLAR: A World Beyond Limits and How to Get There.*

Like other disruptions throughout history that have transformed foundational sectors, the new energy system that emerges will require entirely new mindsets to understand, new metrics to evaluate, new business models and strategies to utilize, and new institutions, policies, and rules to govern.

Disruptions of this magnitude create conditions for a global race-to-the-stars, which are often won by outsiders rather than incumbents.

Despite an explosion of interest among policymakers, investors, and the general public about clean energy technology in recent years, the full magnitude of the energy disruption by solar power, wind power, and batteries (SWB) is still not widely understood. For millennia, plentiful energy at minimal cost without harmful side effects has remained an elusive goal. But now, thanks to SWB, the age-old goal of clean energy superabundance is finally within reach.

The prize on offer in the race to Stellar Energy is extraordinary: ***clean energy superabundance.***

Humanity will use far more energy by the 2040s than we do now – at least as much per capita as today's wealthiest societies, and possibly a great deal more.

Clean energy superabundance is possible because solar, wind, and batteries are not merely one-to-one substitutes for coal, oil, natural gas, and nuclear fission – just as a butterfly is not merely a caterpillar with wings. The disruption of energy by SWB, like other disruptions throughout history, will create an entirely new Stellar Energy system that requires a new mindset to understand, new metrics to evaluate, new policies and institutions to govern, and new strategies and business models to utilize.

The implications of the new Stellar Energy system that will emerge from the disruption are utterly profound. When optimized correctly, Stellar Energy systems can bring clean energy superabundance to every populated region of the planet at a fraction of the cost of today's conventional energy system.

It is difficult to overstate how extraordinary the benefits of clean energy superabundance will be – chief among which are peace, prosperity, productivity, and resilience at levels that have simply seemed unimaginable up until now.

Energy utilization is strongly correlated with nearly every aspect of human flourishing, but up until now we have always sought to minimize rather than maximize energy use because of its high marginal costs as well as harm to people and planet. With clean energy superabundance based on stocks of SWB assets instead of flows of dirty fossil fuels, humanity will utilize far more energy after the disruption than we do today – just as we now utilize far more information and communications than we did before the Internet disrupted that sector with near-zero marginal cost digital technologies. Stellar Energy systems will thus help humanity thrive worldwide, especially in the world's poorest communities and countries, by removing barriers to socioeconomic development with clean energy superabundance.

It is no longer a question of *if* the disruption of energy by SWB will enable clean energy superabundance, it is a question of *who, what, where, when, why, and how?* The key to answering all of these questions is *SWB Superpower™*.

Stellar Energy systems can bring clean energy superabundance to every populated region of the planet at a fraction of the cost of today's conventional energy system.

What is SWB Superpower?

SWB Superpower is superabundant clean electricity produced by Stellar Energy systems whose marginal cost is near-zero.

Stellar Energy systems have two extraordinary properties that together create the conditions of clean energy superabundance throughout the majority of all hours each year.

1. Stellar Energy systems based on SWB are sized for the most challenging season (typically, the cloudiest several weeks of winter), and therefore naturally produce a superabundance of clean electricity throughout the rest of the year.
2. Solar, wind, and battery technologies all operate at near-zero marginal cost.

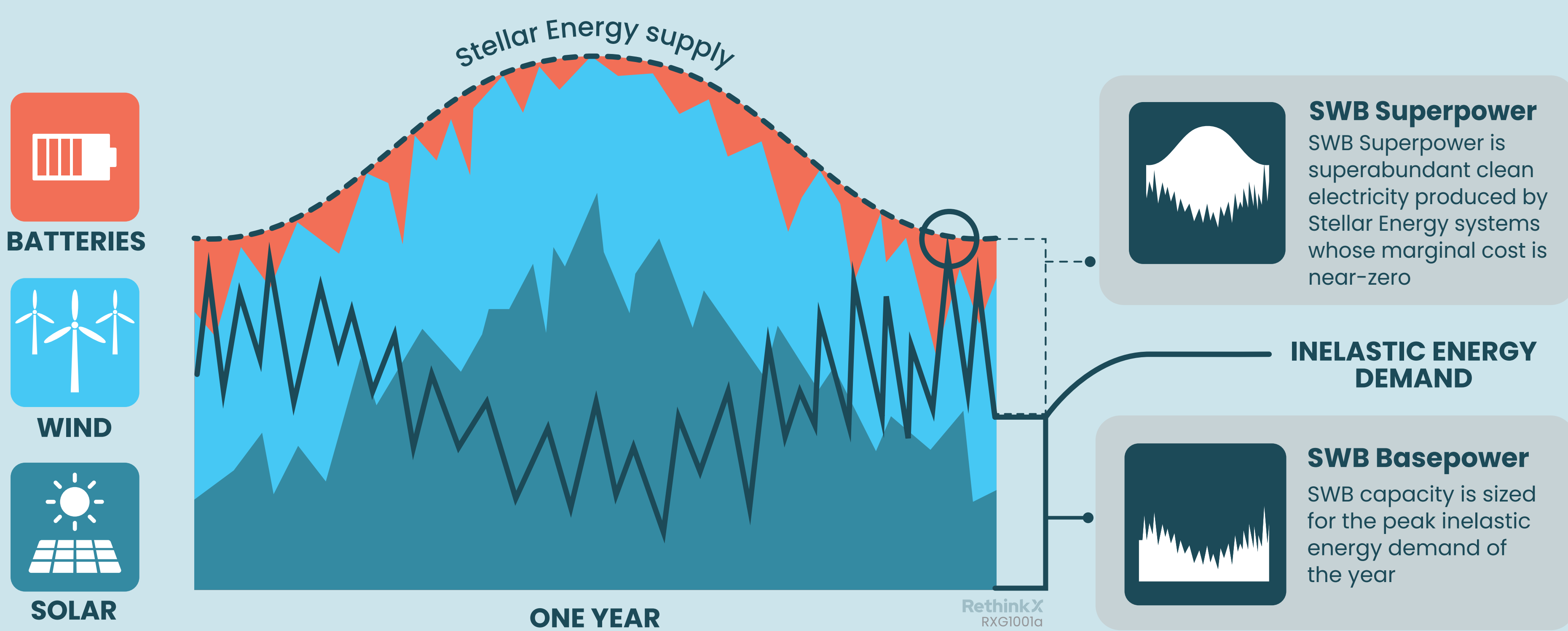
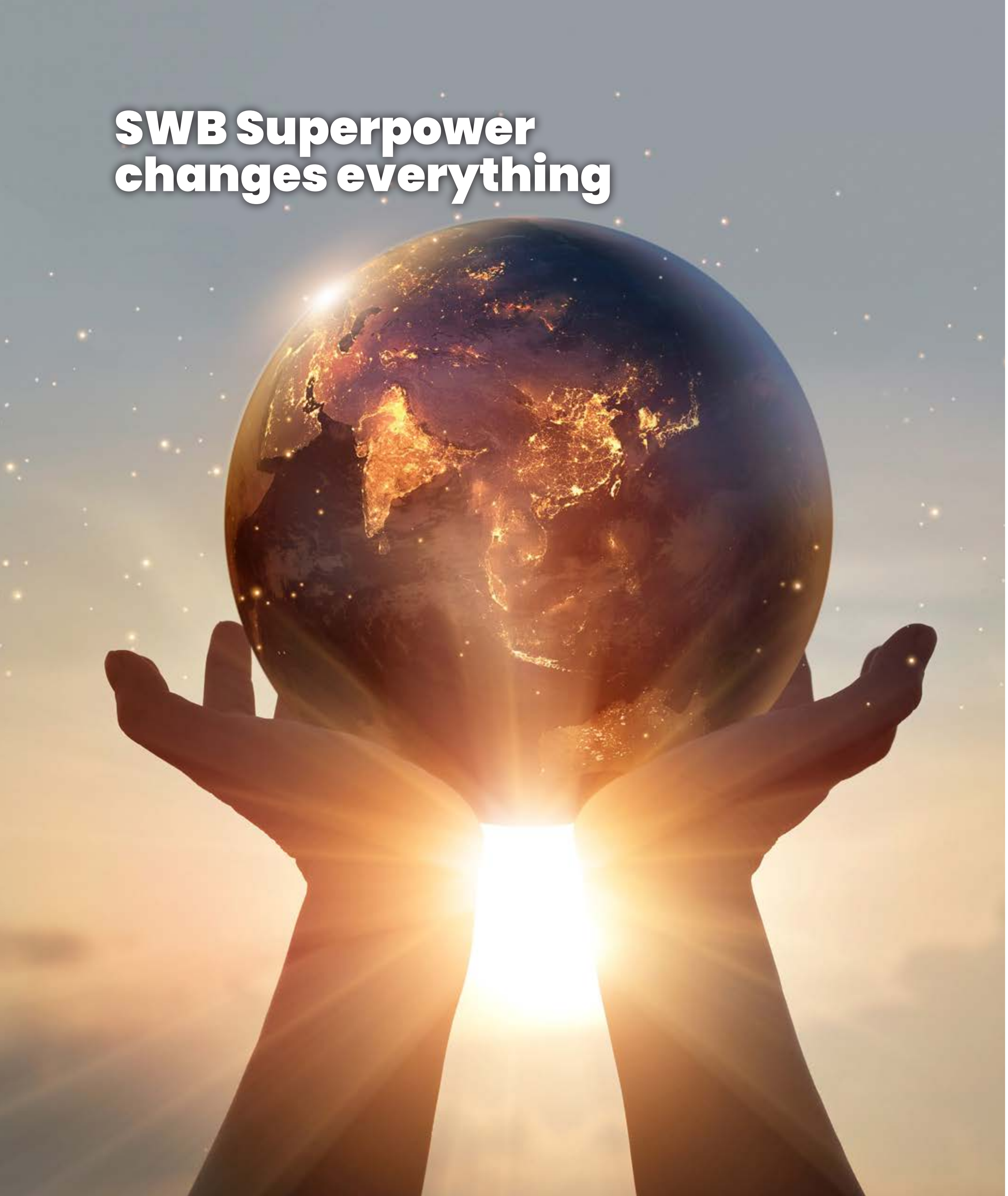


Figure 1. SWB Superpower and SWB Basepower in a Stellar Energy system

SWB Superpower is a natural and inevitable output of any Stellar Energy system.

Yet, its true significance is still not fully appreciated by policymakers, investors, other decision-makers, the general public, or even academic and industry experts.

SWB Superpower changes everything



SWB Superpower is an extraordinary opportunity

In our 2020 report *Rethinking Energy 2020-2030: 100% Solar, Wind, & Batteries is Just the Beginning*, we wrote, “clean energy superabundance from near-zero marginal cost SWB Superpower will create a new possibility space for novel business models, products, services, and markets across dozens of industries, with dramatic increases in societal capabilities and economic prosperity for regions”.

Prior to that time, incumbents labeled the surplus electricity output of solar and wind power a problem of “overproduction” whose only solution was “curtailment”.

We showed for the first time that instead of framing SWB Superpower as a problem where the only solution is to flush huge quantities of clean electricity down the drain, it should instead be viewed as an extraordinary opportunity and valuable property of radically new energy system architectures and business models based on SWB.

SWB Superpower is reliable and predictable

Another widespread misconception about SWB Superpower is that because solar and wind power are intermittent, they are problematic for planning purposes. This is false as well. The reason why is that battery energy storage is increasingly being deployed alongside solar and wind generating capacity. So although the electricity generated by any individual solar panel or wind turbine will of course vary hour-by-hour according to weather conditions and sunlight, battery energy storage – whether co-located with those generating assets, or separately serving the grid at large, or decentralized in smaller installations near the point of end use – nullifies this intermittency. Furthermore, the variability of solar and wind power generation is not random, but is instead a product of weather conditions, which means that weather forecasting can be used to plan battery charging and discharging accordingly.

Another widespread misconception about SWB Superpower is that because solar and wind power are intermittent, they are problematic for planning purposes. This is false as well.

SWB Superpower emerges at all scales

The logic of SWB supersizing applies not just at the grid scale, but also at the commercial and residential scale as well. Any home or business that installs rooftop solar and battery capacity sufficient to meet its inelastic energy demand through the most difficult time of year will naturally produce SWB Superpower throughout the rest of the year. SWB Superpower is therefore a property of all Stellar Energy systems, regardless of their size or the extent of their decentralization.

SWB Superpower emerges early, when SWB is still only a small fraction of total supply

SWB Superpower can emerge once SWB capacity reaches as little as 20% of existing conventional installed capacity, depending on geographic conditions. For example, in leading regions of Australia, Scotland, Germany, and California which have been early adopters of SWB, the combination of solar and wind power already exceeds 100% of existing electricity demand for some of the year.

SWB Superpower returns on SWB investment are nonlinear

The amount of SWB Superpower output from a Stellar Energy system is not linearly proportional to capital investment. Instead, SWB Superpower output increases enormously with additional incremental investment in generating capacity beyond the lowest-cost system configuration. This non-obvious and counterintuitive property of Stellar Energy systems is explained by the *Clean Energy U-Curve* as shown in Figures 11-13.

SWB Superpower is the central feature around which Stellar Energy systems must be architected.

It won't be individual *killer apps* but rather *killer combos* that will emerge as the winners in the race to utilize SWB Superpower.

Stellar Energy systems should be architected specifically to optimize SWB Superpower

The core conceptual leap that decision-makers must make regarding today's energy disruption is that SWB Superpower is not merely an intriguing side effect or emergent property of Stellar Energy systems, but rather is the *central feature* which such systems must be designed to optimize.

SWB Superpower is the nucleus around which Stellar Energy systems must be architected. Furthermore, optimization should be informed by the *Clean Energy U-Curve* in order to account for the fact that returns on SWB Superpower are nonlinear.

SWB Superpower will be best utilized by combinations of use cases

While it is easy to imagine many individual uses for superabundant clean energy, the key to realizing maximum value from SWB Superpower will be to go beyond one-dimensional thinking and identify pairs, triplets, or even quadruplets of use cases that complement one another. Large computing clusters, for example, will clearly benefit from clean, cheap electricity – but the low-temperature heat they output as waste is precisely the energy input that other industrial applications like precision fermentation (a disruptive technology which produces food, medicine, and materials from microbes) require. And so these two industries could offer a promising pairing of SWB Superpower utilization. Dozens of other such combinations await discovery.

SWB Superpower unlocks clean energy superabundance

RethinkX has developed a set of analytical tools including the *Clean Energy U-Curve*, the *SWB Superpower Curve,* and the *SWB Coverage Curve* with which to optimize Stellar Energy system design for SWB Superpower. These tools together with modeling and analysis (see Part 3) can help decision-makers plan for the disruption of energy and make the transformation to clean energy superabundance as quickly and smoothly as possible.

Understanding the value of *Stellar* Energy

The power to:

Flourish

Think

Act

Work

Protect

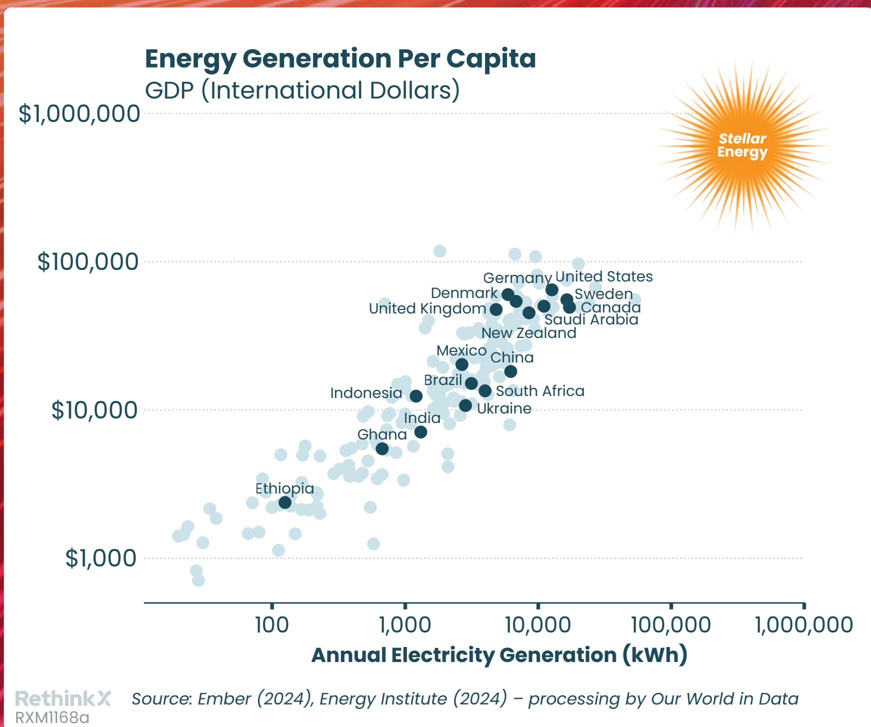


Figure 2. Energy and Prosperity

Stellar Energy systems and the SWB Superpower they produce will open the door to global clean energy superabundance. This will empower humanity as never before.

The power to flourish

Energy is prosperity. It illuminates the night, letting us see when we would otherwise be blind. It keeps us cool through the heat of summer and warm through the cold of winter, letting us live and work where we otherwise could not. It transports us, letting us move when we would otherwise be trapped and connecting us when we would otherwise be isolated.

Energy saves us from the suffering of darkness, discomfort, and drudgery, and in doing so it enables all other value creation across the entire global economy. It allows us to not just survive but thrive, and is therefore a cornerstone of human prosperity. We see unequivocal evidence for this in the extremely strong correlation between energy usage and the availability of goods and services as measured by GDP (Figure 2).

With enough energy, almost anything is possible. Without it, nothing is possible.

Energy is far more important than is widely appreciated. It is much more than just kilowatt-hours of electricity or barrels of oil – it is the lifeblood of modern civilization. Figure 2 shows the striking correlation between energy abundance and overall economic prosperity.

Moreover, these data show that there are *no exceptions*: **no country that is energy-poor is economically rich, and no country that is energy-rich is economically poor.** Stellar Energy systems offer a unique opportunity for countries to climb the energy-prosperity curve.

The power to think

Energy is intelligence. Artificial Intelligence is another profoundly transformative technology, and just as our human minds must be well-nourished to thrive, so too must digital minds be fed energy in the form of electricity. The explosion of AI over the next two decades will demand enormous quantities of energy – so much so that the scale of AI training facilities and the models they yield is now being measured not just in terms of computational resources, data, and time but also in gigawatts as well.

As with SWB Superpower, a superabundance of intelligence at near-zero marginal cost will transform every sector of the economy, society, geopolitics, the environment, and the human condition itself. This is particularly true for intelligence embodied in humanoid robots, which will disrupt human labor at the same time SWB is disrupting energy.

RethinkX terms the upcoming superabundance of intelligence *Cognitive Superpower*. And just like with SWB Superpower, achieving Cognitive Superpower status is a race to the stars.

The more Cognitive Superpower humanity has access to, the more and faster we can achieve scientific discoveries, technological progress, product innovations, economic growth, environmental restoration, human development, and solutions to challenges of all kinds.

To build Cognitive Superpower, we must build SWB Superpower

The power to act

Energy is freedom. It unlocks possibilities, opportunities, and thus choices that would otherwise remain out of reach. For individuals, it liberates us in body, mind, and spirit, and in doing so it enables us to explore options and chart new pathways toward goals that were either impractical or outright impossible for our energy-starved ancestors. For societies, it can help grant economic and geopolitical independence that also open new options and pathways that would otherwise remain unavailable.

The power to work

Energy is labor. It allows human and biological systems to export local entropy, enabling the rearrangement of material and information into new and more useful forms. Whether this means digging a hole or erecting a skyscraper, harvesting a field or replanting a forest, we use energy to transform the world around us in beneficial ways. For millennia, the only way to utilize energy was via human and animal muscle power. Then, from the dawn of civilization through to the modern industrial era, we discovered ways to harness energy with primitive unthinking machines like sailboats and bulldozers. In the very near future, artificial intelligence embodied in humanoid robots will increase the amount of work our societies can do by an order of magnitude or more.

The power to protect

Energy is security. It makes essentials like electricity, water, food, and other basic goods and services both reliable and affordable. In doing so, it gives individuals, communities, and nations greater capacity to absorb or adapt to system shocks from natural disaster, economic downturn, social unrest, or geopolitical conflict and even war. The combination of resilience and self-sufficiency that energy enables is therefore an indispensable form of protection against any threats or problems that arise.

A digital revolution for energy

In our 2020 energy report, we wrote, **“what happened in the world of bits is now poised to happen in the world of electrons”.**

In the 1990s, digital technologies converged to enable the modern Internet, which disrupted the information and communications sector – the world of bits. That disruption transformed society and the global economy by slashing the marginal cost of information and communications to near-zero.

New industries and novel business models built on abundance rather than scarcity then grew the digital economy to the trillion-dollar scale within two decades.

Prior to the 1990s, huge swathes of the human population couldn’t access one another or the world’s knowledge. But today we are awash in information and communications: all of the world’s knowledge is at our fingertips, and calls come free and unlimited with the price of Internet service and smartphones so cheap that more than five billion people now have them.

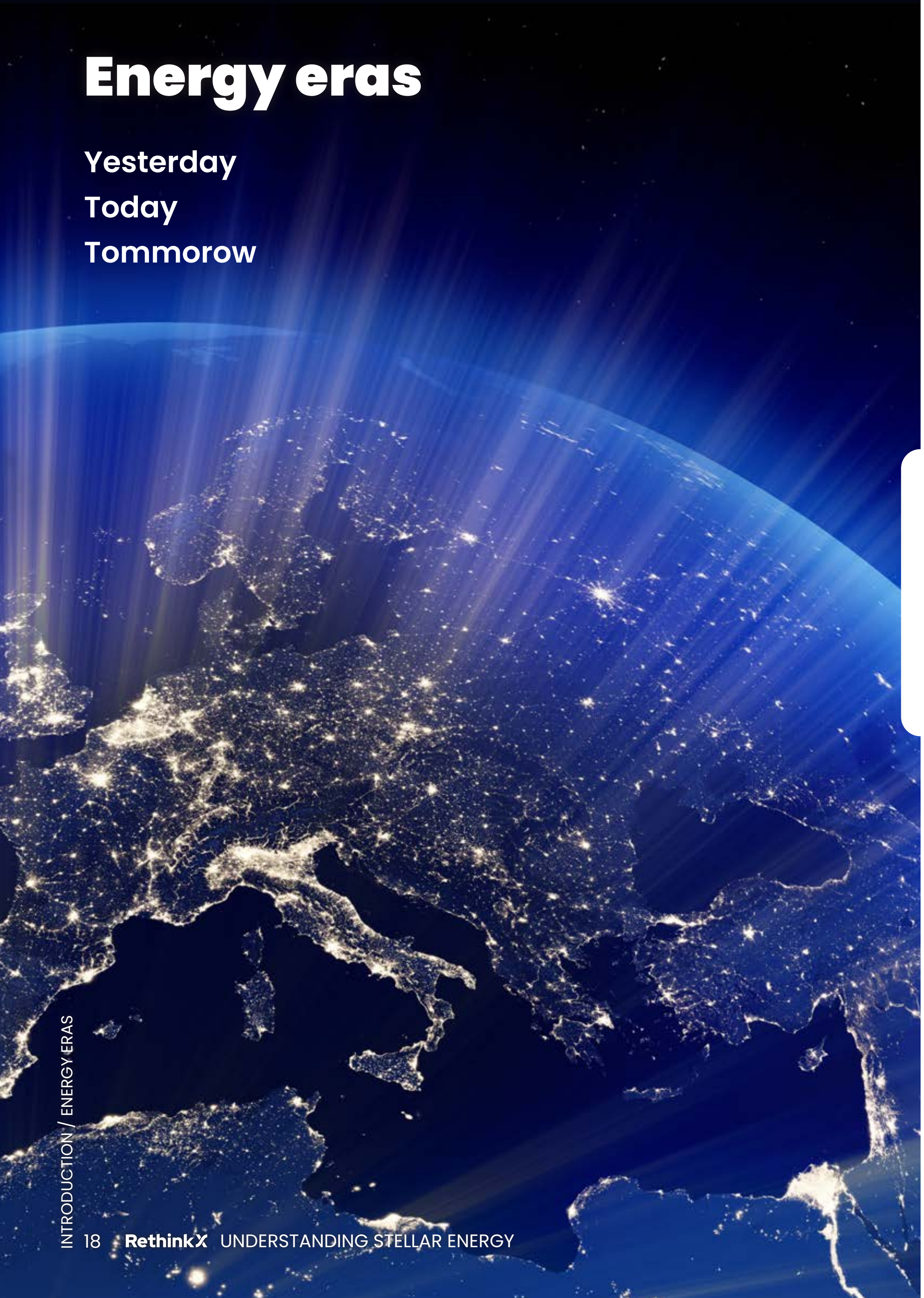
Likewise, the SWB disruption of energy has now begun, and within 20 years the world will be awash in clean electricity.

The energy disruption is a race to the stars.

The winners will be those industries and societies who maximize deployment and utilization of clean electricity from the new Stellar Energy system, not those who minimize it.

Energy eras

Yesterday
Today
Tommorow



Yesterday
Escaping from energy scarcity

The story of energy predates not just modernity, or even recorded history, but our species itself.

Life for all animals, including our ancient hominid ancestors, was a perpetual struggle simply to find enough food to survive. And for animals, food is energy. Energy scarcity was thus the rule, rather than the exception, for eons.

Humanity's first great leap upward away from energy scarcity came with the mastery of fire, over one million years ago, which allowed us to use energy in wood and other biomass to stay warm, to cook food and make it safer and more digestible, and to ward off predators whom we would otherwise have to fight or flee.

We have made many other energy leaps since then, both great and small. Two of the greatest came at the end of the 19th Century, with the advent of electricity and combustion engines which have together powered modernity for over one hundred years.

Both of those technologies have relied largely on fossil fuels as their primary energy source so far, and for those of us fortunate to live in the world's wealthier societies, our uses of them are so widespread and so essential that we often take them for granted. Indeed, electricity and fuels are now so ubiquitous that we only really notice them on those rare occasions when they are not available, such as during a power outage.

Today
Energy inequality

History shows that as energy availability grows, so too does prosperity.

Post-World War II America serves as a case in point: the country's rapid development and unparalleled global influence were, in part, a consequence of ample energy from fossil fuels, which slashed costs and increased access to electricity, heating, transportation – and thus all other goods and services – to unprecedented levels.

Energy scarcity finally became the exception rather than the rule for the first time in human history, which in turn laid the groundwork for a Golden Age of economic expansion and upward socioeconomic mobility in the United States during the 1950s and 1960s that elevated tens of millions of people into a material quality of life previously accessible only to the wealthy few.

Although energy has been relatively abundant in the wealthier nations of the world for over half a century, its costs remain high enough to be constraining, as well as volatile and unpredictable due to macroeconomic and geopolitical factors.

These constraints have in turn limited human flourishing along many other dimensions, both material and social.

So while there has been an astounding increase in wealth and prosperity worldwide over the last several generations thanks to a broad range of innovations, the limited availability and affordability of energy nevertheless continues to hinder human development.

In short, energy is not yet abundant enough to free humanity fully from the shackles of scarcity. But that is about to change, because we are entering a new era of clean energy *superabundance.*

In short, energy is not yet abundant enough to free humanity fully from the shackles of scarcity. But that is about to change, because we are entering a new era of clean energy *superabundance.*

Tomorrow
Clean energy superabundance

Clean energy is good, and humanity needs more energy, not less.

Solar power, wind power, and batteries are the core technologies that have converged to build a transformational energy system and disrupt the conventional energy sector.

Unlike fossil fuels, which were only able to bring humanity relative energy abundance with a whole host of negative consequences (including geopolitical, social, and environmental), SWB offers a stellar path to clean energy superabundance worldwide over the next two decades.

The difference between relative abundance and superabundance is profound. Relative abundance merely means affordable and accessible, like the foodstuffs at a supermarket in a prosperous country today.

Superabundance is different

A good or service becomes *superabundant* when marginal cost is near-zero and supply overwhelmingly exceeds inelastic demand much or all of the time.

Superabundance fundamentally breaks scarcity-based economics because the per-unit equilibrium price at the actual quantity of available supply is too low to support traditional market transactions.

Instead, superabundance necessitates new and entirely different kinds of business models, as we saw with the rise of the Internet and the emergence of information superabundance.

It is important to recognize that superabundance does not require a good or service to be totally costless or omnipresent, like air. Rather, it only requires that a good or service be ***effectively*** free and unlimited for practical purposes from the end user's perspective. Water from a drinking fountain, paper napkins from a restaurant dispenser, images captured by a smartphone – these and many other goods and services are available effectively for free in quantities that far exceed the typical end user's needs, and thus do not require a formal market transaction.

Subscription-based business models can approach conditions of superabundance if the fee is low enough and supply is large enough, as in the examples of Internet access and streaming services. Similarly, advertisement-based business models such as search and social media that exchange services for users' attention and personal data are also examples that approach superabundance.

In order for energy to be superabundant, it must become "too cheap to meter" as Lewis Strauss said in 1954, when he was Chairman of the *United States Atomic Energy Commission.* Strauss along with many others correctly recognized that clean energy superabundance is a "Holy Grail" of technology precisely because of how transformative its benefits would be for all of humanity.

While the inherent difficulties and dangers of nuclear fission technology have unfortunately kept costs of nuclear power prohibitively high, the costs of solar photovoltaics (PV), wind power, and electrochemical batteries have fallen so low over the last decade that the convergence of these technologies finally offers a clear pathway to clean energy superabundance.

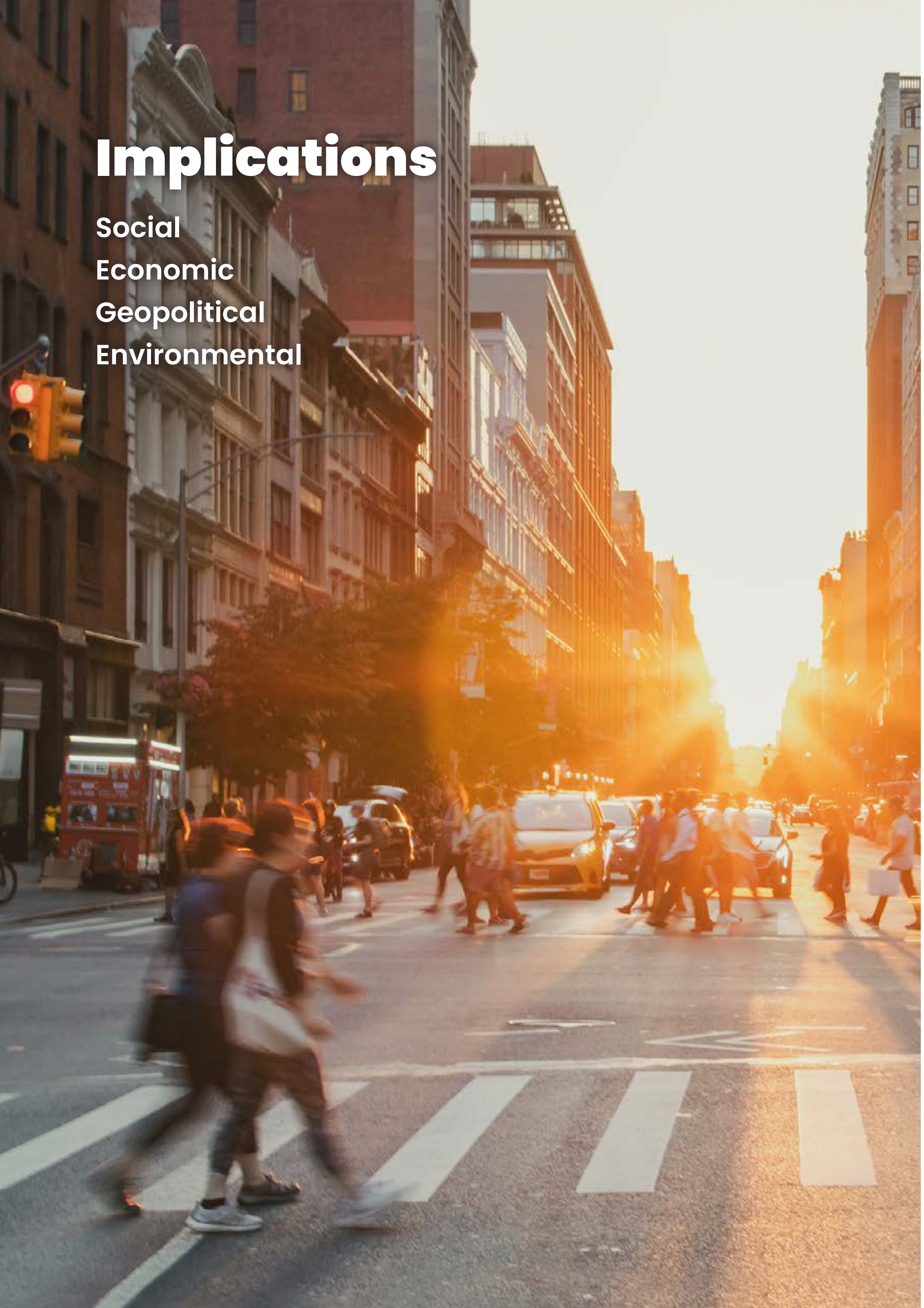
Despite all of humanity's remarkable progress up until now, we still remain prisoners of energy scarcity.

Clean energy superabundance will therefore liberate us in the purest sense: it will open the door to a vastly larger possibility space by enabling us to solve problems, surpass limitations, and mitigate dangers that up until now have blocked progress and prosperity at every turn.

Stellar Energy will liberate humanity in the purest sense.

Implications

Social
Economic
Geopolitical
Environmental



Social implications

Prosperity: rising standards of living for everyone everywhere as costs fall rapidly and universally across virtually all goods and services.

Freedom: genuinely actionable options expand as obstacles to development diminish and opportunities grow – most especially for individuals, communities, and nations who are currently impoverished or otherwise disadvantaged.

Poverty reduction: greater affordability of basic goods and services raises the floor of standards of living everywhere, via both individual spending and government programs.

Access and opportunity: democratized access to electricity catalyzes prosperity in disadvantaged communities, helping to remove prior obstacles to development.

Health: direct reduction in illness and death from indoor and ambient air pollution (which together kill as many as 6 million people per year) through the shift to clean energy, along with indirect reductions driven by rising overall prosperity.

Security: greater affordability, access, and reliability of essential goods and services like electricity, water, food, and other basic goods and services leads to greater capacity of individuals, communities, and nations to withstand and adapt to system shocks from natural disaster, economic downturn, social unrest, geopolitical conflict, and even war.

The shift to Stellar Energy systems will bring clean energy superabundance, which will rank among the most profound transformations humanity has ever experienced; so sweeping that virtually every aspect of our lives will be positively affected.

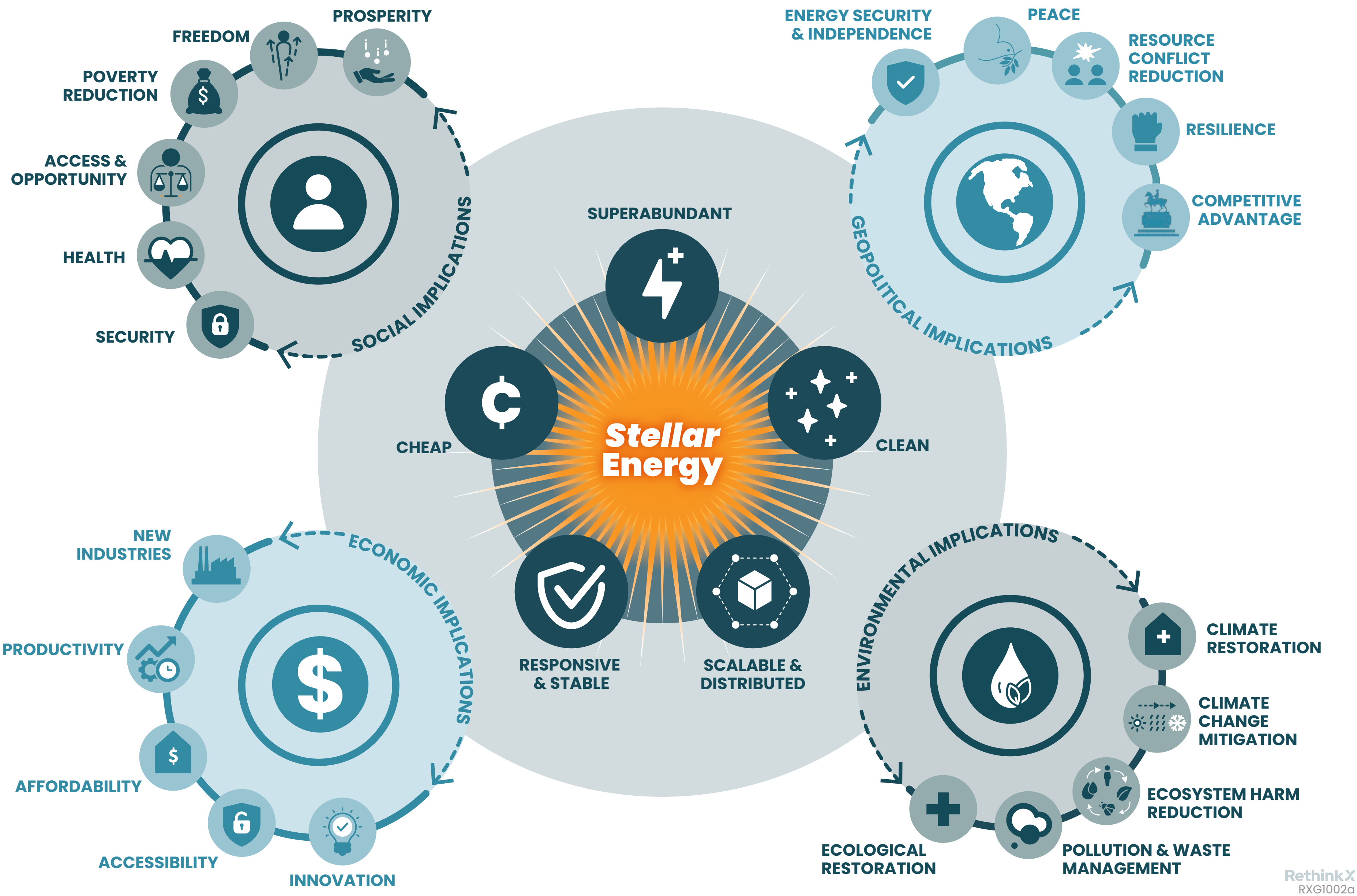


Figure 3. Implications of Stellar Energy and Clean Energy Superabundance

Economic implications

New industries: entirely new domains of value creation based on products and services that were previously impossible.

Productivity: greater value creation at every level of the global economy.

Affordability: reduction in the cost of all goods and services, into which energy is a universal input, with savings accumulating down every value chain.

Accessibility: individuals, communities, and nations at greatest disadvantage will be able to seize opportunities and participate in marketplaces and industries whose barriers were previously too onerous.

Innovation: new business models built around superabundant clean energy that were previously impossible.

Resilience: increase in capacity to absorb systemic shocks of all kinds, and to recover from natural or human-made catastrophes.

Competitive advantage: large shifts in the international competitive landscape across many sectors such as agriculture, mining, and manufacturing that are mediated by the cost and availability of energy.

Geopolitical implications

Energy security and independence: decrease in reliance upon energy imports, as well as decrease in vulnerability to volatile energy prices driven by macroeconomic and geopolitical forces.

Peace: increase in cooperation and trade together with decrease in conflict and violence, both within and between nations, driven by rising overall prosperity.

Resource conflict reduction: substantial decrease in local, regional, and international disputes over scarce and concentrated deposits of fossil fuels, as well as over other resources such as water which are mediated by the cost and availability of energy.

Environmental implications

Climate change mitigation: near-total mitigation of greenhouse gas emissions from the energy and transportation sectors.

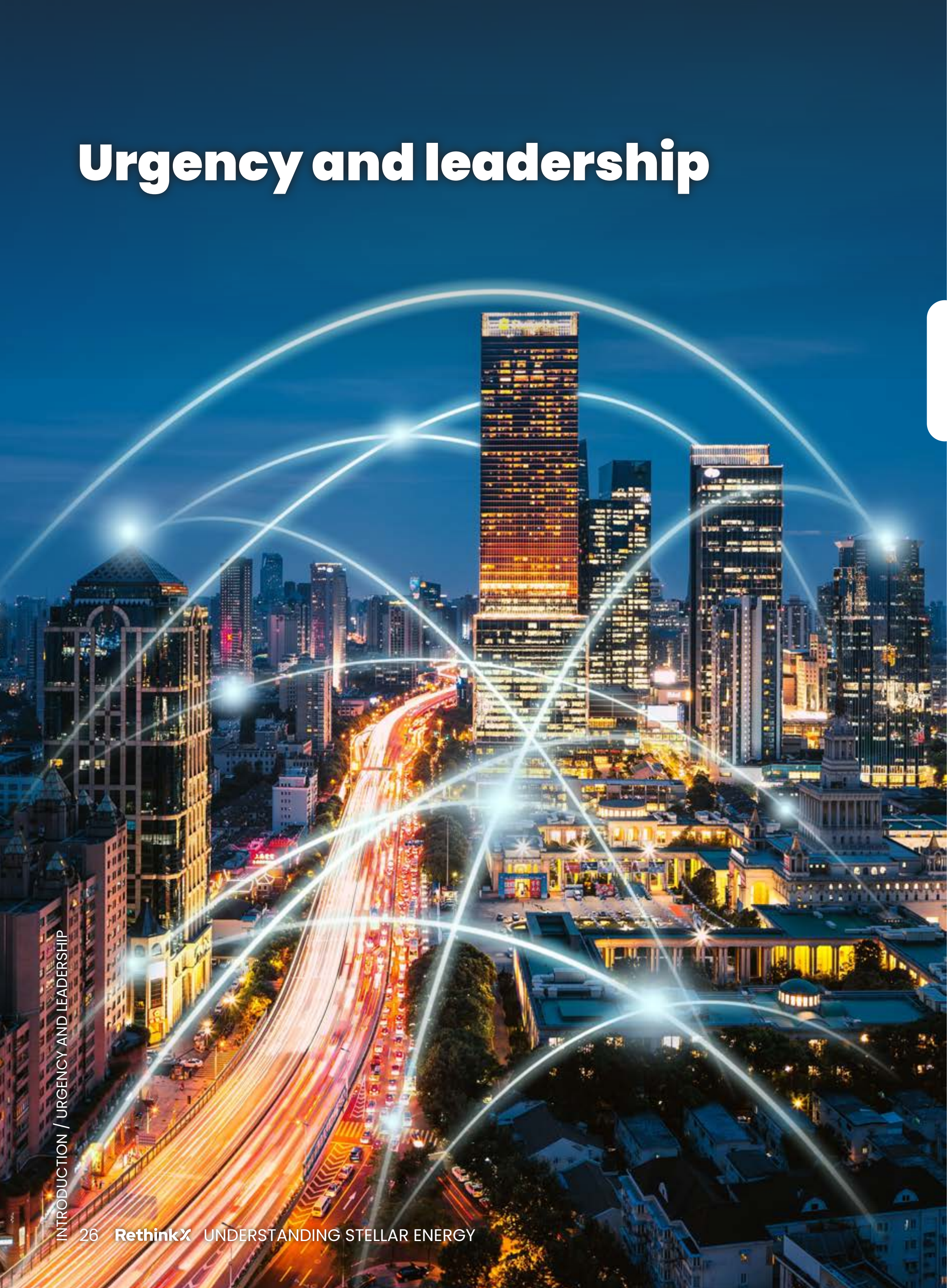
Pollution and waste management: near-elimination of direct pollution produced by the energy sector itself, plus dramatic expansion of affordable waste management options for other sources of air, water, soil, groundwater, and ocean pollution and contamination via rising overall prosperity.

Ecosystem harm reduction: decrease in ecological footprint of energy sector from fossil fuel and biofuel production

Climate restoration: dramatic expansion of affordable carbon withdrawal and ocean alkalinization options.

Ecological restoration: direct reduction in terrestrial and marine habitat fragmentation, habitat destruction, and biodiversity loss associated with fossil fuel production and use itself, along with dramatic expansion of affordable environmental restoration options via rising overall prosperity.

Urgency and leadership



Building Stellar Energy systems to achieve clean energy superabundance is more essential now than ever before, and vastly more important than is widely recognized.

Deploying SWB must therefore become one of the top priorities for every community, region, and nation across the globe.

The reason why it is urgent to build Stellar Energy systems and achieve clean energy superabundance is not just because of the astonishing benefits on offer, but also because of the growing dangers we must avoid to ensure prosperity and prevent conflict, chaos, and collapse.

Despite unprecedented and unequivocal progress toward shared global prosperity, our era has nevertheless been called one of “multi-crisis”, and the signs of trouble are plain to see: geopolitical conflicts have escalated into war; economic turmoil still roils in the wake of the global COVID-19 pandemic; populism is on the rise; natural disasters and record temperatures indicate looming climate change impacts; and the disruption of labor by AI and robotics threatens to destabilize societies with technological unemployment.

Throughout history, civilizations have reached the limits of what their organizing system and production system could support.

RethinkX refers to these events as *Rupture Points*, where the old systems must give way to the new, and where societies face a choice of whether to break through or break down in response. We have arrived at a new rupture point, and changes are inevitable as the ground beneath our feet is beginning to shift.

Rupture Points have historically been fraught with danger, and without good decision-making that gives our societies the means to solve major problems and overcome enormous challenges, the changes we face today could prove catastrophic.

Clean energy superabundance is the ultimate safeguard against catastrophe.

As long as energy remains readily available across society, then other challenges – no matter how daunting – remain solvable.

But if the lights go out in people's homes, if the power falters at a region's factories, if electricity or heat are unavailable or even just too expensive to make ready use of, then any other major problem society faces could quickly prove overwhelming.

In order to safeguard against catastrophe in all its forms – social, economic, geopolitical, environmental – societies should immediately begin deploying SWB at scale to accelerate the advent of Stellar Energy systems and thereby achieve clean energy superabundance as soon as possible.

As long as energy remains readily available across society, then other challenges – no matter how daunting – remain solvable.

Part 1:
Solar, wind, and batteries are different

Despite an explosion of interest among policymakers, investors, and the general public about clean energy technology over the last several years, most observers nevertheless still fail to fully appreciate the transformative impact that the new Stellar Energy system based on solar power, wind power, and battery energy storage (SWB) will have worldwide.

A new system, **not just new technologies**

Solar power, wind power, and batteries are not mere substitutes for coal, oil, natural gas, and nuclear fission – just as a butterfly is not merely a caterpillar with wings. The new energy technologies have very different properties from the conventional ones they are disrupting, and so it is a mistake to imagine that a solar park, wind farm, or grid-scale battery can simply be dropped into the old energy system as a one-to-one replacement for traditional power plants. Instead, just as we have seen with other disruptions throughout history, the new Stellar Energy system will have properties and behaviors that differ from today's conventional energy systems in important ways.

> "There is nothing in a caterpillar that tells you it's going to be a butterfly."
> – R. Buckminster Fuller

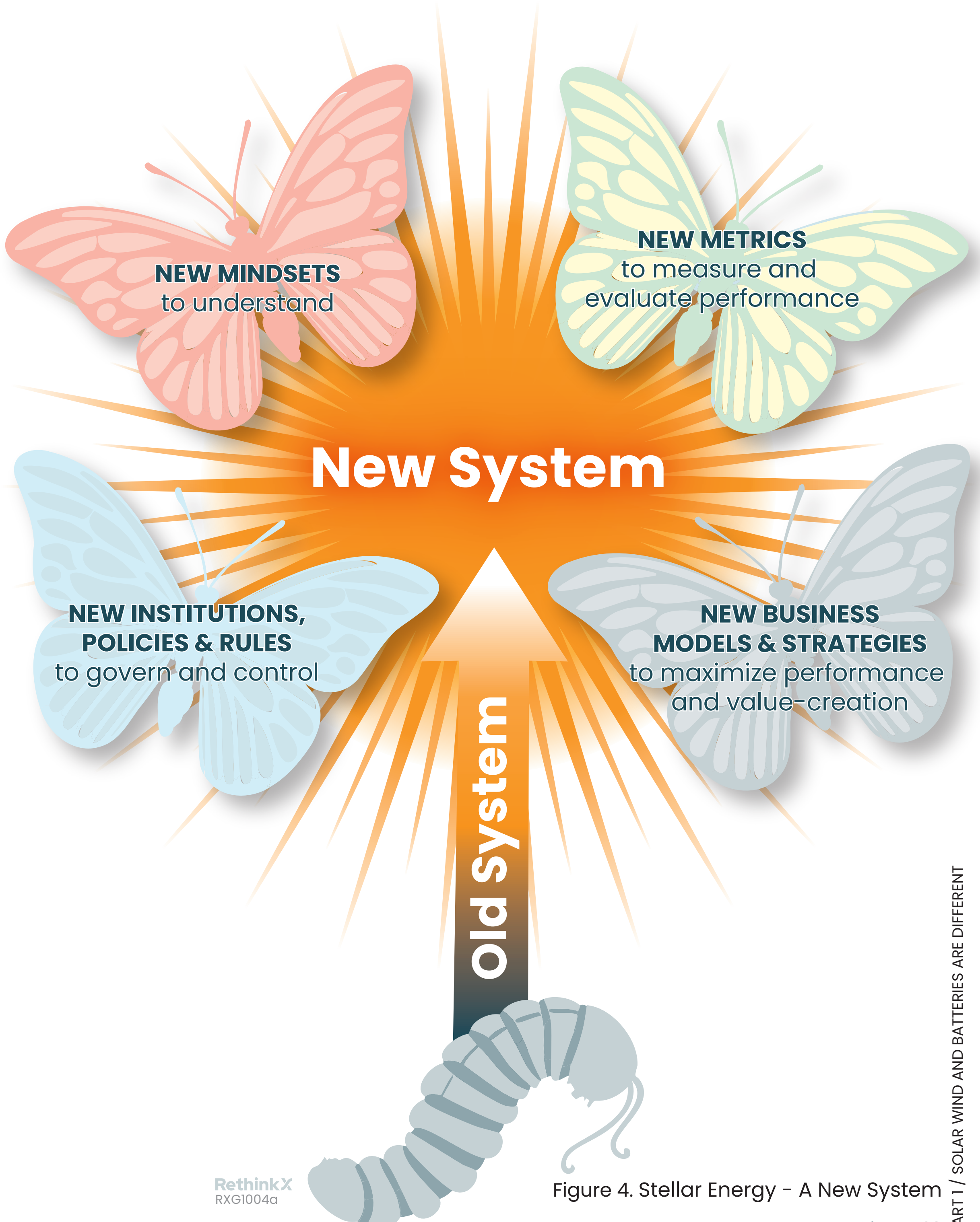


Figure 4. Stellar Energy - A New System

An energy **transformation,** **not an energy transition**

Disruptions are not linear. They do not proceed slowly and incrementally over the course of many decades.

The evidence from hundreds of cases throughout human history shows that when new technology offers an overwhelmingly competitive value proposition, adoption follows an s-shaped curve over the course of just 10-20 years.

Even titanic incumbent industries cannot stop disruption when it arrives, as we saw when horse-based transportation was disrupted by automobiles, and when hardcopy-based media was disrupted by the Internet.

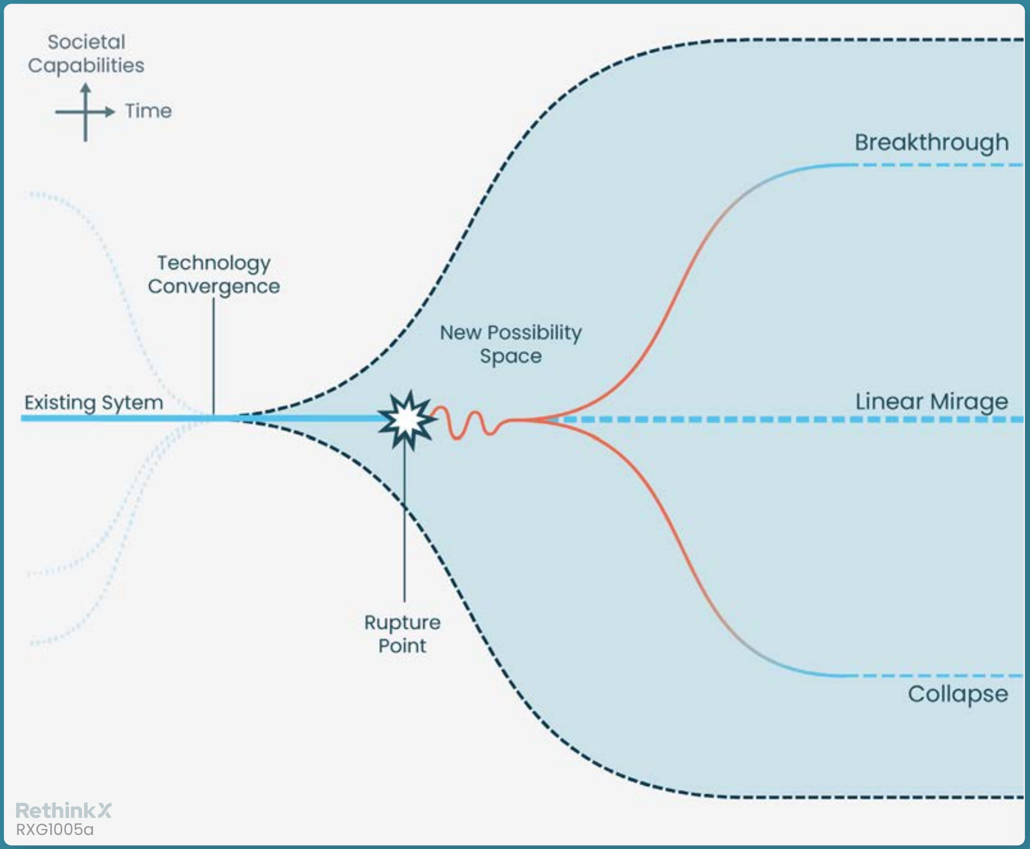
Yet, incumbent firms, industries, or sectors facing disruption will often indulge in wishful thinking, and claim that *this* time, for *them*, it will be different. We call this the *Linear Mirage*.

There is no reason to believe that the disruption of energy by SWB will deviate from the same fundamental pattern of disruption we have seen for millennia.

And that means there will not be a slow, incremental "energy transition" that takes place over the entire 21st Century, but a rapid transformation that will be largely complete by the end of the 2040s.

Even titanic incumbent industries cannot stop disruption when it arrives, as we saw when horse-based transportation was disrupted by automobiles, and when hardcopy-based media was disrupted by the Internet.

Figure 5. System Transformation and the Linear Mirage



Fundamental difference 1: **stocks, not flows**

It was only a century ago that humanity at last answered the age-old question of what stars are and why they shine.

For countless millennia, we knew of only one kind of fire. But in 1920, building upon the work of Albert Einstein which showed the equivalence between mass and energy, Cecilia Payne and Arthur Eddington proposed that the enormous gravity of the sun and other stars could ignite an entirely different and vastly more powerful reaction than fire: *nuclear fusion.*

Like the sun and stars, once a Stellar Energy system based on SWB reaches critical mass it no longer requires significant ongoing inflows of fuel to generate energy.

Once the stock of solar and wind generating assets is built, those installations can produce power at extremely low marginal cost for decades. Solar panels do not have any moving parts and require virtually no maintenance, and so their marginal cost can even approach zero under some circumstances. Electrochemical batteries have minimal operations and maintenance expenses too, and so they can store and output power at extremely low marginal cost as well – and this has profound implications for SWB Superpower availability and clean energy superabundance. With fossil fuels, the focus of energy investment, policymaking, and planning is naturally centered on the flow of fuels into power plants in exchange for flows of electricity out. With SWB, energy development can focus instead on asset deployment rather than on managing ongoing operations and maintenance.

Solar panels and batteries are much more durable than is widely believed

The performance of solar photovoltaic panels and electrochemical batteries degrades over time, but the extent of degradation is often exaggerated in conventional energy analyses.

These analyses typically assume an operational lifespan of just 20 years for solar panels and no more than 10 years for batteries. This is badly misleading, and significantly inflates the estimated cost per kilowatt-hour of these technologies..

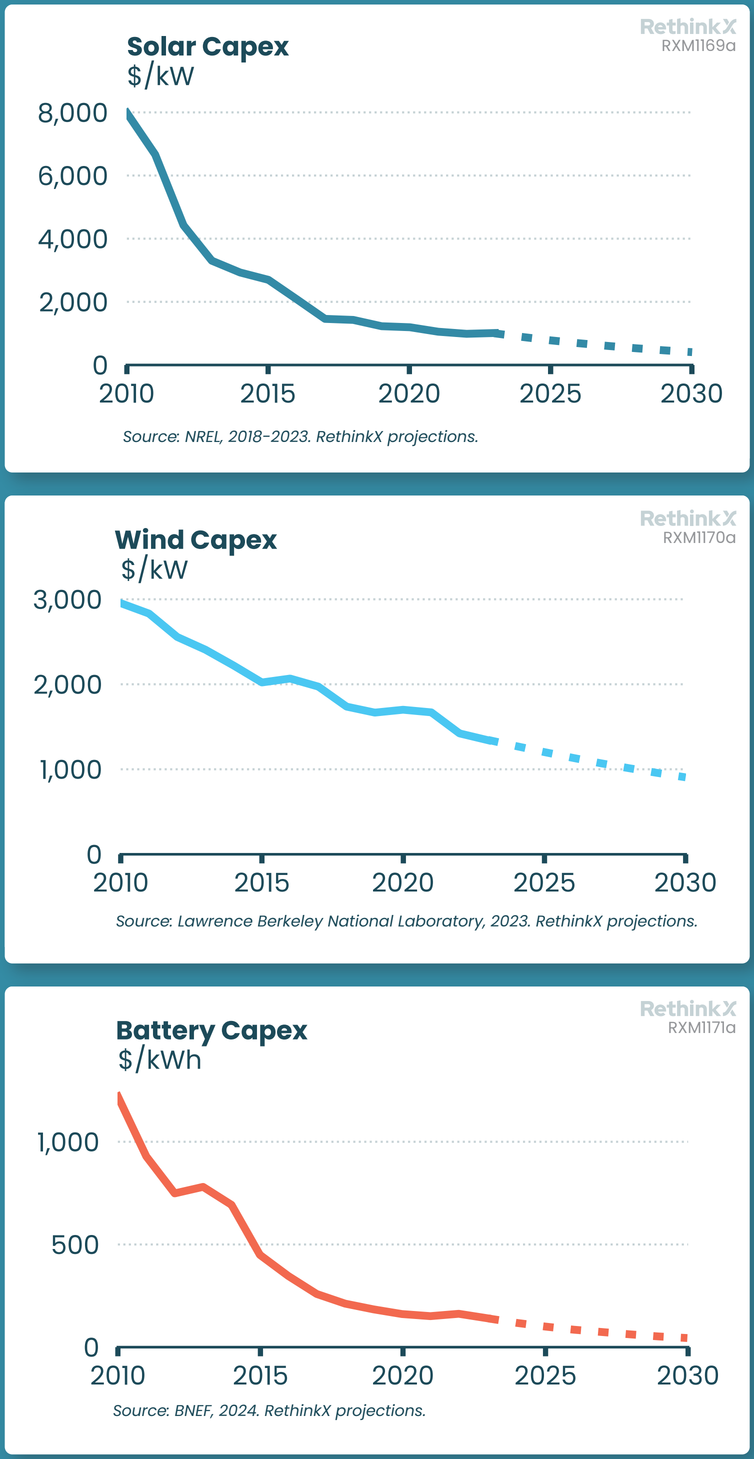
According to the U.S. Department of Energy, "the estimated operational lifespan of a PV module is about 30-35 years, although some may produce power much longer," where operational lifespan is defined as retaining 80% or more of original capacity.

NREL, the National Renewable Energy Laboratory, a part of the U.S. Department of Energy, believes it is reasonable for "possible commercialization of modules with 50-year lifetimes". Even retailers of home solar panels, such as IKEA and its partner SunRun, offer a 25-year warranty on solar panel and total system performance.

Moreover, even if the panels do degrade to 80% or less capacity after many decades, they seldom fail outright. This means these nearly-costless assets can continue to generate a useful amount of electricity almost indefinitely – certainly much longer than any meaningful social or economic planning horizon.

For electrochemical batteries, a number of low-cost chemistries including lithium-iron-phosphate and sodium-ion show operational lifespans of 4000+ cycles (roughly 10 years) under heavy duty with full depth of discharge, but – more importantly – nearly-indefinite lifespan under light duty with limited depth of discharge. It is therefore likely that batteries using these chemistries will have operational lifetimes of 20 years or more – and more durable chemistries are in active development as well.

Figures 6, 7, 8. Solar, Wind and Battery Energy Storage Capacity Cost



SWB capex can be viewed as prepayment for electricity for the next 30 to 50 years.

The structural shift in focus from stocks to flows – and therefore from opex to capex – means that SWB will share more in common with the economics of information goods and services than the economics of material goods and services.

Fundamental difference 2: cheap, not expensive

Since 2010, the capital costs of solar have fallen by over 80%, wind by over 50%, and batteries by over 90%.

Up until the mid-2010s, solar power, wind power, and battery energy storage were all still relatively expensive, and so the prevailing wisdom was that any switch to these technologies would have to be motivated by "sustainability" or other non-economic incentives – and often enforced by governments. But as costs have continued to fall, solar and wind have simply become the cheapest form of electricity generation available in many areas.

By 2030, SWB competitiveness will grow into an overwhelming and unassailable advantage that makes these energy technologies the clear economic choice in virtually every inhabited region of the planet.

Like other disruptions throughout history, the disruption of energy by SWB will be driven by economic forces. But beyond being cheaper and more competitive overall, Stellar Energy systems have the additional advantage of being near-zero marginal cost, which makes them even more competitive in wholesale markets where prices tend to clear near the marginal cost.

Fundamental difference 3:
superabundant, not scarce

Solar power and wind power do not extract energy contained within a fuel like coal or uranium, but instead harvest ambient energy.

Solar and wind power both originate with the sun and are thus not depletable, and the supply of Stellar Energy continually delivered to the Earth is enormous relative to our needs. The planet receives almost as much energy every hour from the sun as the whole of humanity uses in an entire year.

Although sunshine and wind are intermittent in any specific geographic location, the ambient energy available to our planet as a whole for harvest with solar and wind technology is superabundant – meaning that its marginal costs are near-zero and the available supply vastly exceeds inelastic (i.e. essential and inflexible) demand.

This stands in sharp contrast to fossil fuels, which are not only finite and depletable but are also now growing increasingly scarce as the "low hanging fruit" of conveniently accessible deposits have already been consumed.

We are now left to pursue the remaining sources of fossil fuels that are increasingly difficult (and expensive) to access, such as offshore oilfields that lie beneath three miles of ocean and rock.

The very opposite is true of solar and wind power: deployment and scaling only drives their costs lower, which in turn opens up further deployment and scaling opportunities.

Superabundance necessitates a wholly different mindset than scarcity.

With a superabundance mindset, the focus is on identifying new opportunities to explore, whereas with a scarcity mindset the focus is on deciding which opportunities to give up.

The contrast between the two is profound, and any individual or organization that continues to operate with a scarcity mindset in the coming era of energy abundance will inevitably make deeply suboptimal decisions.

Superabundance also necessitates entirely new institutions, rules, and business models. Economics is traditionally defined as the study of the allocation of scarce resources. A new and very different economics is therefore required to understand the allocation of superabundant resources with near-zero marginal cost and supply surpluses – and along with it, our institutions, laws, policies, and business practices will need to grow and adapt.

The recent disruption of information and communications by the Internet and related digital and computing technologies provides a case in point for how markets, industries, economies, and entire societies have been forced to change as technology disruptions rapidly transformed information and telecommunications from scarce and expensive things into superabundant ones.

And just as we produce and consume far more information via the new near-zero marginal cost technologies of the Internet than we ever did with the older technologies like newspapers and magazines that they disrupted, so too will we produce and consume far more energy via solar, wind, and batteries than we have up until now with fossil fuels and other conventional technologies.

What happened in the world of bits is soon going to happen in the world of electrons.

Fundamental difference 4: **clean and safe, not dirty and dangerous**

Fossil fuels are dirty and nuclear power is dangerous. SWB simply does not pose the same risks as conventional technologies.

Moreover, SWB can be co-located with other land use such as rooftops and agricultural fields, meaning that their footprint need not be inherently impactful in the way that conventional energy assets are. Although the buildout of SWB requires resources just like any other kind of manufactured goods, the scale of these resource requirements is small relative to fossil and nuclear fuels. For example, global coal production peaked at 8 billion tons each year. Even at its transitory maximum, the total resource intensity of the SWB buildout is unlikely be more than a small fraction of that amount.

Once the buildout is complete, maintaining the stock of SWB can rely mostly on recycling – powered, of course, by Stellar Energy from SWB itself.

Fundamental difference 5: **distributed, not centralized**

Solar photovoltaic panels and lithium-ion batteries can be installed anywhere at any scale, unlike other energy technologies.

As such, they are the quintessential distributed energy resource or DER, because they can be economically and technically viable in remote locations and for small numbers of users where coal, gas, nuclear, hydro, and even wind power cannot. In many instances, solar and batteries can operate off-grid, making reliable electricity available even without any supporting transmission, distribution, or logistics infrastructure at all.

Tony Seba's research has shown that when DER – and especially solar photovoltaics and batteries – become cheaper than the cost of transmission and distribution infrastructure (a tipping point known as generation-on-demand or GOD parity), the investment logic around conventional centralized energy assets inverts entirely.

Fundamental difference 6: **resilient, not fragile**

Coal, gas, nuclear, and even hydro and wind power plants all utilize the kinetic energy of large moving masses to generate electricity.

This makes these older energy technologies fragile in two key ways. First, they require a minimum scale in order to be practical, which is why conventional power plants are large and centralized. Second, they are relatively slow and costly to ramp electricity output up and down.

By contrast, solar photovoltaic panels and electrochemical batteries (especially lithium-ion chemistries) are viable at any scale, and their lack of moving parts means that their electricity output can be ramped far faster than any conventional power plant – typically within milliseconds. Moreover, the cost of keeping gas or coal power plants "spinning" in a state of readiness is high because they must continue to consume fuel. Similarly, the cost of keeping a nuclear power plant at the ready is extremely high, regardless of whether its electricity is utilized or not.

But the cost of doing so for solar photovoltaics and batteries is near-zero. The responsiveness of batteries also enables them to perform balancing, frequency control, voltage control, and other ancillary services far better than conventional technologies, leading to a more stable grid.

SWB Superpower for resilience

Today's electricity grids which are sized to provide only enough capacity to meet existing demand plus a modest amount of headroom, typically around 15%, as an emergency *planning reserve margin* in case of unprecedentedly high demand or the loss of one or more large power stations.

However, this margin is tuned to past experience of high-stress periods. In Texas, for example, the grid proved inadequate for the demands of the exceptional winter storm in February 2021, despite having a planning reserve margin of over 15%, which ultimately led to nearly $200 billion in damage and losses.

With Stellar Energy systems, the same sizing logic that gives rise to SWB Superpower also automatically creates an enormous planning reserve margin.

Any Stellar Energy system optimized for SWB Superpower will thus be easily capable of meeting an unexpected 15% surge in electricity demand for all but a few hours of the year.

Satellite imagery of Winter Storm Viola 2021

Source: commons.wikimedia.org

Resilience translates directly into reliability and security. Conventional electricity systems, for example, must keep a large amount of generating capacity online in standby mode simply as a safeguard against supply side or demand side emergencies. This *planning reserve margin* is legally mandated in most areas, and is typically around 15% of total system capacity.

But for SWB systems, the same logic that gives rise to SWB Superpower (i.e. that they must be sized for the most challenging hours of the year) means that for the rest of the year they will be easily capable of meeting an unexpected 15% surge in electricity demand, meaning that they will automatically have an adequate planning reserve margin for all but a few hours per year.

Fundamental difference 7: **democratizing, not divisive**

The distributed nature of solar photovoltaic panels and lithium-ion batteries (and to a lesser extent wind turbines) means that SWB opens an entirely new possibility space for energy utilization.

Just as the Internet radically expanded access to information and the opportunities it affords to billions of the world's most vulnerable and marginalized people, SWB will radically expand access to energy and the opportunities it affords in exactly the same way.

In the same way that the Internet has been a powerful democratizing force by slashing barriers to access and removing centralized control over the production and consumption of information, so too will Stellar Energy slash barriers to access and remove centralized control over the production and consumption of energy.

Fundamental difference 8:
maximize instead of minimize energy use

In the past, the high marginal cost, environmental impact, inefficiency, and hazards of fossil fuels and nuclear power strongly incentivized societies to minimize energy use.

For several generations, we have been encouraged to "conserve energy" by voluntarily minimizing our energy utilization, despite the fact that energy utilization is a fundamental enabler of prosperity and strongly correlated with economic development, social stability, and human wellbeing across the board. As a result, there has existed a long-standing misalignment of incentives between the use of energy and the pursuit of prosperity.

Stellar Energy brings the incentives between the use of energy and the pursuit of prosperity into direct alignment for the first time.

The disruption of energy by SWB inverts the meaning of energy conservation and frugality from *"don't waste energy"* to *"don't let energy go to waste".*

The conventional wisdom of energy conservation derived from the scarcity mindset makes no sense and is instead counterproductive in the new context of Stellar Energy and superabundance.

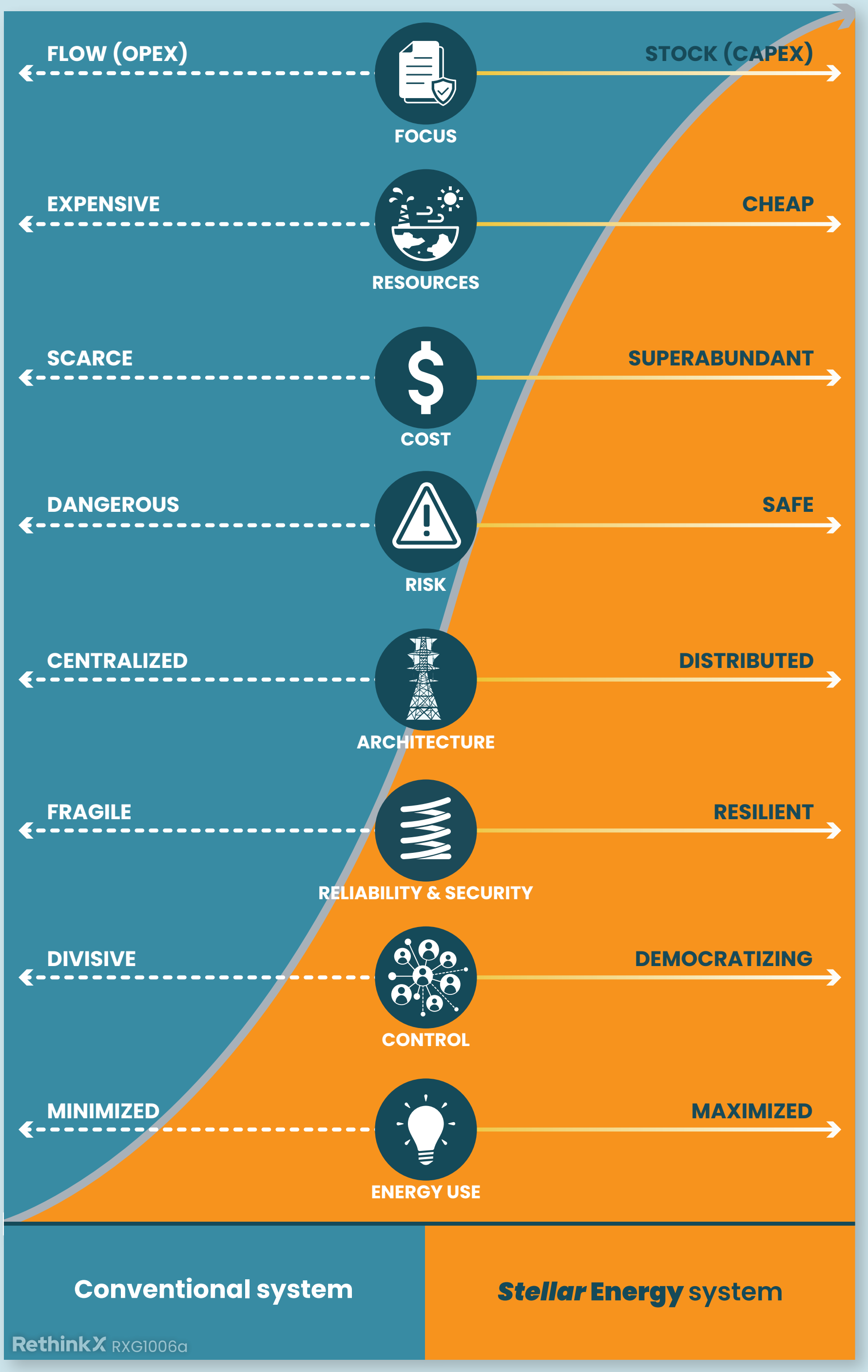


Figure 9. Fundamental differences between Stellar and conventional energy systems

Part 2:
SWB Superpower is the answer

It is no longer a question of *if* the disruption of energy by SWB will enable clean energy superabundance, it is a question of ***who, what, where, when, why, and how?***

The key to answering all of these questions is: SWB Superpower.

SWB Superpower is superabundant clean electricity produced by Stellar Energy systems whose marginal cost is near-zero.

Any energy system predominantly comprised of SWB must be sized for the most challenging season (typically, the cloudiest several weeks of winter), and will therefore naturally produce a superabundance of clean electricity throughout the rest of the year. Furthermore, solar photovoltaics, wind turbines, and electrochemical batteries all operate at near-zero marginal cost. In combination, these extraordinary properties of Stellar Energy systems have the non-obvious but profound implication that surplus electricity can be served to end users at extremely low cost all day, all night, throughout most of the year.

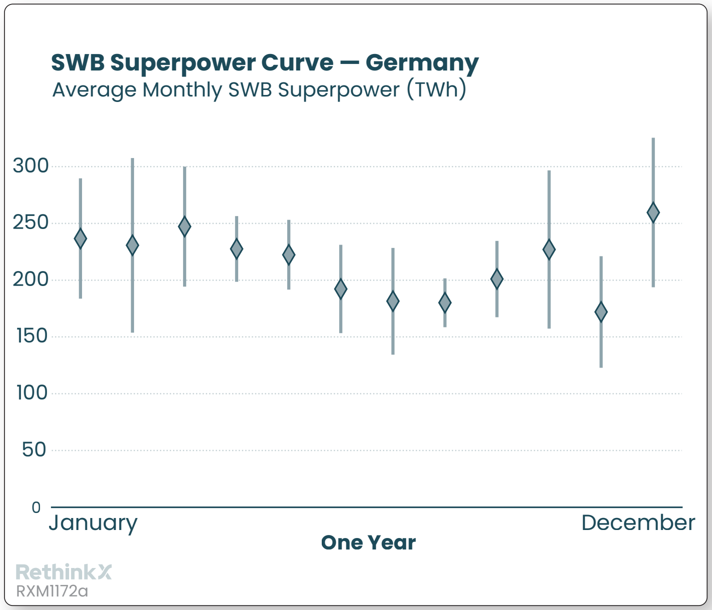


Figure 10. The SWB Superpower Curve (ex. Germany)

The *SWB Superpower Curve* charts the month-by-month average quantity of SWB Superpower produced in a region over the course a typical year. Confidence intervals on either side of the mean give investors, policymakers, planners, and other decision-makers a clearer sense of what is reasonable to expect from a Stellar Energy system in their region.

Building to peak – Amazon Web Services

SWB Superpower is not a unique phenomenon, but rather an important individual example of the more general pattern of "building to peak" – meaning, building capacity to meet peak-period requirements that we see across industries and systems of many different kinds. Another instructive example can be found in computing: Amazon Web Services.

In order to become the world's largest online retailer, Amazon necessarily had to build one of the world's most sophisticated information technology infrastructures. The high-volume, end-of-year holiday season is a crucial time for any retailer, and rather than contract out for computing services, Amazon saw that building its own capacity to serve those few peak weeks of the year was the cheaper option.

But this also meant that Amazon would naturally have a large amount of idle computing assets throughout the rest of year.

Amazon turned the problem of building to a seasonal peak into an opportunity, and thus Amazon Web Services was born.

Amazon opened its huge computing infrastructure to customers who needed data storage, processing, and delivery ability. Netflix, for example, became an adopter. This arrangement allowed Netflix to focus on creating the content customers want, not the messy business of actually running the computer systems that deliver the shows, and this has proven to be a win-win for both companies.

Instead of treating its seasonal surplus of computing capacity as a problem of "overbuilding", Amazon recognized this as an extraordinary opportunity, and by 2024 Amazon Web Services grew to generate $100 billion in annual revenue.

Who?

Q: Who will utilize superabundant clean energy?

A: *Everyone.*

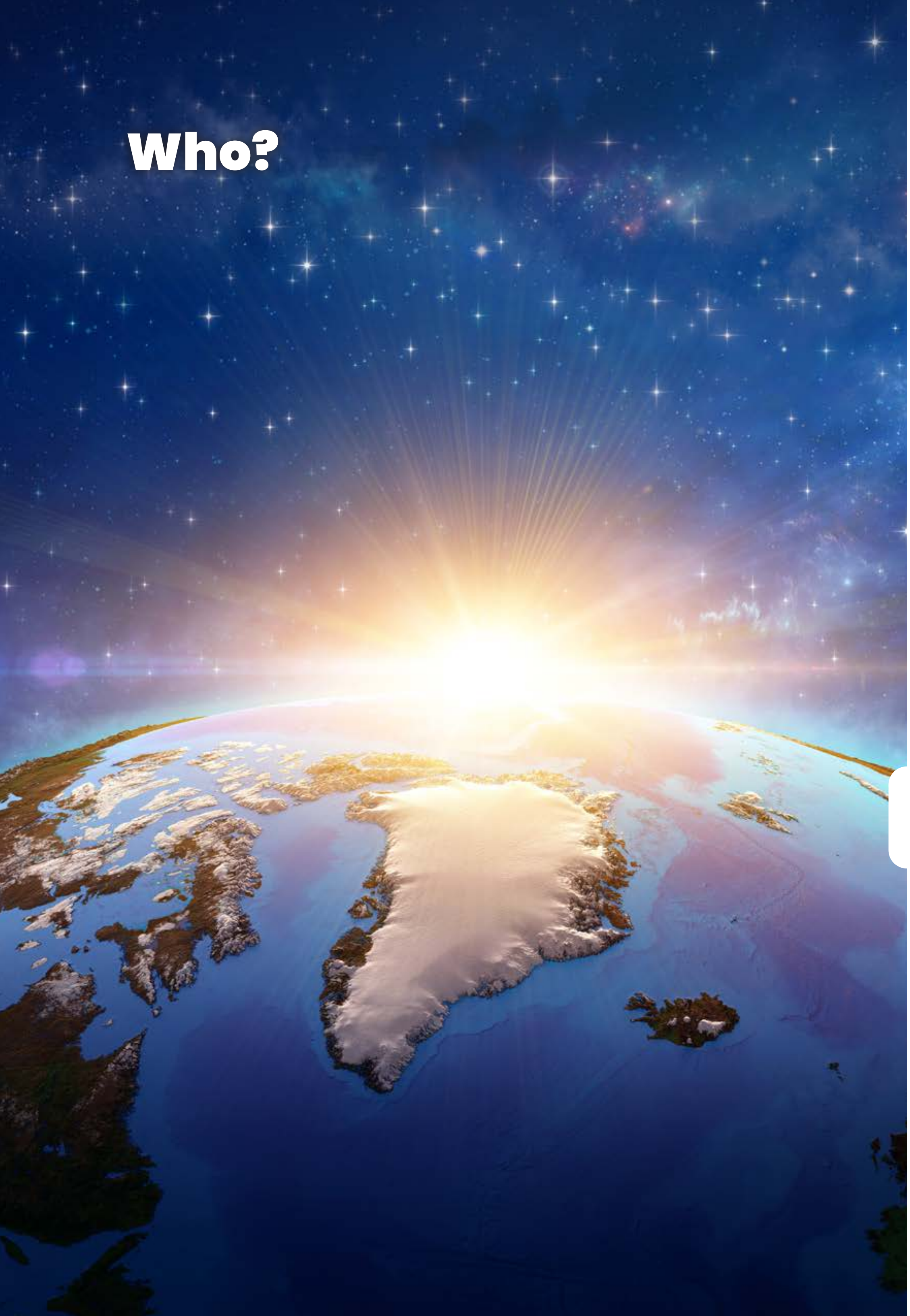
For over a century, energy has only been readily available to those who can afford it. Like most other goods and services ruled by conditions of scarcity, there have tended to be large discrepancies of both access to and consumption of energy on the basis of wealth and income.

In the wealthiest nations that were able to afford the large capital expenditures needed to develop energy infrastructure, electricity has been accessible to virtually all citizens for many decades. But even in countries prosperous enough to make such public investments in energy *access*, large disparities of *utilization* remain because poorer communities and households are still less able to afford the relatively high cost per kilowatt-hour of electricity generated from conventional fossil fuel and nuclear power plants.

Moreover, the externalized social and environmental costs of electricity generated by fossil fuels in particular, such as air pollution, have also tended to fall overwhelmingly on those same poorer communities and households.

Stellar Energy systems optimized for SWB Superpower will make superabundant clean energy accessible and affordable to everyone.

SWB Superpower is the key to universally delivering the benefits of clean energy to all people for the same reasons that the convergence of digital technologies in the 1990s created information and telecommunications superabundance via the Internet: marginal costs will fall to near-zero while at the same time supply hugely expands relative to nominal user demand.



Q: Who will produce superabundant clean energy?

A: *Everyone.*

For over a century, the overwhelming majority of the world's fuels and electricity have been produced in large centralized facilities. These costly facilities have in turn been owned, operated, and thus controlled by governments and a small number of private firms.

Unsurprisingly, energy production has tended to be rife with market inefficiencies in the form of monopolies and oligopolies, corruption, lack of transparency, ineffective regulation, and misaligned incentives.

Moreover, centralization of energy production has naturally resulted in severe vulnerability because failure of even a single facility such as a refinery or power plant represents a major shock to the system.

Stellar Energy systems optimized for SWB Superpower will allow anyone to be a producer.

SWB Superpower is the key to decentralizing energy production because solar and battery assets can be deployed viably at any scale, from a wristwatch up to the multi-gigawatt level. Anyone, from single households to entire nations, can deploy SWB and become an energy producer without major barriers to market entry.

By optimizing for SWB Superpower output, virtually any producer can immediately achieve clean energy super abundance throughout much of the year.

RethinkX has argued that Stellar Energy systems must aim to maximize freedom of choice, and to that all persons should have three fundamental energy rights protected by an *Energy Bill of Rights.*

An Energy Bill of Rights

Article 25 of the Universal Declaration of Human Rights states that, "everyone has the right to … food, clothing, housing and medical care and necessary social services". All of these are dependent upon energy.

For electricity, the European Union has outlined six individual rights for consumers:

- The right to produce energy at home and sell it
- The right to switch suppliers easily
- The right to access reliable price comparison websites
- The right to receive clearer energy bills
- The right to monitor electricity consumption in real time
- The right to receive special protections for vulnerable customers

The latter five of these rights presuppose the existence of central suppliers of power against whom consumers must be safeguarded.

In the United States, the concept of energy rights is being propounded via entities like Solar United Neighbors (SUN), a Washington DC-based nonprofit organization that, like the EU, advocates the producing solar power at home and protecting consumers from utility companies' "punitive or arbitrary charges, fees, or rules" that get in the way of home-based solar power production. Centralized utilities – in the form of both public agencies and private companies – represent the incumbent energy paradigm, whose business model is increasingly being challenged by decentralized electricity generation (especially via solar PV) and battery energy storage.

RethinkX has argued that Stellar Energy systems must aim to maximize freedom of choice, and that all persons should have three fundamental energy rights protected by an *Energy Bill of Rights*:

- The right to generate and store energy
- The right to utilize energy in their homes, farms, and other buildings without monitoring or interference by outside parties
- The right to trade energy with any and all other energy users, directly and via public markets

No authority should have the power to transgress these fundamental energy rights: no government (national or local); no company or utility; no non-governmental organization (homeowners association, neighborhood association, chamber of commerce, etc).

These rights closely mirror the basic universal rights around information and communications (i.e. Internet infrastructure) and mobility (i.e. road infrastructure) that are already guaranteed in most countries.

What?

Today, SWB has become overwhelmingly economically competitive with fossil fuels and nuclear power, and no additional breakthroughs are required.

Q: What energy system can deliver clean energy superabundance to all of humanity?

A: *Stellar Energy systems optimized for SWB Superpower output.*

Traditional biofuels like wood, dung, fats, and oils were humanity's only source of energy for over a million years, starting with the discovery of fire. Although fossil fuels were known in classical antiquity, they were seldom utilized because they offered few real advantages over biofuels until demand for energy expanded via industrialization, which triggered a search for new supplies of fuels. That search succeeded in the 19th Century with the discovery that huge quantities of coal and petroleum were obtainable from underground deposits by mining and drilling. Together with the discovery of electricity, this set the stage for 150 years of fossil-fuel-based energy that encompassed the entire 20th Century.

By the late 20th Century, however, the convergence of solar photovoltaic power, wind power, and electrochemical batteries began to approach economic competitiveness with fossil fuels and nuclear power for supplying electricity, as each of the new technologies progressed down their respective experience and cost curves. Today, SWB has become overwhelmingly economically competitive with fossil fuels and nuclear power, and no additional breakthroughs are required.

Electrification of heating and transportation will be a key element of the SWB disruption of the energy sector. In the past, electricity was too expensive to compete with burning fossil fuels for heat because conventional electricity itself was mostly generated by burning fossil fuels. But in Stellar Energy systems optimized for SWB Superpower, electricity will be far less expensive than fuels, making the electrification of heating and transportation the only rational economic choice.

Stellar Energy systems optimized for SWB Superpower offer the lowest-cost, lowest-risk, and most-timely option for delivering clean energy superabundance to all of humanity.

A key conceptual tool discovered by RethinkX for understanding how SWB Superpower can be optimized for clean energy superabundance is the *Clean Energy U-Curve.*

The Clean Energy U-Curve shows that many different combinations of solar, wind, and batteries could meet our energy needs, but that the capital cost of these varies enormously. Moreover, the tradeoff pattern between generating capacity and energy storage capacity is not obvious – it is nonlinear and deeply unintuitive.

The Clean Energy U-Curve shows that the lowest-cost combination of SWB needed to meet inelastic energy demand will be a system that naturally possesses many times more generating capacity than today's grids.

This is because the large surplus of generating capacity drastically reduces the amount of accompanying energy storage capacity that is required. In most regions, the necessary battery capacity is less than 100 average demand hours' worth of energy storage.

SWB Superpower, as we have already seen, is an extraordinary capability that emerges naturally from the surplus generating capacity of a Stellar Energy system. But even more profound is the fact that SWB Superpower returns on investment are nonlinear as well. An additional 20% in total capital investment, for example, can double or even triple SWB Superpower output.

Stellar Energy systems should be designed to maximize SWB Superpower returns on investment using the Clean Energy U-Curve.

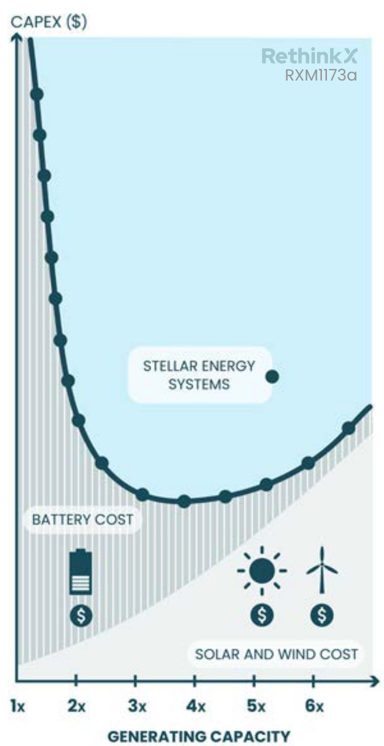


Figure 11. The Clean Energy U-Curve

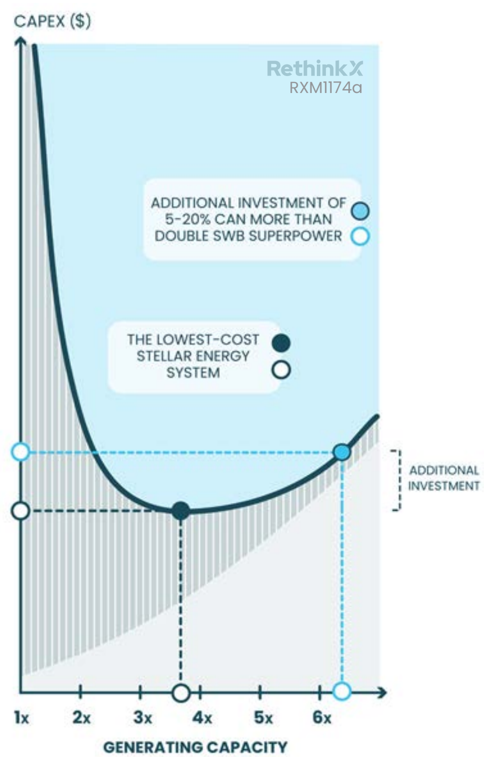


Figure 12. Nonlinear returns on additional investment in SWB Superpower

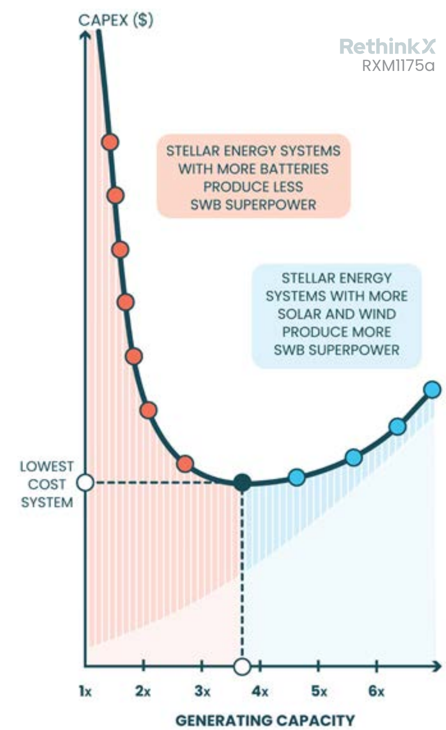


Figure 13. Optimizing on the right side of the Clean Energy U-Curve

The SWB Coverage Curve

RethinkX's prior energy research was among the earliest to show that solar, wind and battery energy systems require only a surprisingly modest amount of battery energy storage. Contrary to widespread misconceptions that still persist today, our analysis showed that most of the populated regions of the world will need less than 100 hours' worth of energy storage, rather than weeks or months of "seasonal" storage as most other mainstream analyses assumed.

Our latest research now shows that even less battery energy storage is required than our original analysis showed, if alternative means of coverage (see Figure 14) are used to supplement batteries for just a few challenging hours of the year.

This logic is captured by the SWB Coverage Curve. In most regions, the size (and therefore cost) of batteries can be reduced by 40% or more, if just 1% of SWB Basepower requirements can be covered by alternate means.

The reason why there is such a large and nonlinear return on investment in alternate coverage is because this reflects the abruptly diminishing returns on additional battery capacity near the limit, where that limit is specifically the most challenging few hours of the year (typically the winter season).

Alternate means of coverage include the following contingency measures:

- Demand shifting and arbitrage (i.e. planning to reduce electricity demand in anticipation of particularly challenging hours, such as during long winter storms)
- Electricity imports from neighboring regions
- Supplementation of energy storage capacity with electric vehicles (i.e. "virtual power plants")
- Pre-existing or specialized energy storage (pumped hydro, thermal batteries, synthesized fuels like hydrogen and syngas)
- Conventional emergency reserve capacity (e.g. from existing gas peaker plants or diesel generators)

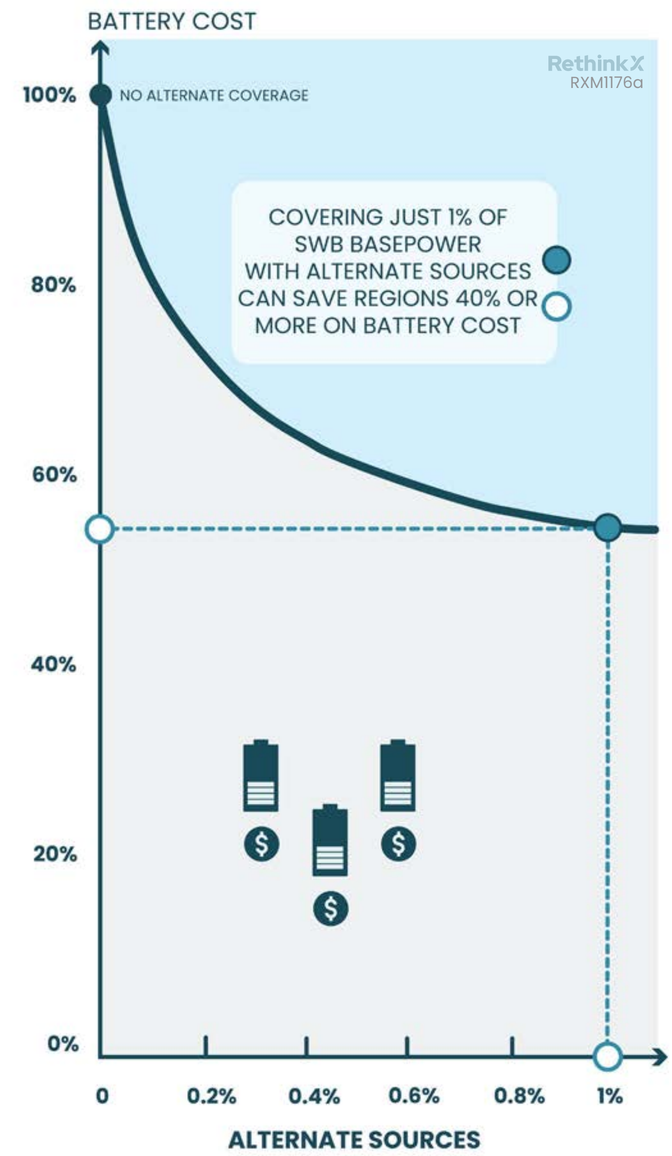


Figure 14. The SWB Coverage Curve

Return on investment in clean energy superabundance

"How will investors in SWB make a return, especially on capacity additions in the later stages of the disruption, if the marginal cost of energy is near-zero?"

Stellar Energy systems will be based on stocks (SWB assets) that deliver electricity at near-zero marginal cost, rather than on flows (fossil fuels) that deliver electricity at high marginal cost.

This frequently asked question misunderstands the nature of disruption because it incorrectly presumes the old energy system – and its associated business models – will remain unchanged by new technology.

Stellar Energy systems will be based on stocks (SWB assets) that deliver electricity at near-zero marginal cost, rather than on flows (fossil fuels) that deliver electricity at high marginal cost. Naturally, business models that depend on high marginal costs to charge high per-kilowatt-hour prices to end users will not survive in the new system. But this does not mean there will be no returns on SWB investments – it simply means new business models will emerge and disrupt the old ones.

The Internet offers an instructive example. Up until the early 2000s, the marginal cost of data and bandwidth was high enough to support the business model of metered pricing for end users. Customers paid for Internet access by the megabyte and long-distance phone calls by the minute. But improvements in technology under competitive conditions drove the marginal cost of data and bandwidth so low that they became "too cheap to meter". This did not end investment in Internet infrastructure assets, even though they still had substantial (or even growing) capex and opex. Nor did it slow the deployment of new technology like 2-5G and Wi-Fi. Rather, it signaled to the market that a transformation in business models was required.

ISPs and telcos switched to subscription-based services with tiers (including unlimited use) and throttling. Internet cafes charging by the minute disappeared, but actual cafes began offering free Wi-Fi to attract customers.

All signs now indicate that Stellar Energy will follow the same trajectory as the Internet.

Where?

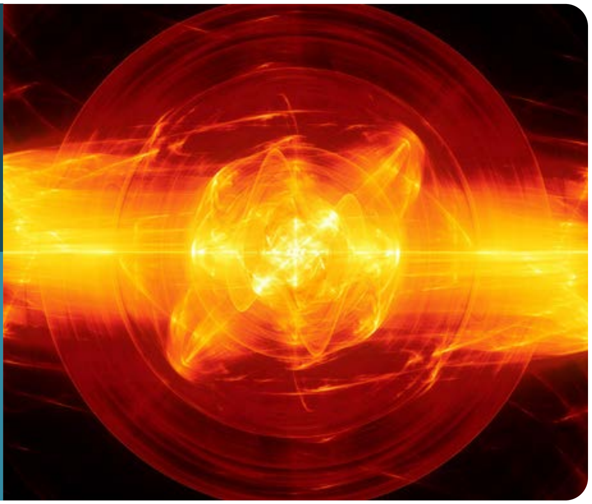
Q: Where is clean energy superabundance achievable geographically?

A: *Everywhere.*

Deposits of fossil fuels are highly concentrated in just a handful of regions worldwide, and this has simultaneously been a windfall of great wealth as well as a source of geopolitical conflict for host countries. Civilian nuclear power plants to date have had stringent geographic requirements in the form of large exclusion zones and enormous water requirements. And hydropower has only been available in countries with appropriately large freshwater endowments together with requisite social and political willingness to tolerate the unavoidable landscape transformation and ecological damage that comes from damming rivers.

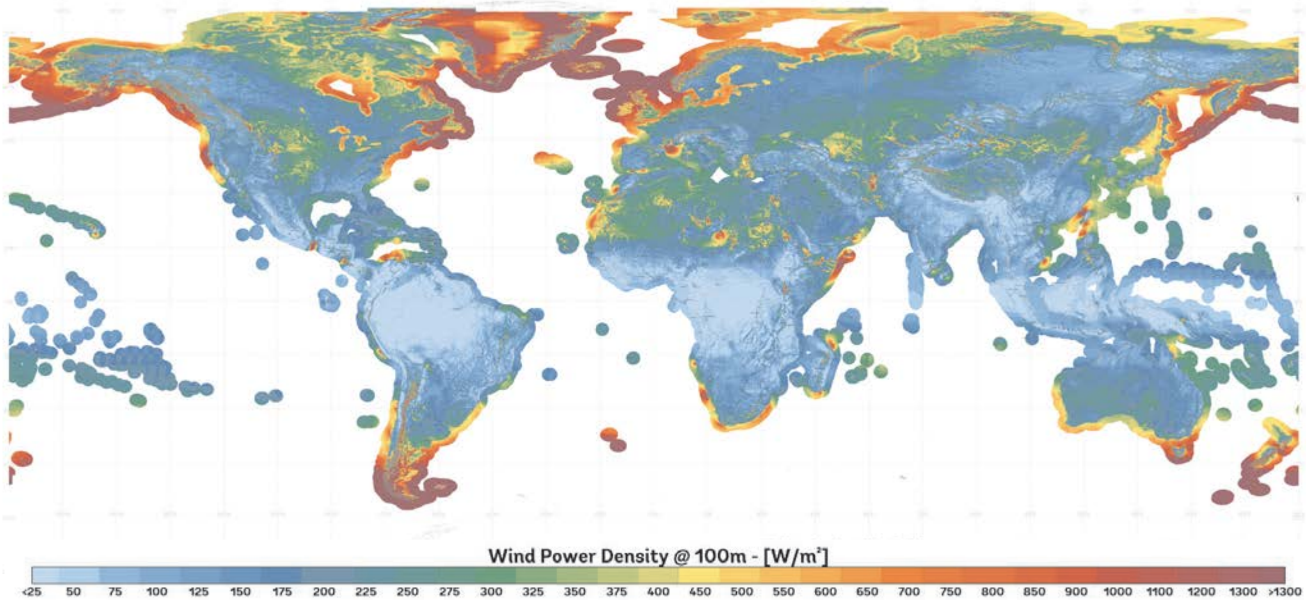
Our previous research, together with the case studies presented in this report, show that Stellar Energy systems are viable in every populated region of the world, including regions at high latitudes, such as Alaska and Sweden. Although there are disparities in solar and wind resources from one region to another, these resources are nevertheless plentiful enough in virtually every geographic location to provide clean energy superabundance so long as they are optimized for SWB Superpower output.

Moreover, the same virtues of decentralization and scale independence that make Stellar Energy systems viable at every economic level also help make them viable across the full spectrum of geographic locations as well.



Stellar Energy systems optimized for SWB Superpower output can bring clean energy superabundance to every populated geographic region worldwide.

Wind



Solar

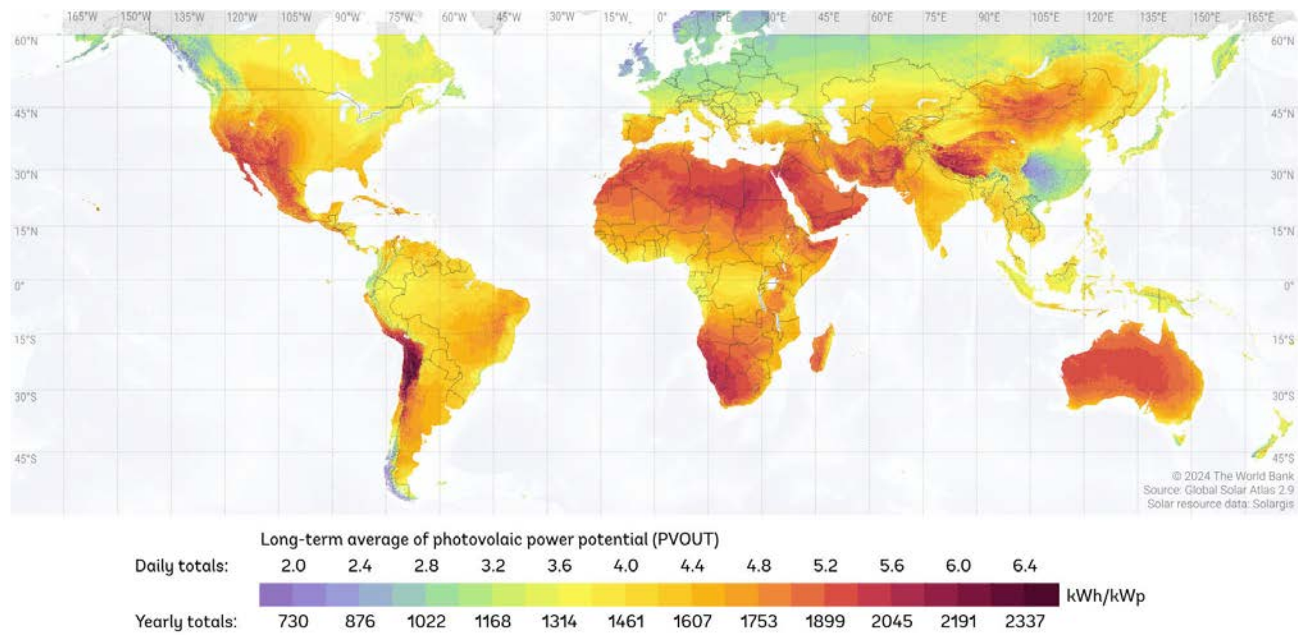


Figure 15. Global Solar and Wind Resource Potential

Source: Global Solar Atlas, 2025; Global Wind Atlas, 2025.

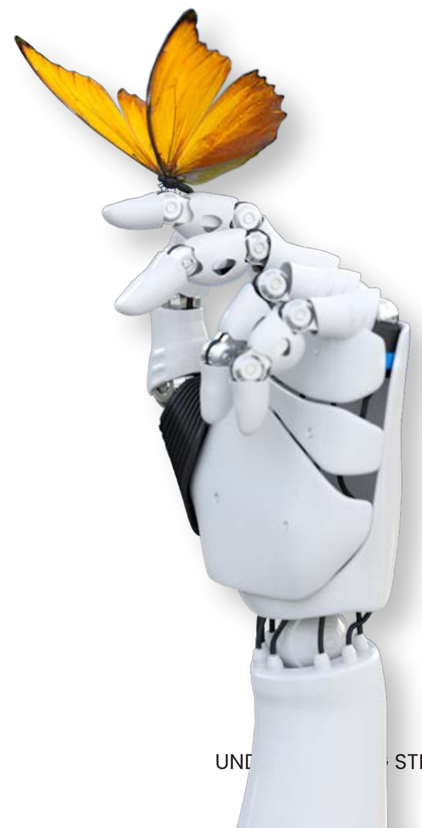
When?

Q: When can clean energy superabundance based on SWB Superpower be achieved?

A: By 2035 in leading regions, and before 2045 for the majority of the world.

The history of technology disruptions shows that they naturally unfold in 15-20 years.

Our research team has documented over 1,000 examples of disruption across technologies of all different kinds, from arrowheads and fabric dyes to carpentry nails and car tires, and we see the same pattern repeated again and again: once a technology convergence triggers a disruption, market share of the new technology grows from around 5% to over 80% share within two decades for any given region.



We see the same pattern today around SWB that we have seen so many times before through history.

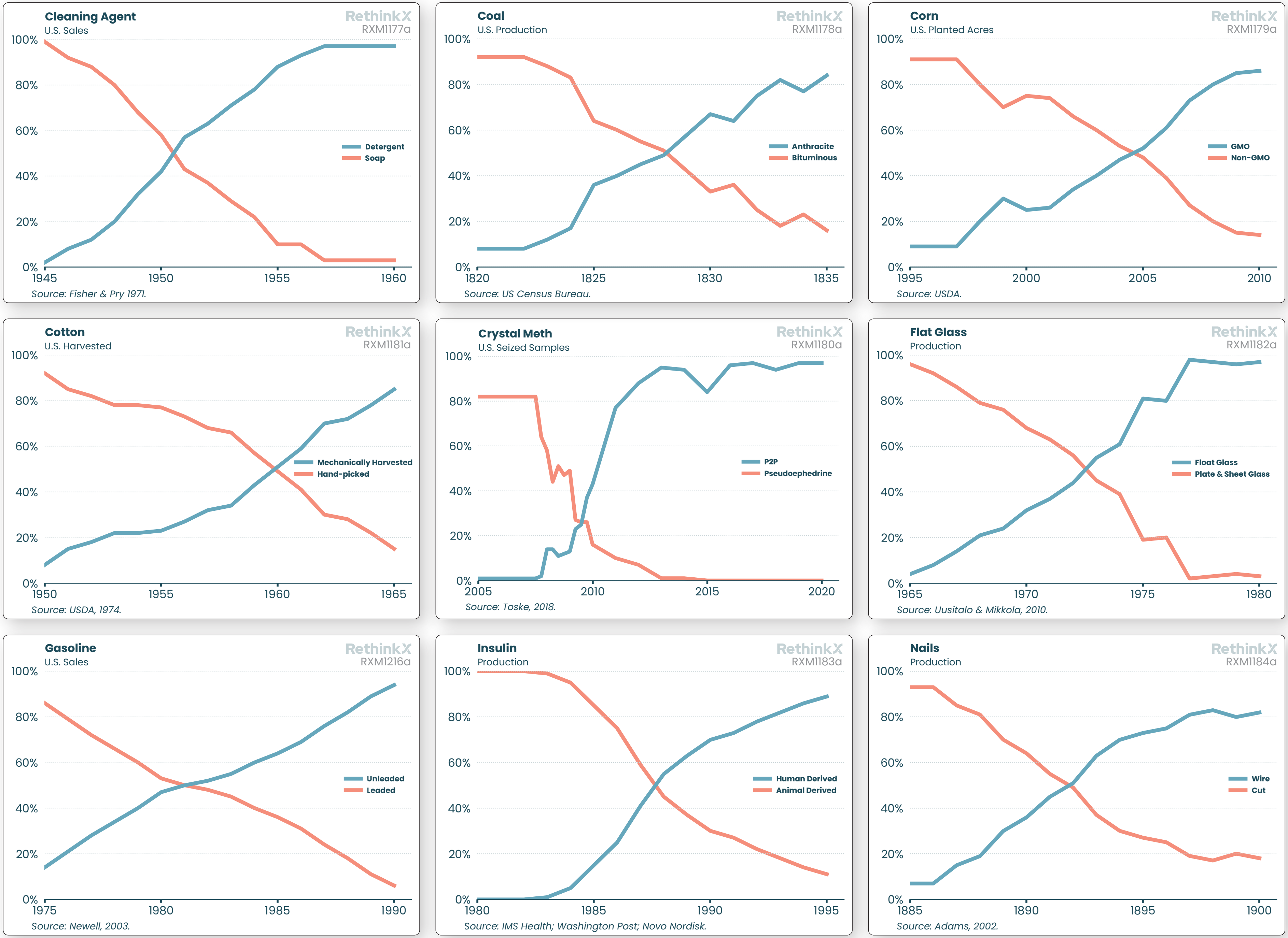
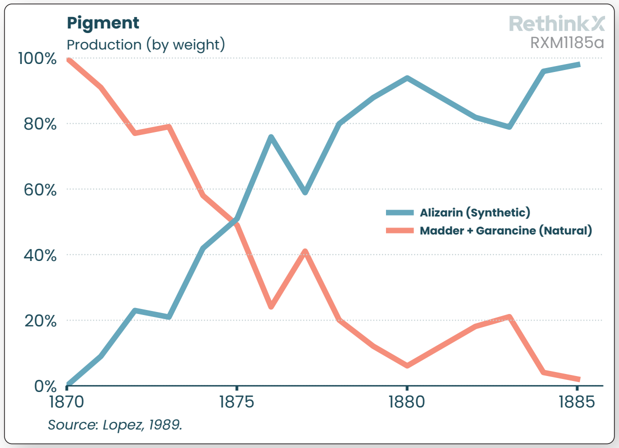
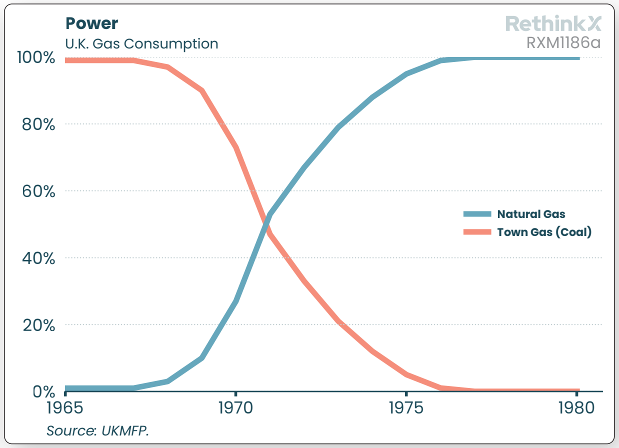
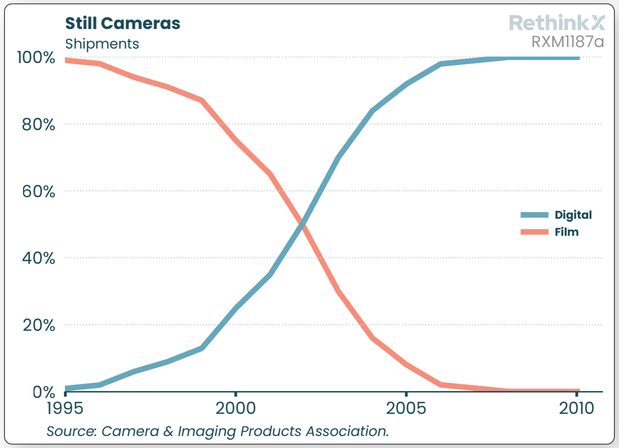


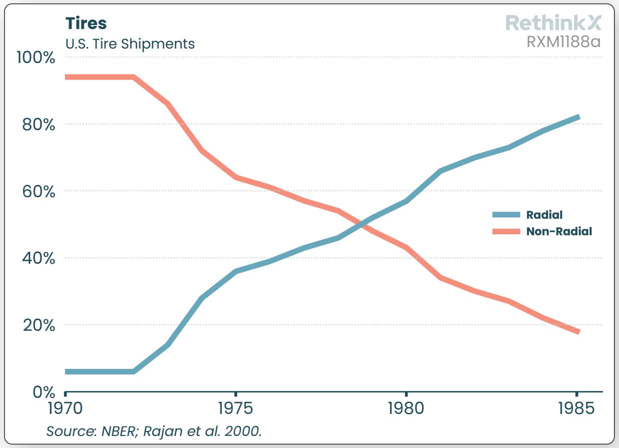
Figure 16. Historical examples of disruption

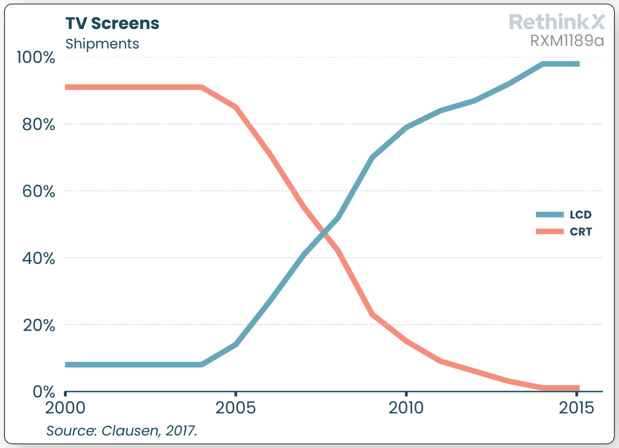
Adoption of solar photovoltaic power, wind power, and electrochemical batteries for stationary energy storage has been growing exponentially for over two decades.

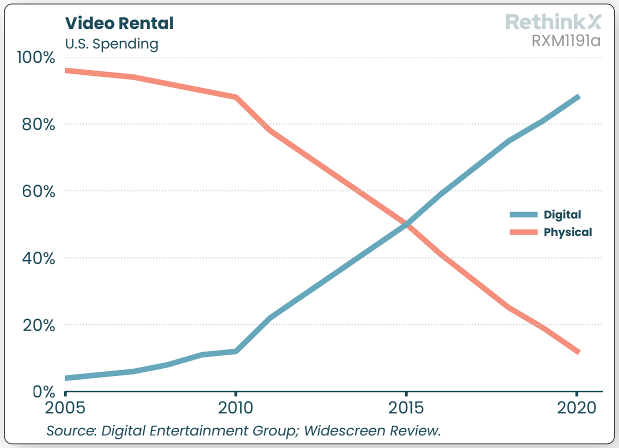




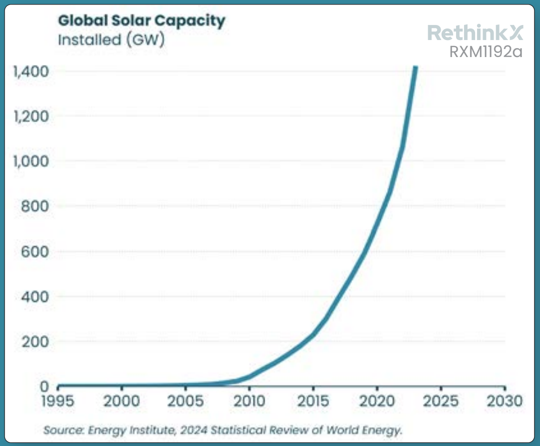


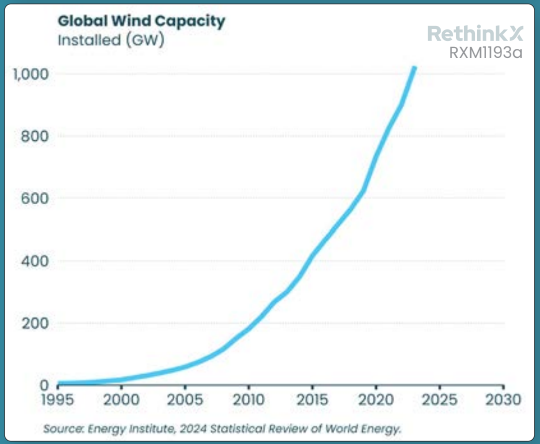


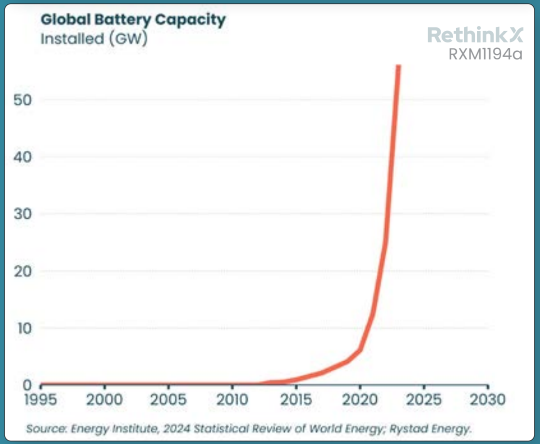




Disruption of the energy sector by SWB has already begun







Figures 17, 18, 19. Solar, Wind, Battery capacity

Globally, 13.4% of electricity was produced by solar and wind in 2023, up over 4x from 3.3% a decade earlier in 2013, during which time total global electricity generation also grew 27.3% from 23,155 terawatt-hours to 29,479 terawatt-hours.

In the United States, 15.6% of electricity was produced by solar and wind in 2023, up over 3.5x from 4.4% a decade earlier in 2013, during which time total U.S. electricity generation also grew nearly 5% from 4,056 terawatt-hours to 4,249 terawatt-hours.

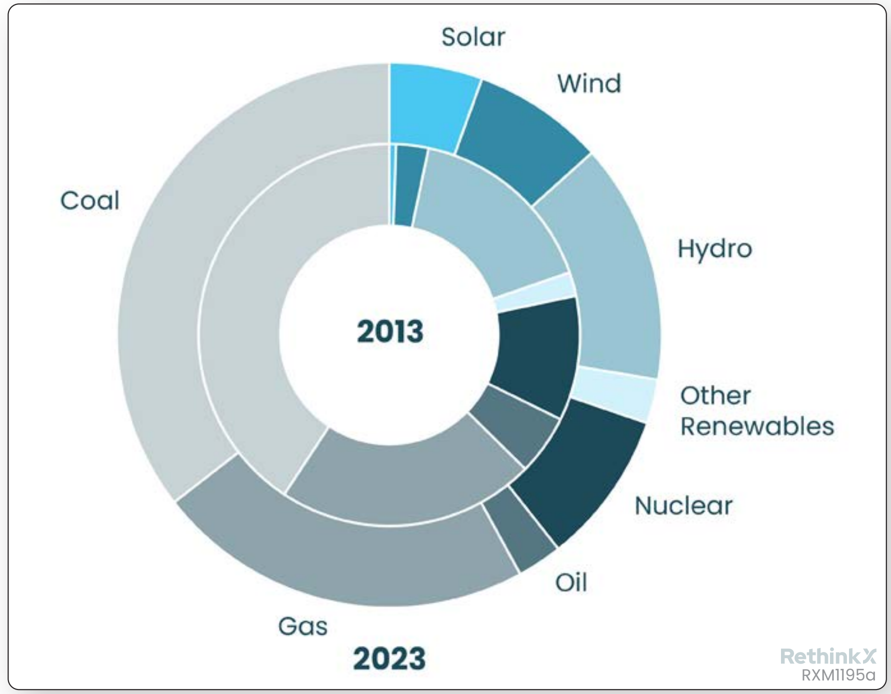


Figure 20. **Global** electricity mix (2013 & 2023)

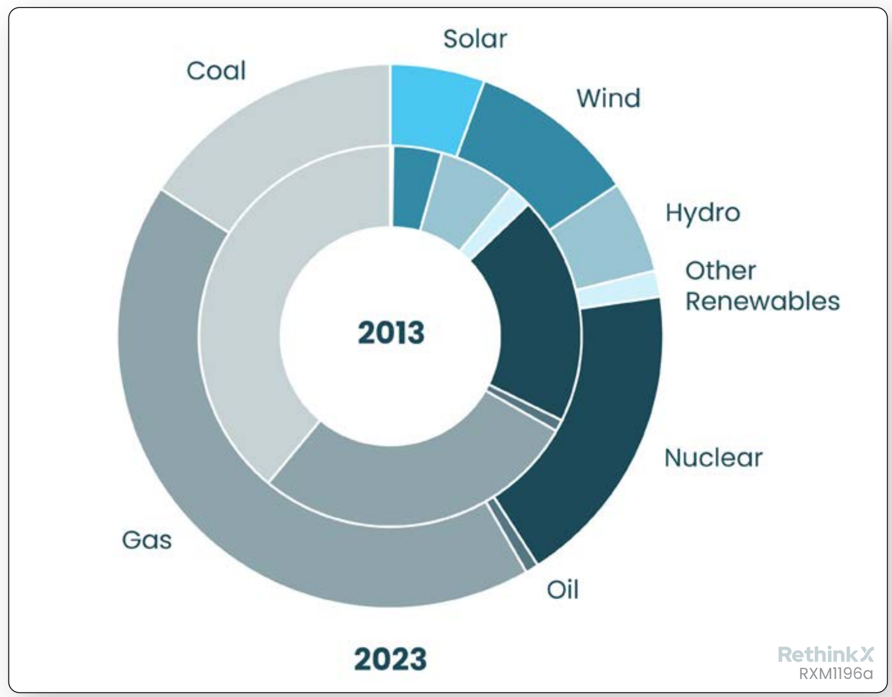


Figure 21. **United States** electricity mix (2013 & 2023)

Why?

Q: Why is clean energy superabundance based on SWB Superpower inevitable?

A: *SWB is cheaper than fossil fuels, nuclear power, or hydropower and other renewables.*

Disruptions occur because the convergence of new technologies offers a value proposition that is overwhelmingly competitive compared to older technologies.

A consistent pattern we have seen throughout history is that disruptions are driven by a set of reinforcing causal feedback loops, dominated by economic forces. The adoption of disruptive new technologies and the corresponding growth of new markets and systems based upon them follows a characteristic S-Curve.

At the same time, the old technologies and their industries and systems collapse along an inverse S-Curve. Together, these form a Disruption X-Curve, examples of which can be seen in Figure 16.

Moreover, the new technologies tend to open up a far bigger possibility space because of their superior value and capabilities, which in turn results in a new system that is larger than the older one it disrupts. When market share – which is a proportional measure – is presented on the vertical axis of a *Disruption X-Curve*, we don't see the absolute size of the new system compared to the old system. If instead we use units delivered or a similar production metric instead, then the size difference becomes clear, as shown in Figure 22.

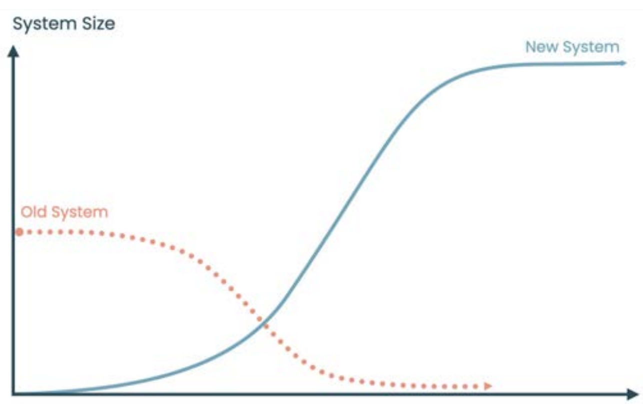


Figure 22. The Disruption X-Curve

Why disruptions are not linear

History shows that technology disruptions are nonlinear because they are driven by reinforcing causal feedback loops.

These loops interact with and amplify one another, accelerating the adoption of new technology in a virtuous cycle while at the same time accelerating the abandonment of old technology in a vicious cycle. The net result of these system dynamics is that disruption tends to unfold with surprising swiftness.

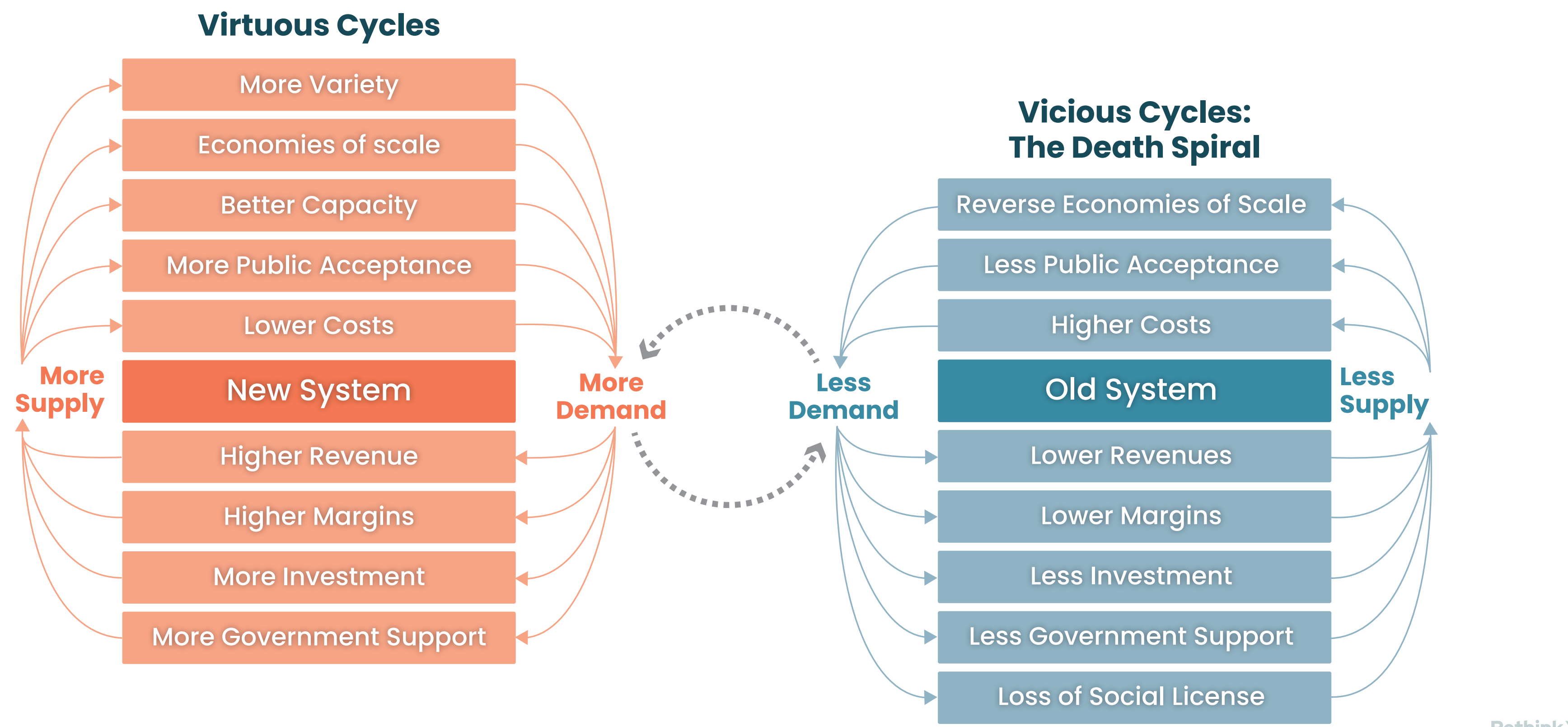
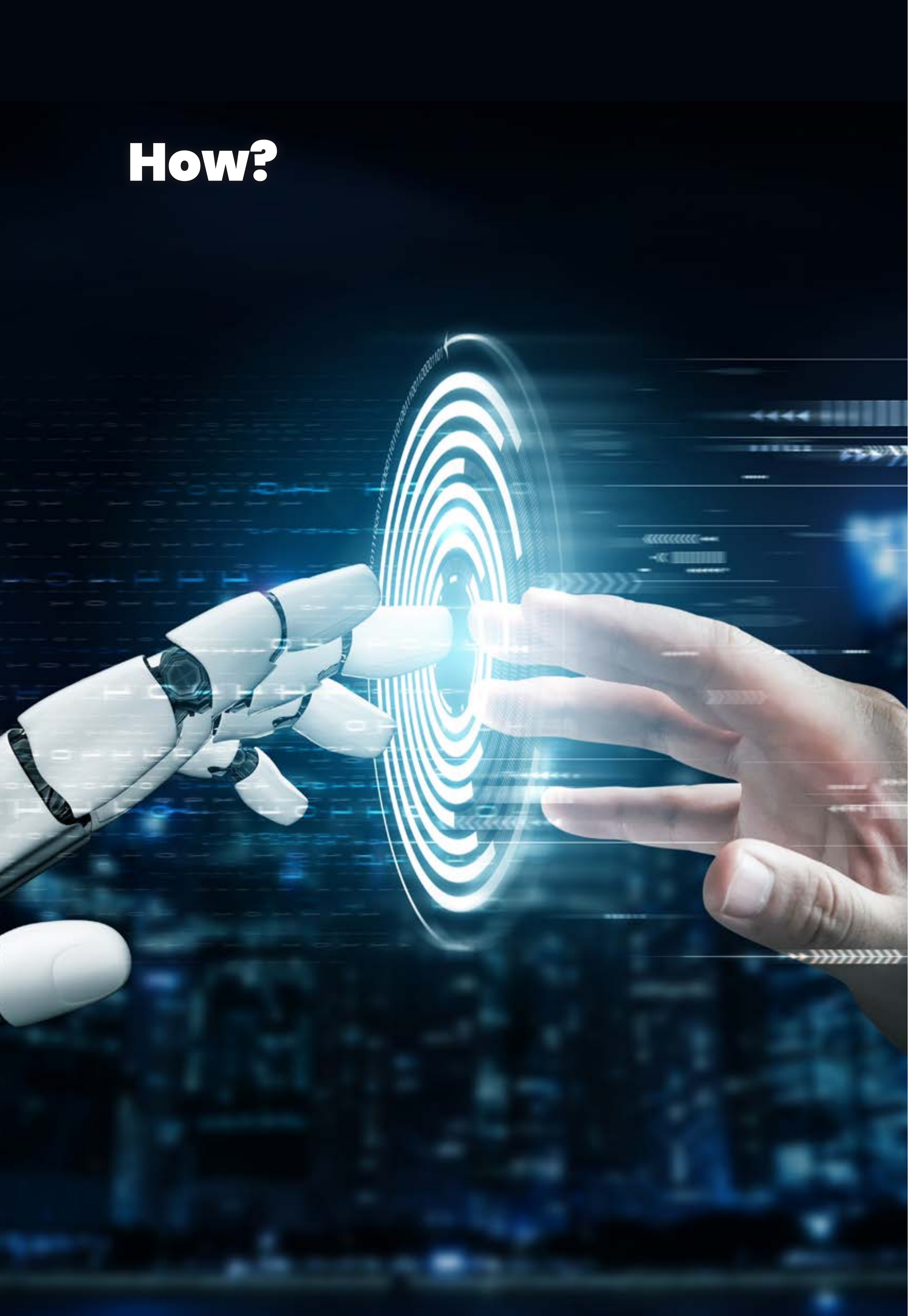


Figure 23. Causal Feedback Loops Drive Disruption

In the specific case of SWB, the cost curves of solar photovoltaic panels, wind turbines, and lithium-ion electrochemical battery technologies began to converge in the late 2010s to offer an economically viable alternative to conventional fossil fuels and nuclear power for electricity production. As their costs continue to fall, SWB will become overwhelmingly competitive at every scale and in virtually every geographic area.

In many instances, the total cost of SWB will be less than the operating cost alone for conventional fossil fuel and nuclear power plants. By the 2030s, the total cost of decentralized SWB will even fall below the cost of transmission alone – a critical threshold identified by Tony Seba as generation -on-demand parity, or GOD parity – across much of the globe.

How?



Q: How will SWB Superpower be utilized?

A: New business models that make seasonally flexible use of near-zero marginal cost electricity in combinations of two or more energy-intensive applications will realize the greatest value of SWB Superpower.

The history of disruption shows that it is very difficult to anticipate which uses of a new technology will ultimately prove to be the most successful.

For example, even once it was clear that automobiles were going to disrupt horses in transportation, it remained very difficult to foresee exactly which types of vehicles would be most popular or which forms of road infrastructure would be most widely adopted – and even today, over a century later, there are significant regional differences in these respects. Similarly, even once it was clear that the Internet was going to disrupt traditional information and communication industries, it remained very difficult to foresee exactly which web-based business models would be the most successful.

However, some aspects of these previous disruptions were indeed foreseeable. The hugely greater cost-capability of automobiles, for example, predictably brought mobility itself to more people in more places than horses ever could. And by the same token, the hugely greater cost-capability of the Internet predictably brought information and communication themselves to more people in more places than landlines, newspapers, and other traditional information and communication industries ever could.

We can apply the same underlying principle that has governed all other disruptions in the past to analyzing the potential utilization of SWB Superpower today: the superior cost-capability of new technology makes products and services possible that were previously too expensive or poorly-performing to contemplate. In the case of automobiles, the new technology made it feasible to rapidly and cheaply transport passengers and cargo door-to-door across continental distances in a way that was totally unachievable with horses (or trains). This in turn brought mobility to more people than ever before, while at the same time created an entirely new and vastly larger transportation system built on new products, services, business models, industries, and markets.

In the case of the Internet, services like search, streaming, and video calls became feasible that were completely impossible prior to the advent of low-cost digital technologies. And, again, this brought information and communications to more people than ever before, while at the same time created an entirely new and vastly larger system (the Internet) built on new products, services, business models, industries, and markets.

We have every reason to expect that the same fundamental pattern will occur in the disruption of energy.

SWB Superpower will bring clean energy to more people than ever before, while at the same time creating an entirely new and vastly larger Stellar Energy system built on new products, services, business models, industries, and markets.

Stellar Energy sharing

While it is easy to imagine many individual uses for superabundant clean energy, the key to realizing maximum value from SWB Superpower will be to go beyond one-dimensional thinking and identify pairs, triplets, or even quadruplets of use cases that complement one another.

It won’t be be individual *killer apps* but rather *killer combos* that will emerge as the winners in the race to utilize SWB Superpower.

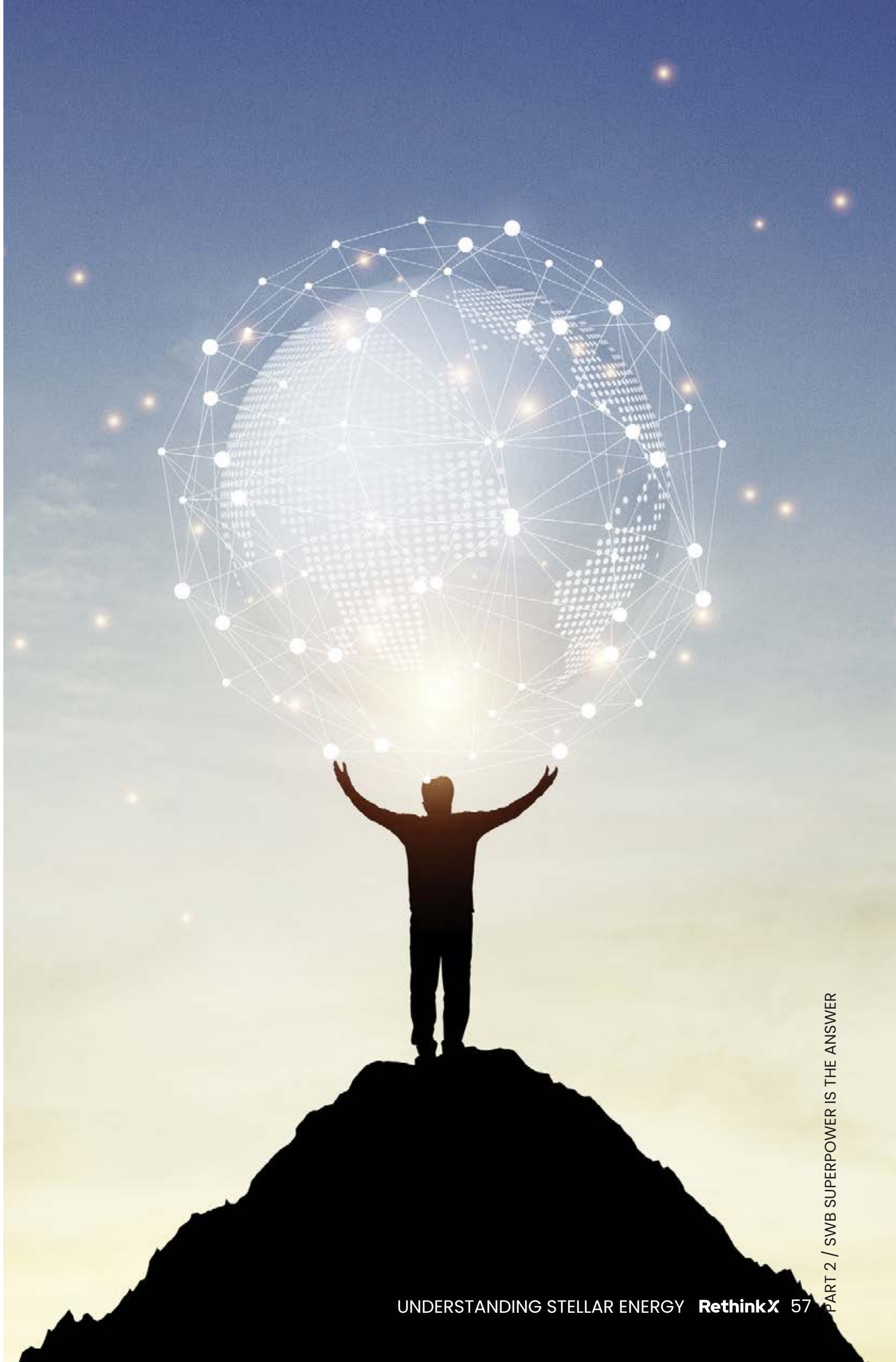
For example, the explosive growth in artificial intelligence (AI) in recent years has raised an important energy-related question: where will the electricity to power huge computing clusters for AI training and inference will come from?

Similarly, the growth in precision fermentation and cellular agriculture (PFCA) has raised the same question: where will all the energy for these food production facilities come from? The answer in both cases is SWB Superpower.

What is less obvious, however, is that the energy requirements of these two new industries are complementary. Computing clusters produce low-grade heat (below 450ºF / 232ºC) as a waste product, while PFCA facilities require low-grade heat as their primary energy input.

A logical choice might therefore be to co-locate AI and PFCA facilities so that they can mutually benefit from shared energy use.

Opportunities to co-locate industries for Stellar Energy sharing will multiply as the disruption progresses, and those who understand and plan for clean energy superabundance will be able to leverage that knowledge to their advantage.



How can a business, industry, or community utilize SWB Superpower?

Some key **questions** to ask when planning for clean energy superabundance based on SWB Superpower include the following:

- What would you do differently if electricity were nearly free for much of the year?
- Where is there latent demand for products and services that are prohibitively expensive today, but which will become economically viable under conditions of clean energy superabundance?
- Can one or more of your processes be electrified?
- Can one of more of your processes be performed and/or utilized flexibly on a seasonal basis?
- Can one or more of your outputs be stockpiled?
- Is one or more of your processes waste-intensive?
- Is one or more of your processes land-intensive?
- Would one or more of your processes benefit from co-locating with other businesses whose processes would benefit from SWB Superpower?

Some key **examples** of SWB Superpower utilization to expect include the following:

- **Food** (e.g. precision fermentation, cellular agriculture)
- **Water** (e.g. desalination and pumped transport)
- **Transportation** (e.g. electric vehicle charging, electric rail, electric aviation)
- **Heavy industry** process electrification (e.g. mining, crushing, sorting, filtering, purifying, fractionating, desalinating, melting and smelting, refining, spinning, boiling and sterilizing, refrigerating and freezing, drying and dehydrating)
- **Computing** (AI training, AI inference, data centers, virtual compute clusters in vehicle and robot fleets, blockchain/cryptocurrency mining)
- **Charging** (e.g. battery-powered tools, machinery, and other equipment, including robots)

Energy *for* disruption

Each of the foundational sector disruptions in transportation, food, labor – as well as the disruption of energy itself – will be accelerated by SWB Superpower, because energy is an input into virtually every link of every industry's supply chain.

However, the transformed transportation, food, and labor sectors will then go on to become huge new consumers of SWB Superpower after the disruptions themselves are complete. The new transportation, food, and energy systems will therefore be key beneficiaries of clean energy superabundance.

Each sector will utilize a great deal of energy at all three major stages of their assets' life cycles:

1. Manufacturing and deployment
2. Operation
3. End-of-life decommissioning and recycling

The use of energy in stages 1 and 3 are quite similar for each sector, as they involve the initial production and final scrapping of machinery like cars, electronics, batteries, bioreactors, and robot chassis. In Stage 2, however, the key modes of energy use during asset utilization differ greatly for each sector:

- **Transportation:** charging electric vehicles
- **Food:** PFCA environmental (temperature) control, refrigeration, ammonia fertilizer production
- **Labor:** AI training and inference, charging humanoid robots

The sooner a region goes Stellar and achieves clean energy superabundance via SWB Superpower, the more rapidly it can benefit from the convergence of disruptions in these foundational sectors.

Principles for new business models built on SWB Superpower

EXPERIMENTATION

- The most successful SWB Superpower business models likely do not yet exist (as was the case in the 1990s when the Internet first reduced the marginal cost of information and communication to near-zero)

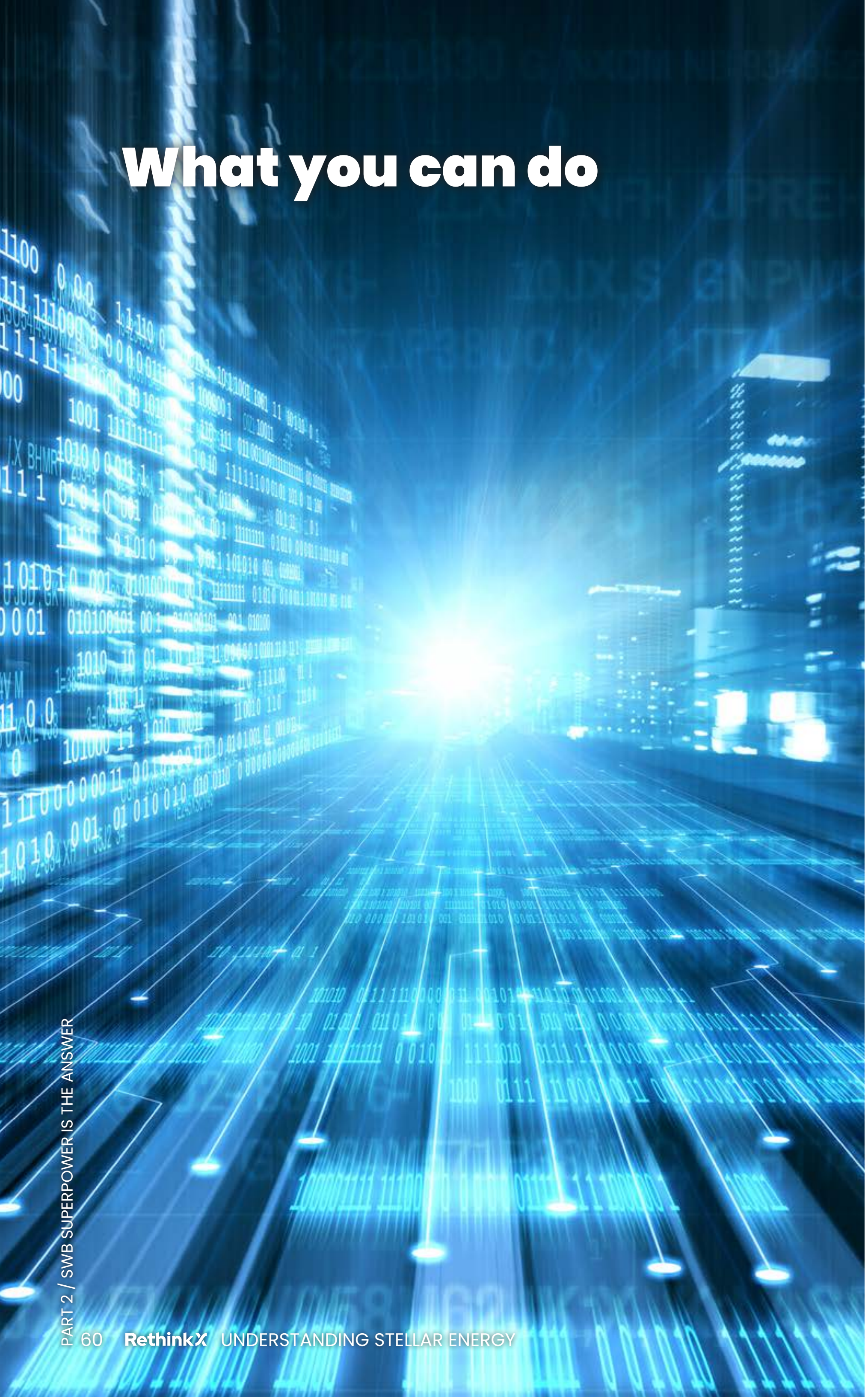
CO-LOCATION

- The most successful SWB Superpower business models will likely be based on combinations of utilization co-located with one another

FLEXIBILITY

- The most successful SWB Superpower business models will utilize energy flexibly in accordance with daily and/or seasonal fluctuations in availability

What you can do



What actions can we take today to leverage an understanding of Stellar Energy – as individuals and businesses, as policymakers and investors, as small communities or entire nations?

See it

See the system that is emerging now, and how it will profoundly change your life, your business, your community, your country, and the world in which you live.

Look out a few years, past the challenges right in front of us, and see the possibilities that are now within our grasp.

Recognize Stellar Energy for what it is, as well as what it isn't. Stellar Energy is a new system, not just new technologies that are drop-in substitutes for coal, oil, and natural gas. Understand that this means we are facing a rapid energy *transformation*, not a slow and incremental energy *transition*.

The new Stellar Energy system will differ from our system today in fundamental ways (shown in Figure 9), with profound social, economic, geopolitical, and environmental implications at all scales from individual households up to the entire global economy (shown in Figure 3).

Share it

Once you see it, share it. Communicate what you see and the profound impacts this will have for those you know and are connected with.

Spread an understanding, help others see it too. Help avoid costly mistakes and accelerate the path forward. Create excitement around the incredible possibilities and opportunities that Stellar Energy represents.

Engage decision makers, investors, businesses and your community so they can join you and spread the word.

Create awareness and understanding about Stellar Energy by communicating, advocating, and educating to the greatest extent possible. Every new person who learns about Stellar Energy and the clean energy superabundance it can bring to their community or nation is a force multiplier for positive change.

This means speaking about both the disruption of energy by SWB today that has already begun, as well as speaking about the path to a Stellar Energy future that we are all now on together.

We publish resources, like this report and our web content, videos, and other resources on rethinkx.com so you can share them and create engagement.

Do it

A Stellar Energy future is inevitable, and it is a global race to the stars, but the journey is nevertheless fraught with obstacles and pitfalls.

There are better and worse choices to make along the way, and the best way to navigate our way forward safely and responsibly through this uncharted terrain is to act in accordance with fundamental guiding principles.

Let go of the old: Don't hang on to past investments or be trapped in the 'sunk cost fallacy' - our old energy system is obsolete and it's days are past. Free up thinking, investment and space for the new.

Experiment: Build "stellar nurseries" that incubate new ways of flexibly utilizing SWB Superpower, and learn from successes and failures - yours as well as those of others.

Adapt: Embrace an anti-fragility posture that regards failure as a healthy part of growth.

Avoid dogma: Recognize the danger in trying to appeal to incumbent authorities who have little to gain and everything to lose from disruption.

Solve the right problems: Protect people (individuals and communities) instead of incumbent industries, and build guard rails to guide experimentation and adaptation.

Find your space: Opportunities and possibilities for creating new capabilities, products, business and societal change are endless. Find the ones that fit you, think big, get creative and get going.

Open source: Wherever possible, open source core technologies to accelerate global collaboration and innovation. Avoid proprietary lock in.

Connect: Find fellow travelers with whom to collaborate, share learnings and expertise. Build networks and capacities, and join the race to the stars.

Get started: Perfect is the enemy of progress. The best way to get started, is simply make a start. Start small, learn, innovate, improve and then scale. What are you waiting for?

Part 3:

Findings

Purpose

Our previous research has shown that it is both physically and economically feasible to meet 100% of existing electricity demand with SWB in the overwhelming majority of populated regions worldwide. In recent years, our earlier findings have subsequently been corroborated by the work of other research teams around the world. Our research also revealed the critical importance of SWB Superpower as a property of those systems, as well as the value of the Clean Energy U-Curve for optimizing SWB-based energy system architectures.

The purpose of the new research we present here is to demonstrate how Stellar Energy systems optimized for SWB Superpower output can bring prosperity and superabundance to virtually all populated regions of the world at a per-capita cost comparable to what we currently spend on today's conventional energy systems. To that end, we present two scenarios for each regional case study that together provide an aspirational range of per-capita energy availability. Even for today's wealthiest nations, this means a significant increase in energy per person. And for the least wealthy nations, it means enormous energy growth by a factor of 100 or more from today's unacceptable energy status quo.

The scenarios we present here are founded on the guiding principle that we must uplift all of humanity – every community, every region, every nation – into the shared flourishing of a Stellar Energy future. Incumbent analyses seldom take this idea seriously, and instead presume that both the technological and socioeconomic status quo will persist indefinitely. For RethinkX, shared flourishing is the foundation upon which our scenarios for the future are built.

By recalibrating our expectations for what kind of energy future is both possible and preferable, we hope these Stellar Energy scenarios highlight the importance of escaping the mindset of scarcity and rethinking energy for a brighter, more prosperous, more equitable future for all of humanity.

Regional case studies

The availability of sunshine and wind varies greatly worldwide, as do the existing energy systems built around them. Here we present findings for a representative range of global geographic diversity.

Locations:

- Brazil
- Canada (Quebec City)
- China
- Denmark
- Ethiopia
- Germany
- Ghana (Accra)
- India (Mumbai)
- Indonesia
- Mexico
- New Zealand
- Saudi Arabia
- South Africa
- Sweden
- Ukraine
- United Kingdom
- Alaska (Kotzebue)

Scenarios

For each regional case study, we present two scenarios: *Stellar Energy Prosperity* and *Stellar Energy Superabundance.*

In both scenarios, all of a society's energy requirements – including for residential, commercial, and industrial use, as well as for road transportation and non-industrial heating – are met with the combination of solar power, wind power, and batteries plus any pre-existing clean energy capacity from legacy hydropower and nuclear power plants in the region. This in turn entails the assumption that existing energy-intensive uses, such as road transportation, industrial heating, and non-industrial heating are electrified to the maximum extent possible.

Both scenarios assume non-industrial heating and cooling of buildings are delivered according to uniform standard of comfort across all regions (unlike the present day). For heating, the standard is based on European consumption. For cooling, the standard is based on U.S. consumption. Energy expended on heating and cooling is thus purely a function of population and weather for all regions (with the exceptions of Alaska, Canada, and Saudi Arabia).

Note that this analysis excludes the use of fossil fuels in aviation and shipping.

The *Stellar Energy Prosperity* scenario

Per-capita energy availability comparable to what is enjoyed today in wealthy European nations.

For the regional case studies of nations that are already relatively prosperous today, this implies a continuation of the existing status quo. For regional case studies of nations that are energy-poor today, this implies substantial growth in per-capita energy availability. It is important to emphasize that although this scenario does indeed fall within the range of possible futures for humanity, it is nevertheless objectively suboptimal according to every meaningful social, economic, and environmental metric. In other words, it represents a good outcome, but not a *great* one.

Energy delivered:

- 700 watts of constant electricity consumption per capita for residential, commercial, and industrial use, or roughly 6,150 kilowatt-hours annually per person (the equivalent of Germany today).
- 4,200 kWh per capita annually for transportation (2,100 kWh for passenger travel and 2,100 kWh for road freight).
- Sufficient electricity to provide heating to a European standard and cooling to an American standard of comfort (varies substantially by geographic location).

The *Stellar Energy Superabundance* scenario

Per-capita energy availability significantly greater than exists anywhere in the world today.

This scenario represents a milestone on the road to superabundant clean energy future for all of humanity, and implies enormous growth in per-capita energy availability worldwide, and especially in energy-poor regions.

More precisely, this scenario is distinguished from the Stellar Energy Prosperity scenario by the assumption that all sources of electricity consumption other than heating, cooling, and transportation grow uniformly by a factor of three. Historical examples suggest that when a society advances to a new level of prosperity, per-capita energy consumption tends to increase accordingly. For example, Taiwan, which since 1980 has made the leap to an advanced economy, roughly tripled its primary energy consumption over the same period.

It is important to emphasize that this scenario – as the name implies – is objectively desirable according to every meaningful social, economic, and environmental metric.

Energy delivered:

- 2,100 watts of constant electricity consumption per capita for residential, commercial, and industrial use, or roughly 18,400 kilowatt-hours annually per person (three times Germany today).
- 4,200 kWh per capita annually for transportation (2,100 kWh for passenger travel and 2,100 kWh for road freight).
- Sufficient electricity to provide heating to a European standard and cooling to an American standard of comfort (varies substantially by geographic location).

Data

Our model takes as inputs each region's hourly weather data as reanalyzed by NASA for a 10 year period (2010-07-01 to 2020-06-30 for the northern hemisphere and 2010-01-01 to 2019-12-31 for the southern hemisphere), and from these data we simulate hourly solar and wind generation as well as hourly energy demand for nominal electricity use, transportation, heating, and industry. Our data synthesis method is guided by real-world data, and utilizes the work of other research teams whose focus is energy generation and demand modeling. (See data sources page 112)

By synthesizing data, we are able to analyze any region globally, including those where reliable real-world data are unavailable. Synthesized data also allow us to analyze each region's *Stellar Energy Superabundance* scenario. For most regions, electricity utilization in the future will greatly exceed today's levels on a per-capita basis. Population estimates for 2040 are based on UN projections.

For capital cost (capex) estimates, our model uses historical cost data for SWB benchmarked to United States markets. For solar, we use NREL data; for wind, we use Berkeley Lab data; and for batteries we use a RethinkX estimate based on a number of industry sources including BNEF, Wood-Mackenzie, Lazard, and Benchmark Minerals. Following these sources and their respective cost estimation methodologies, the capex estimates included in our scenarios reflect core hardware (PV modules, wind turbines, battery packs, etc.) plus balance-of-system and other hardware (transformers, inverters, power electronics, etc.) as well as soft costs (installation, permitting/inspection, fees, etc.). Capex findings are reported in 2024 USD unless otherwise noted. Note that Capex does NOT include any infrastructure costs, land costs (lease, purchase, etc.) required to facilitate installation of SWB assets (these vary enormously from project to project), nor any existing or predicted tariffs or subsidies (these are social choices subject to change without notice by non-market forces).

Assumptions

Both our ***Stellar Energy Prosperity*** scenario and ***Stellar Energy Superabundance*** scenario make a number of assumptions in order to bound our analysis and frame the conclusions that can be drawn from it.

Most of these assumptions are conservative, meaning they impose unrealistically stringent constraints compared to what we ought to expect in most real-world situations, and we therefore ought to expect true requirements and costs to be somewhat less than these scenarios assume.

The scenarios and findings we present here are intended only to illustrate the overall scale and direction of travel for the SWB disruption of energy. For more detailed analysis, RethinkX works with directly with communities, regions, and other interested parties on a case-by-case basis.

Assumption 1: **no imports**

It is common practice for regions to trade electricity with their neighbors. Indeed, energy trade is essential for many nations. However, our analysis assumes each region is a self-sufficient energy island, meaning that it must meet all its needs without assistance from neighbors who may have better weather during a particularly challenging period.

Assumption 2: **no conventional coverage**

As a region's energy system approaches 100% SWB, it becomes increasingly cost-effective to maintain a small (< 5%) reserve of existing (not newly-built) conventional

CAPEX Costs

Our analysis does not attempt to estimate regional capital expenditure (capex) differences because these are both highly variable and highly opaque. Instead, we apply capex benchmarked to United States levels (excluding subsidies and tariffs) as of 2024 to both our *Stellar Energy Prosperity* and *Stellar Energy Superabundance* scenarios for all regions. Rather than attempt to make adjustments ourselves, we encourage readers to make adjustments according to their own detailed regional knowledge and assumptions.

In general, our findings therefore tend to conservatively over-estimate the SWB capex for most regions, because actual capital costs are likely to be significantly lower than those for similar assets deployed in the United States in the near term. In the longer term, however, we expect regional cost differences to diminish as the disruption of energy, transportation, food, and labor by new technologies radically levels the global playing field – as reflected in the core principle of globally equal per-capita prosperity and superabundance underlying the two energy scenarios we present here.

generating capacity as coverage for brief high-stress periods. Judicious use of alternative coverage guided by the SWB Coverage Curve can reduce total system capex by as much as 25% for some regions. However, the optimal quantity of conventional coverage capacity varies a great deal according to regional geography and climate conditions, as well as policymaking and planning priorities. Instead of trying to account for this variability, we make the conservative assumption of 100% SWB coverage and 0% conventional coverage in our analysis. .

Assumption 3: **no other zero-carbon energy technologies**

Our analysis assumes that regions will leave their existing zero-carbon energy sources online as they build out SWB toward clean energy superabundance. This primarily means hydropower, but also includes legacy nuclear power, and in rare circumstances other renewables such as geothermal and tidal power. The only major exception is biofuels, which we exclude from our analysis due to their prohibitively high marginal costs.

(Regions could, however, choose to run any conventional operating reserve with biogas, synthetic methane, or other manufactured gas instead of natural gas in order to retain carbon neutrality).

Assumption 4: **no distributed energy resources**

Distributed energy generation and storage resources (DER) such as residential rooftop solar PV and onsite batteries will play a large role in the disruption. Depending on precisely when, where, and how DER are deployed will have substantial impacts on a region's grid and infrastructure requirements – all subject to overarching geographic factors. Moreover, mobile energy storage in the form of EVs can be viewed as a class of DER as well. The analysis we present here does not attempt to capture these complexities, but instead presumes (for costing purposes) that SWB will be deployed only at large scale. The economics underlying the disruption and SWB Superpower remain the same irrespective of the ratio of centralized to decentralized energy resources. A Stellar Energy system that emphasizes DER may have somewhat higher infrastructure costs, but will benefit from greater robustness and resilience, whereas a system that emphasizes centralized SWB assets may have lower upfront costs in terms of infrastructure but greater exposure to risk. The optimal balance between centralized and decentralized SWB is therefore something each region will need to determine according to its own social priorities and goals.

Assumption 5: **no demand response, load shifting, energy arbitrage, or peak shaving**

Residential, commercial, and industrial users all have scope to adjust the time of day or night during which they utilize electricity. In regions with well-functioning markets and guaranteed energy rights, supply and demand will be coordinated via price signaling facilitated by advanced "smart" metering technology along with smart appliances and other devices. The result is that electricity demand will be shifted according to when SWB Superpower is available. Our analysis does not attempt to model the capacity savings from any systematic reduction in demand volatility on these bases, but instead conservatively assumes demand will continue to vary substantially hour-by-hour as it does today.

Assumption 6: **no technology breakthroughs**

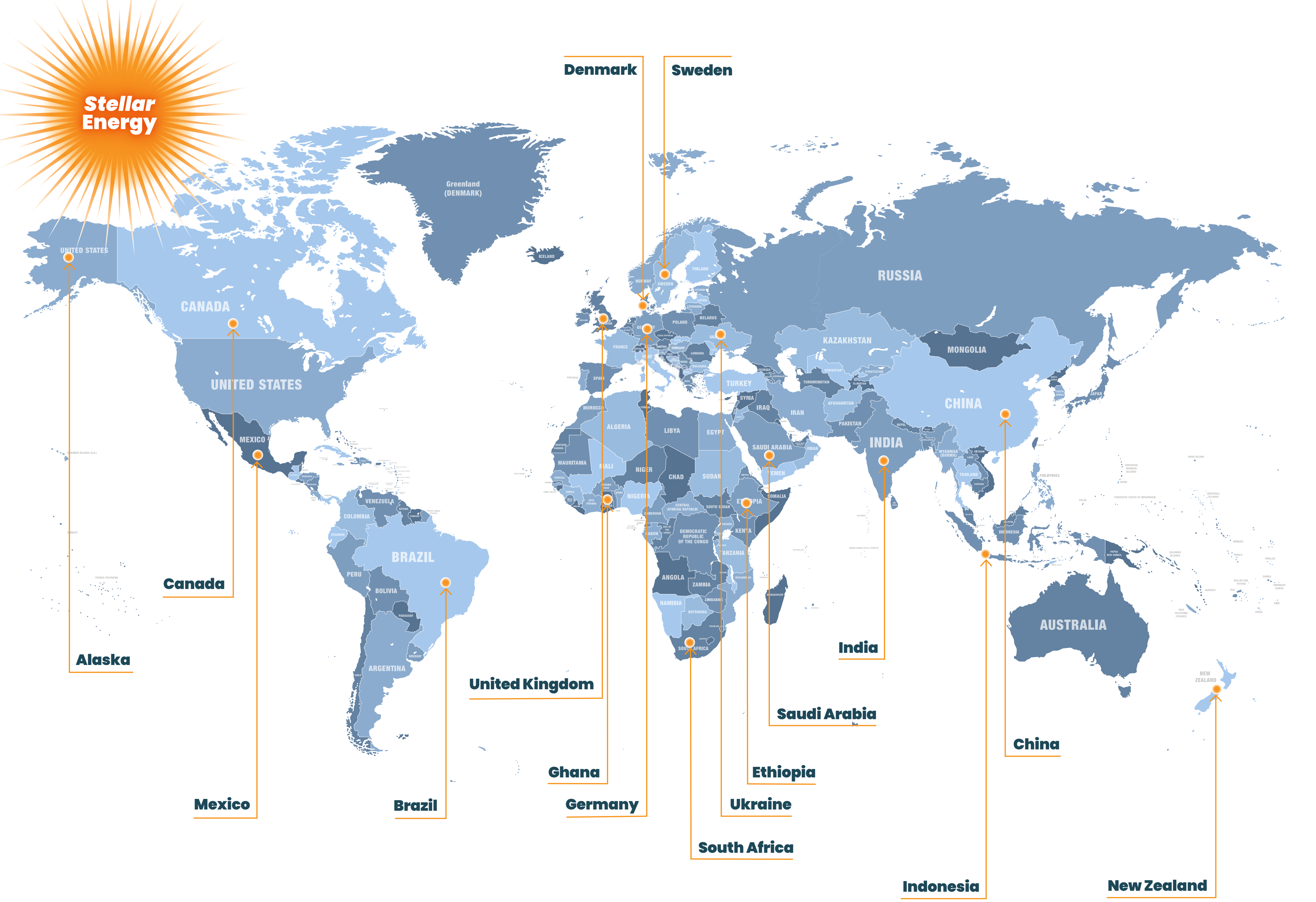
Our analysis does not assume any breakthroughs in SWB or other energy technologies. This is a very conservative assumption, given some of the extraordinary progress already evident in research labs around the world. Substantial improvements in photovoltaics and battery chemistries are already showing great promise, and will almost certainly be commercialized at scale within a decade.

Assumption 7: **no subsidies, carbon taxes, or other financial supports**

Our analysis assumes no subsidies, carbon taxes, or other financial supports for SWB technologies. However, the policies and regulatory frameworks of many countries already include such supports. In the United States, for example, the Inflation Reduction Act of 2022 has committed tens of billions of dollars to support SWB, and billions more to support the electrification of transportation, heating, and industry. Although these supports are not strictly necessary to ensure that the SWB disruption of energy will occur, they will nevertheless accelerate the disruption.

Assumption 8: **disruption versus integration**

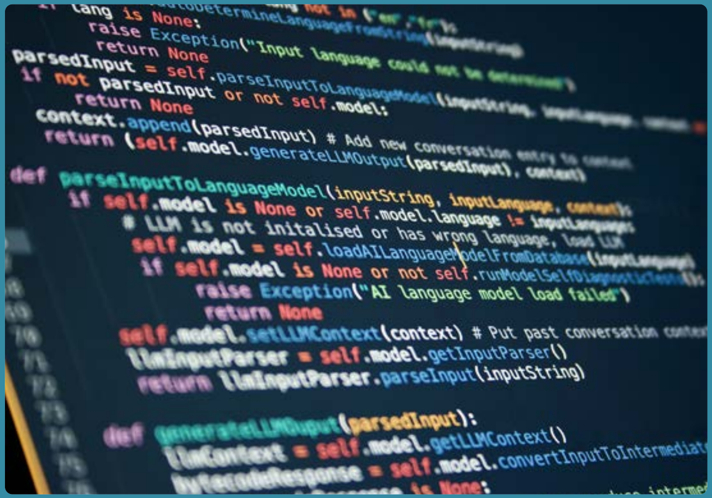
Our analysis does not model interconnection, transmission, or distribution infrastructure requirements and their associated costs. The deployment of SWB will not only be complicated, but will vary greatly from one region to another according to geographic considerations, policy and regulatory decisions, and societal choices. Furthermore, we assume SWB capex at U.S. levels for all regions – as mentioned earlier.



Stellar Energy Explorer

Understand the possibilities for ***Stellar* Energy** in your town, city, region or country.

***Stellar* Energy Explorer** lets you rapidly model scenarios for SWB Superpower and the pathway to superabundant energy almost anywhere on earth.



Run the numbers for yourself. See just how cheap and fast it can be to achieve superabundant, near zero marginal cost energy for your region.

Discover the best possible mix of solar, wind and batteries for your locations that will deliver both, the lowest cost system and the highest level of SWB Superpower.

Model and compare different scenarios, starting points, timeframes, capital costs and architectures.

Compare different locations to see the ideal positioning for assets. Compare your region with others and see how you can lead in this race to the stars!

Put *your* region on the map.

Get in touch with us to learn more about our ***Stellar* Energy Explorer** software and support services and how you can get started with your own modeling and analysis - scan the code or email **inquire@rethinkx.com**

Brazil's path to *Stellar* Energy

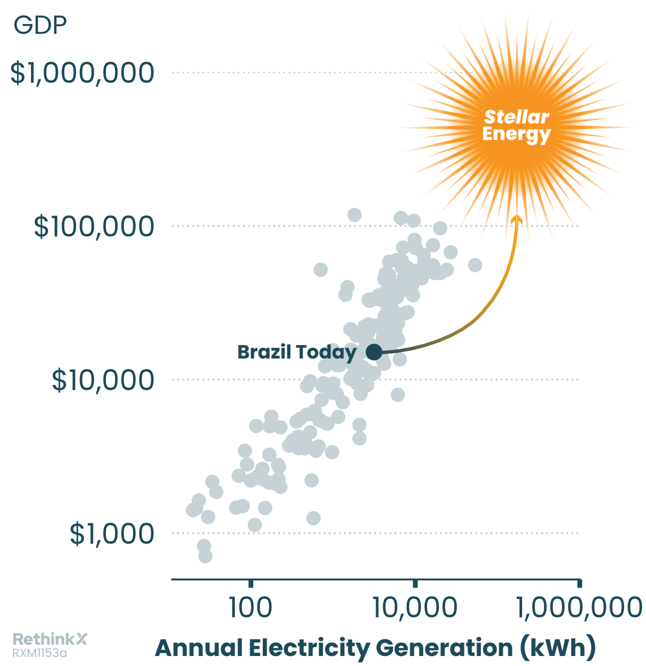
Population in 2040: **219,237,084**

Key Insights:

- Brazil generates 5-11 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Brazil produces less than half as much SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is consistently available in Brazil throughout the year, with an increase in late summer and early autumn associated with somewhat greater seasonal wind abundance.
- Solar plays a predominant role in Brazil's SWB mix.
- Just 16-18 average demand hours of battery capacity is required, which reflects the consistency of Brazil's abundant solar resources.

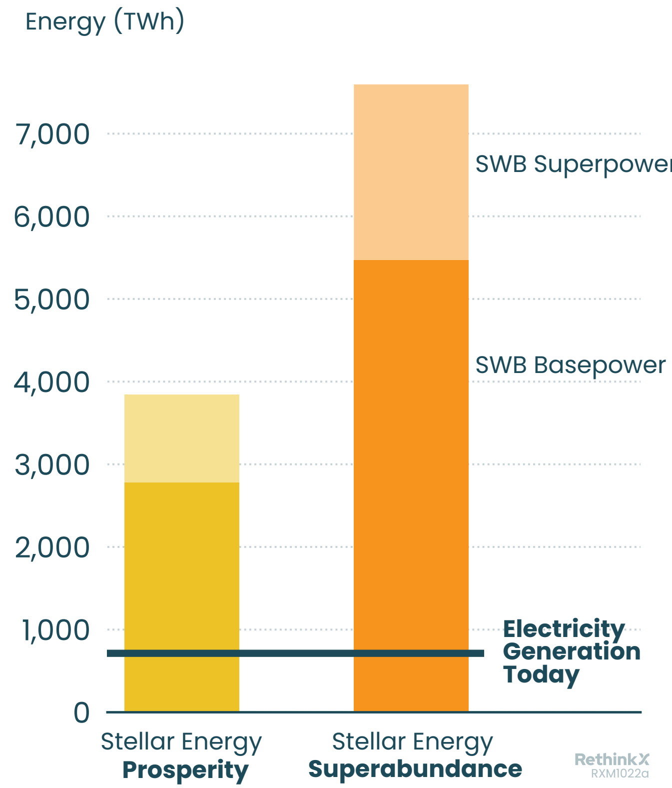
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Brazil

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$311 per year over 20 years
SWB Base power: 2,783 TWh
SWB Superpower: 1,061 TWh

Solar: 2,009 GW
Wind: 232 GW
Batteries: 5,103 GWh
(16 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$685 per year over 20 years
SWB Base power: 5,472 TWh
SWB Superpower: 2,124 TWh

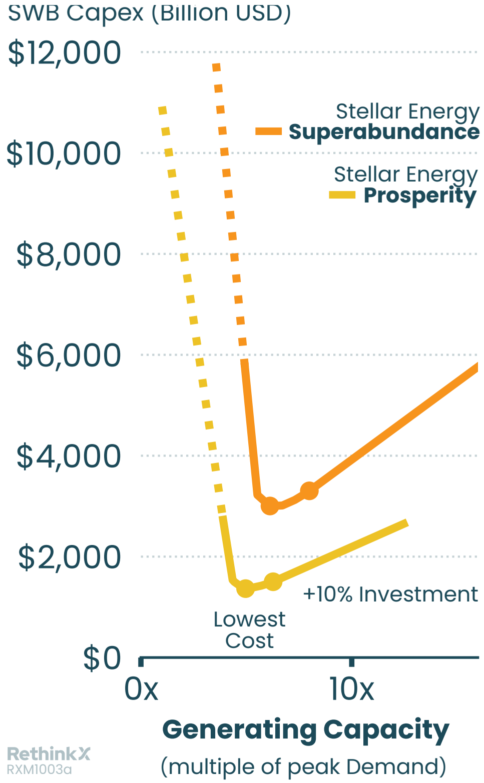
Solar: 3,990 GW
Wind: 663 GW
Batteries: 11 TWh
(18 average demand hours)

Brazil's path to **Stellar Energy**

Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

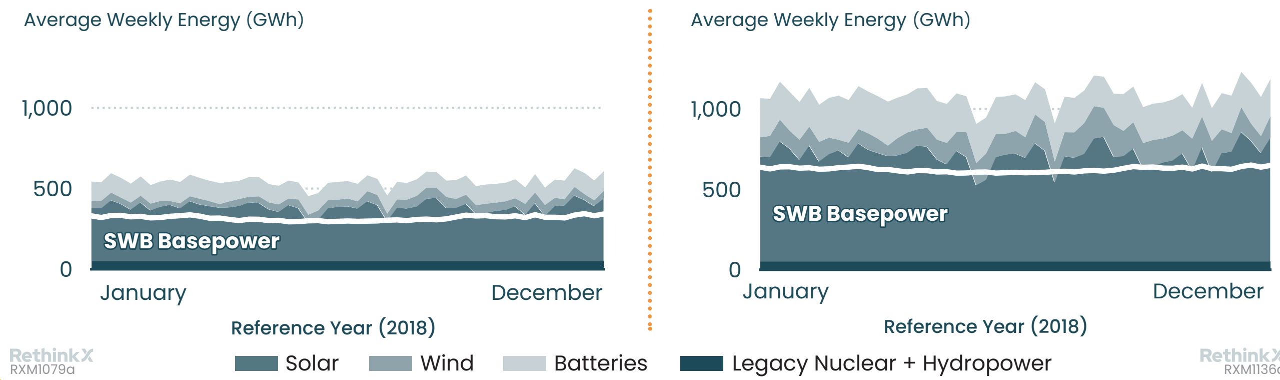
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



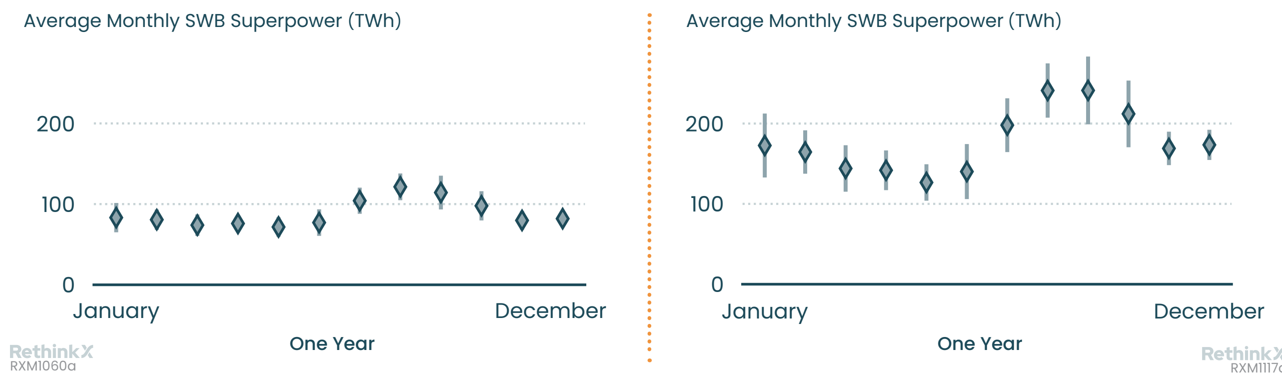
Learn more about this modelling go to https://go.rethinkx.com/V7EE

Brazil

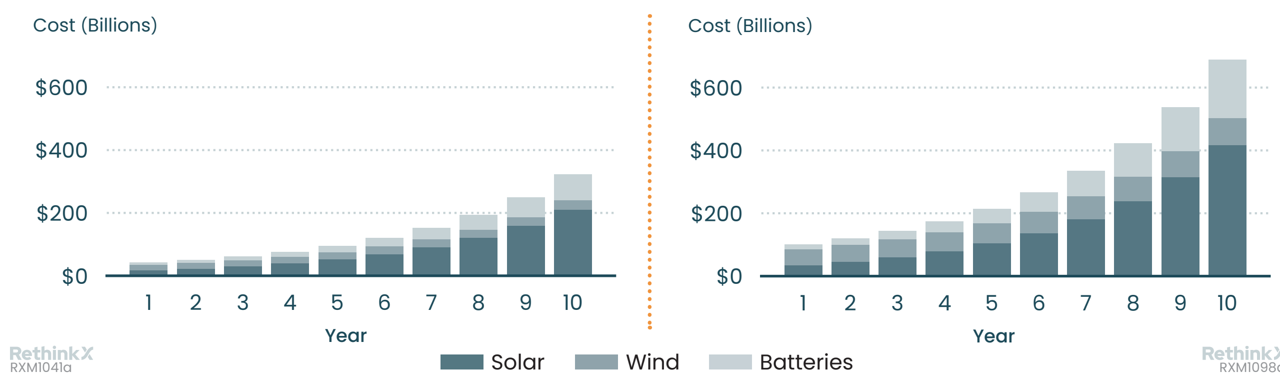
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Canada's path to *Stellar* Energy

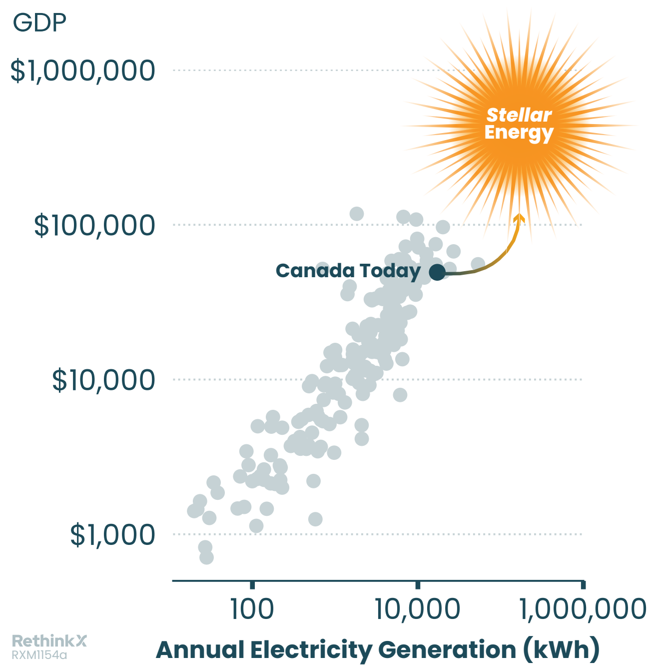
Population in 2040: **43,951,417**

Key Insights:

- Canada generates 3-4 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Canada produces roughly as much SWB Superpower as SWB Basepower in each of our scenarios as a result of sizing to peak winter stress at high latitude.
- SWB Superpower is available in Canada throughout the year, but shows a clear seasonal pattern due to greater solar abundance in the summer months.
- Solar plays the largest role in Canada's SWB mix.
- Battery capacity of only 41-46 average demand hours is required for the country as a whole, given the overall consistency of solar and wind availability year-round that emerges when summed across Canada's very large geographic area.

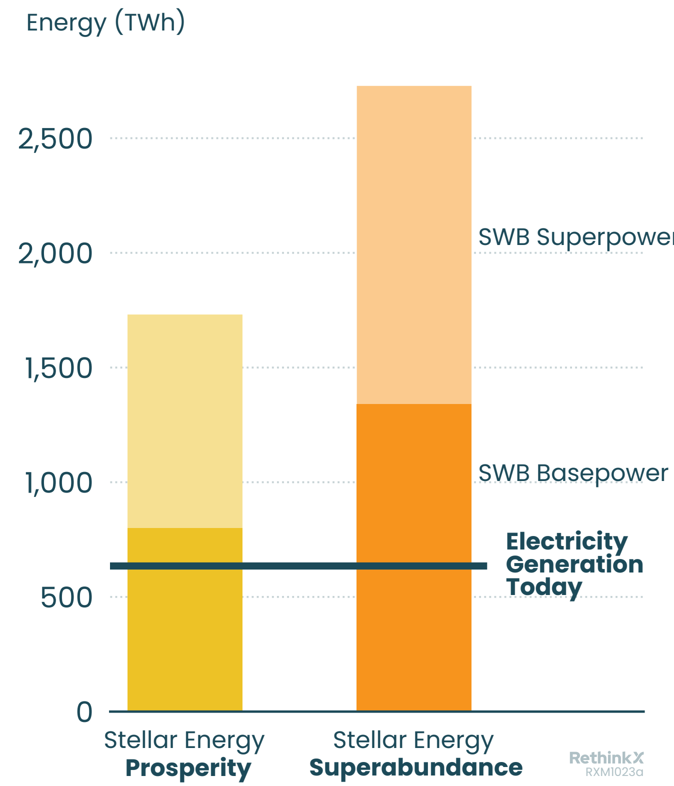
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Canada

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$865 per year over 20 years
SWB Base power: 802 TWh
SWB Superpower: 929 TWh

Solar: 488 GW
Wind: 296 GW
Batteries: 4,188 GWh
(46 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$1390 per year over 20 years
SWB Base power: 1,341 TWh
SWB Superpower: 1,387 TWh

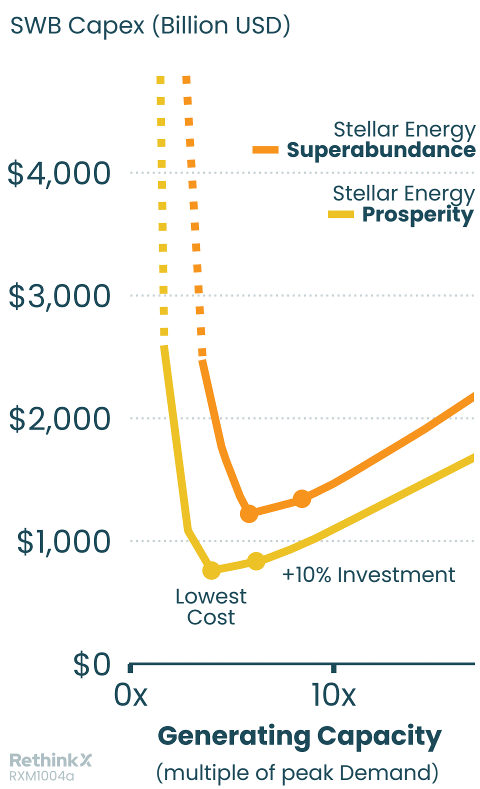
Solar: 1,194 GW
Wind: 338 GW
Batteries: 6,339 GWh
(41 average demand hours)

Canada's path to *Stellar* Energy

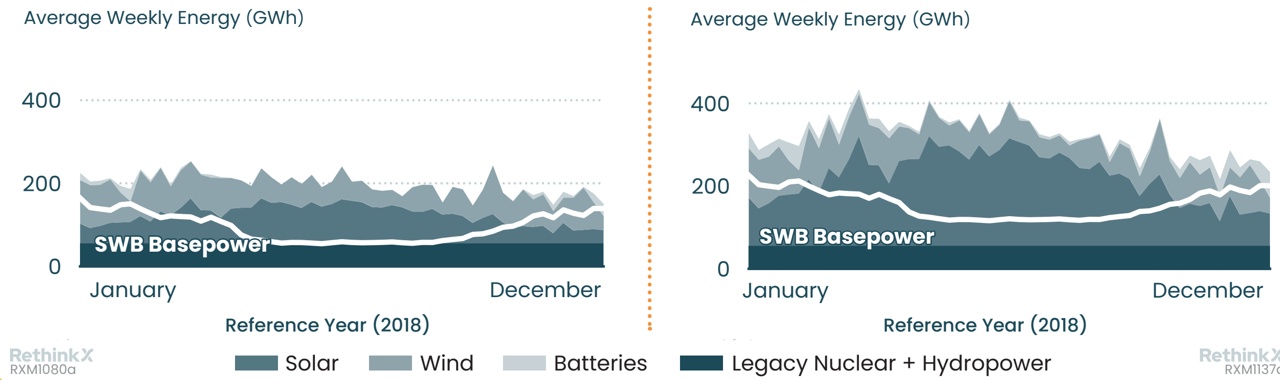
Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

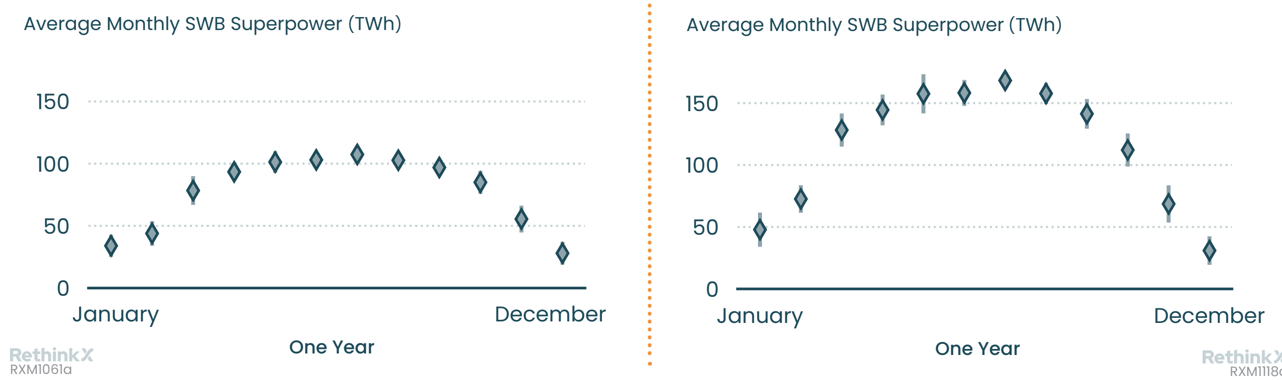
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



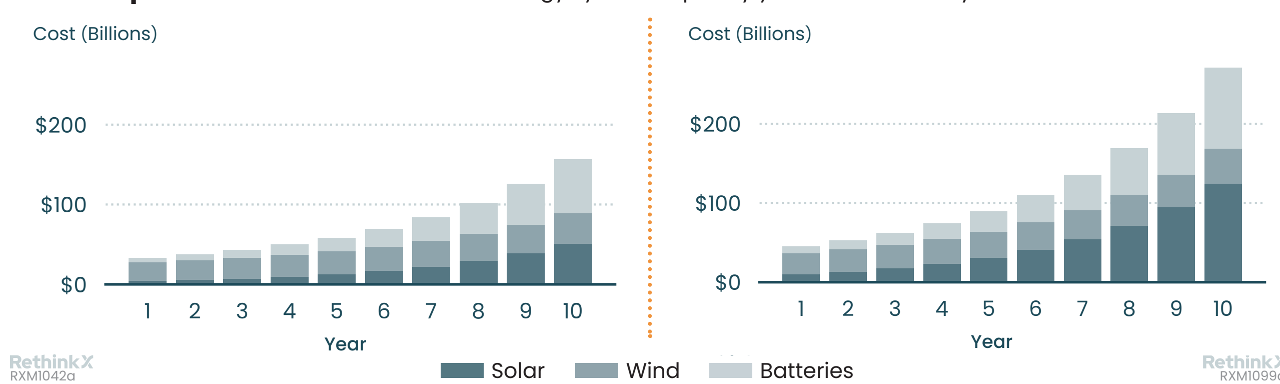
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Learn more about this modelling go to https://go.rethinkx.com/N9NK

Canada

Quebec City, Canada's path to *Stellar* Energy

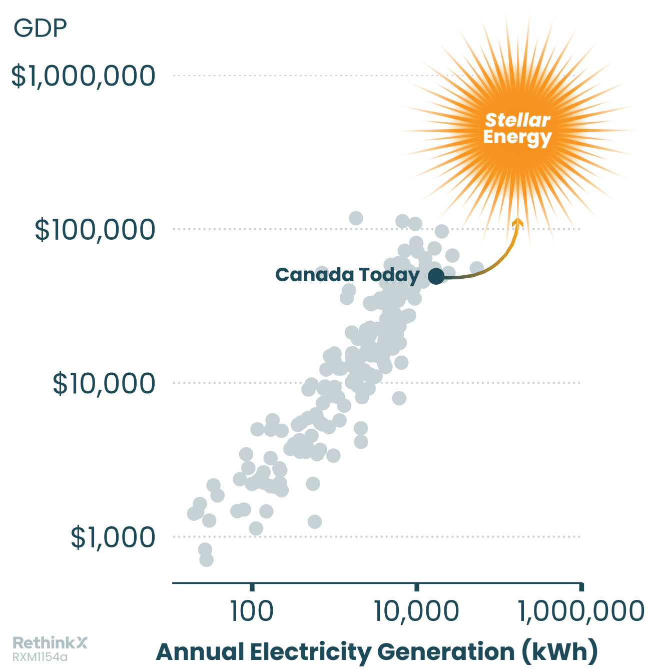
Population in 2040: **665,055**

Key Insights:

- Quebec City generates 5-7 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Quebec City produces twice as much SWB Superpower as SWB Basepower in each of our scenarios as a result of sizing to peak winter stress at high latitude.
- SWB Superpower is available in Quebec City throughout the year, but shows a clear seasonal pattern due to greater solar abundance in the summer months.
- Solar plays the largest role in Quebec City's SWB mix.
- Battery capacity of roughly 75-76 average demand hours is required, which suggests Quebec City could realize substantial savings with a modest amount of alternative coverage as per the SWB Coverage Curve.

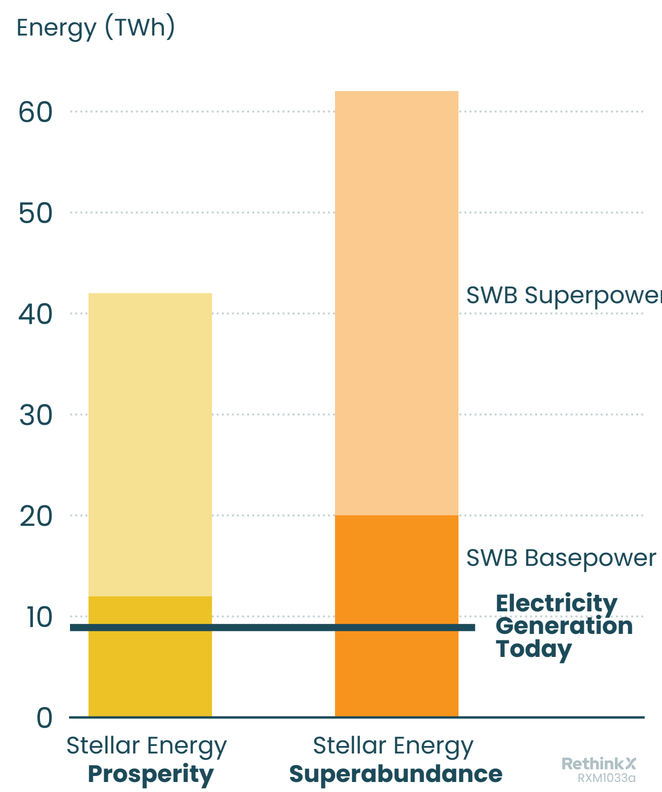
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Quebec City, Canada

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$1608 per year over 20 years
SWB Base power: 12 TWh
SWB Superpower: 30 TWh

Solar: 24 GW
Wind: 5 GW
Batteries: 104 GWh
(75 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

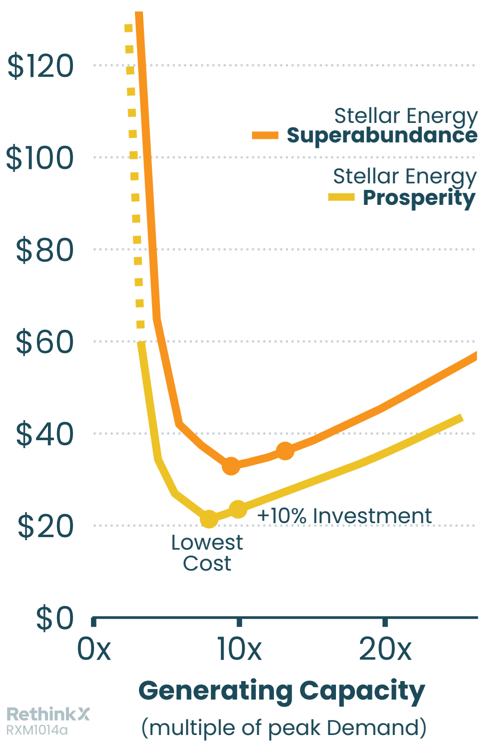
SWB Capex per capita:
$2474 per year over 20 years
SWB Base power: 20 TWh
SWB Superpower: 42 TWh

Solar: 37 GW
Wind: 7 GW
Batteries: 178 GWh
(76 average demand hours)

Quebec City, Canada's path to ***Stellar* Energy**

Clean Energy U-Curve

Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

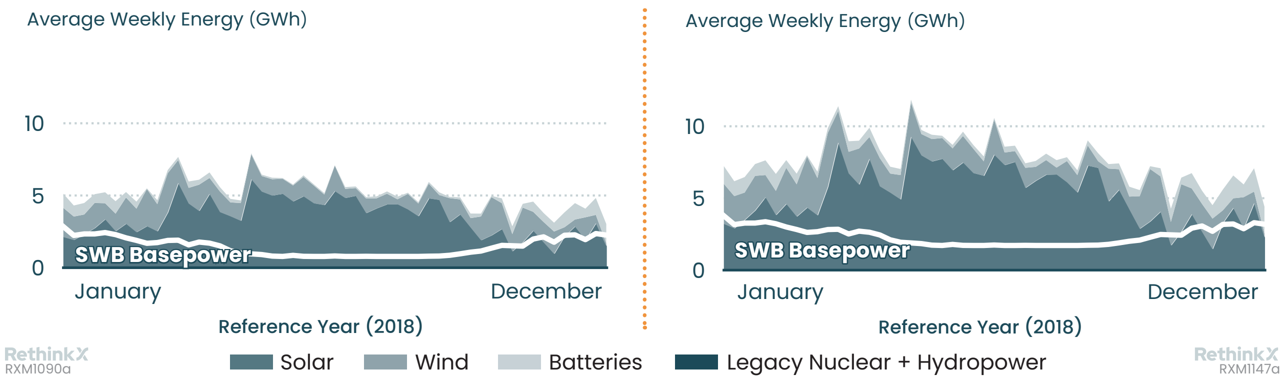


Learn more about this modelling go to https://go.rethinkx.com/B7WT

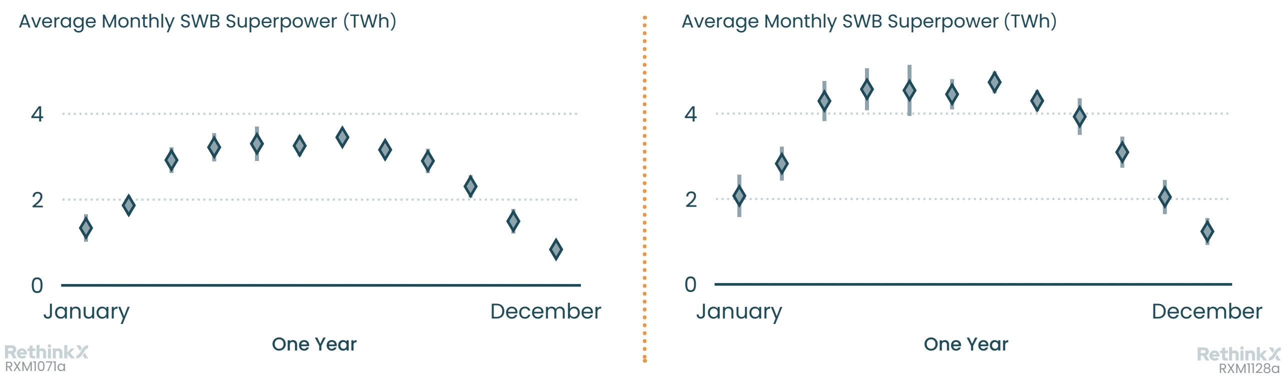
Quebec

Stellar Energy Prosperity | Stellar Energy Superabundance

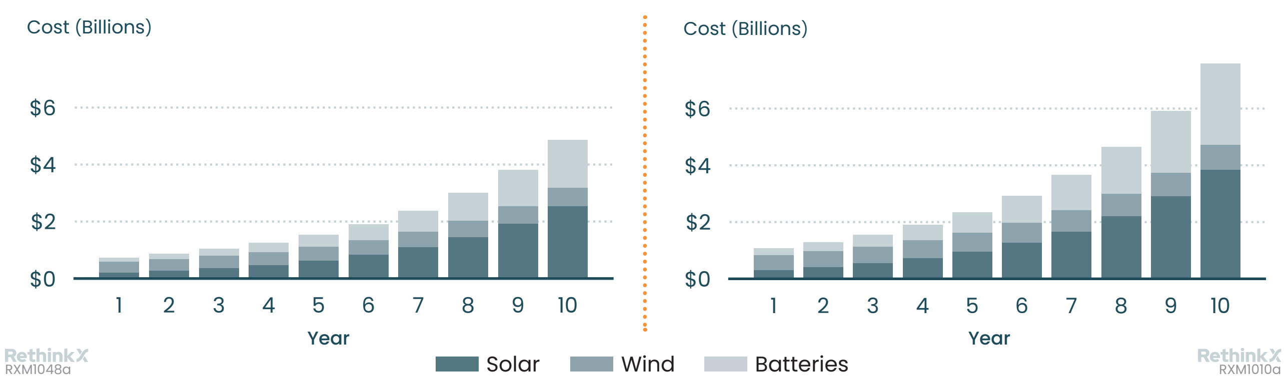
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



China's path to *Stellar* Energy

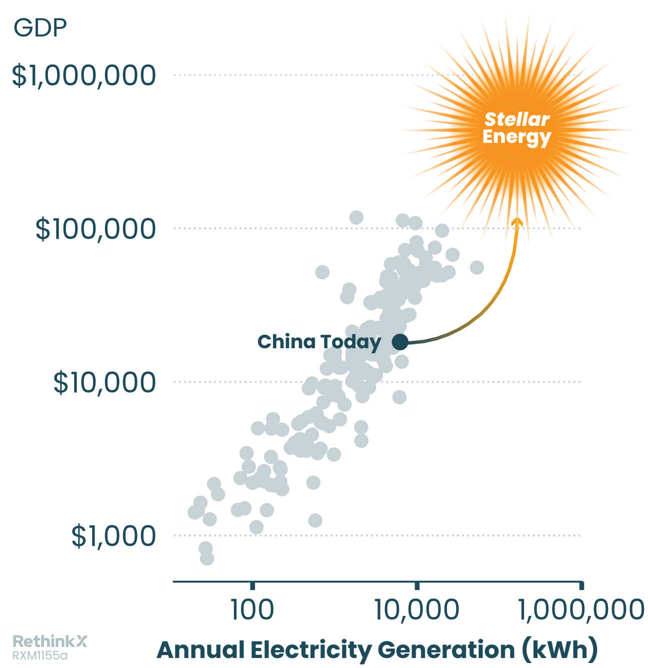
Population in 2040: **1,342,816,657**

Key Insights:

- China generates roughly 3-6 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- China produces roughly as much SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is available in China throughout the year, but shows a clear seasonal pattern due to overall greater wind abundance in the spring months.
- Solar plays larger role than wind in China's SWB mix.
- Battery capacity of just 26 average demand hours is required for the country as a whole, given the overall consistency of solar and wind availability year-round that emerges when summed across China's very large geographic area.

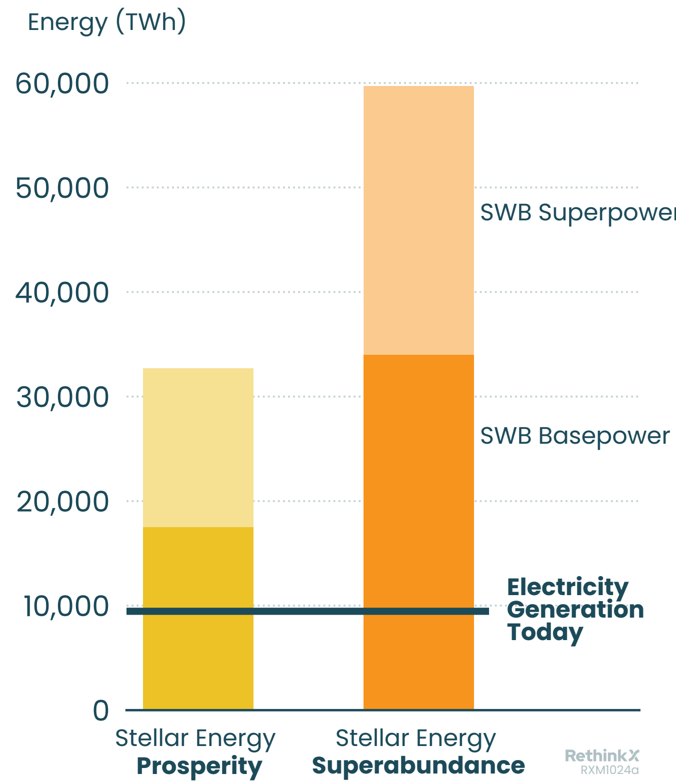
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - China

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$481 per year over 20 years
SWB Base power: 17,531 TWh
SWB Superpower: 15,155 TWh

Solar: 18 TW
Wind: 2 TW
Batteries: 53 TWh
(26 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$916 per year over 20 years
SWB Base power: 34,000 TWh
SWB Superpower: 25,712 TWh

Solar: 33 TW
Wind: 5 TW
Batteries: 100 TWh
(26 average demand hours)

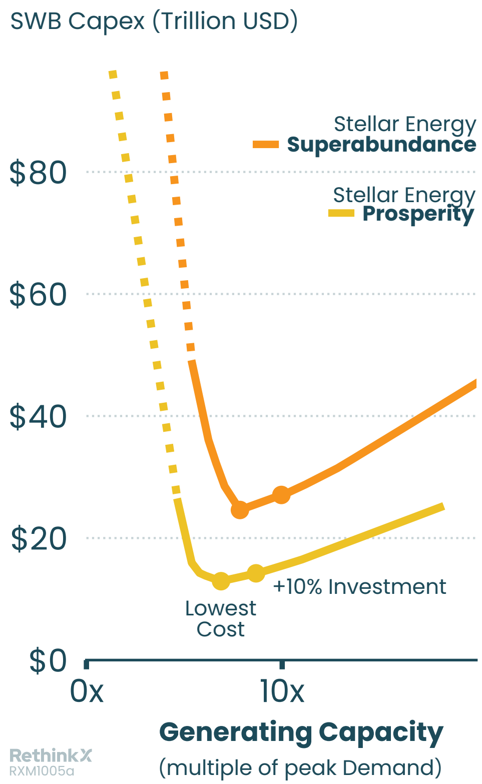
China's path to *Stellar Energy*

Stellar Energy Prosperity

Stellar Energy Superabundance

Clean Energy U-Curve

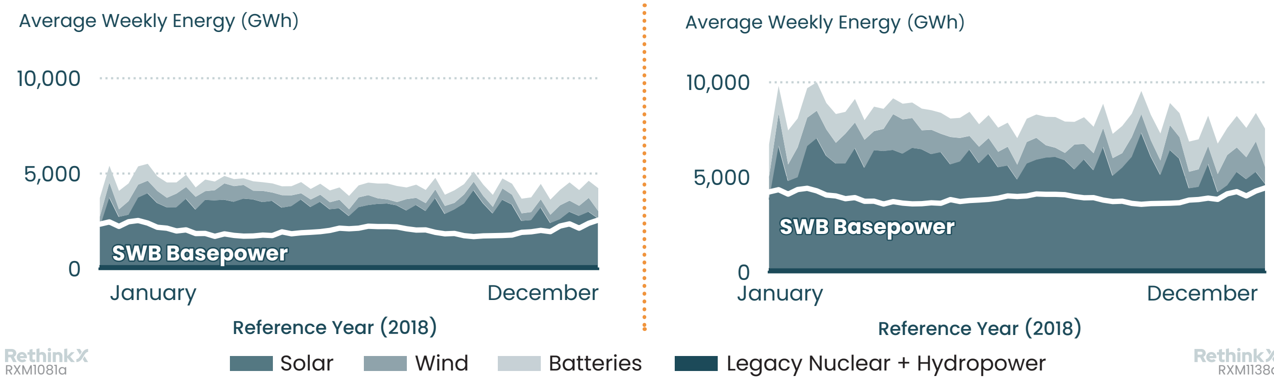
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



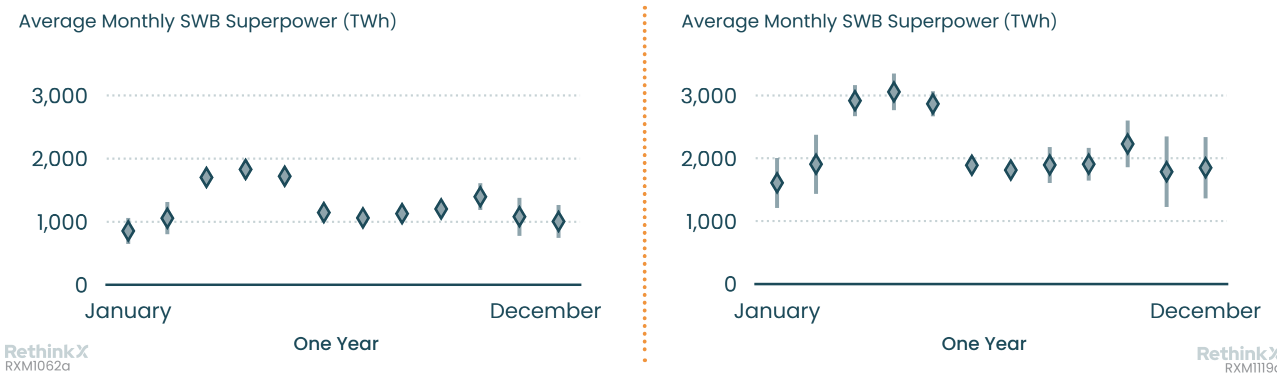
Learn more about this modelling go to https://go.rethinkx.com/O6TA

China

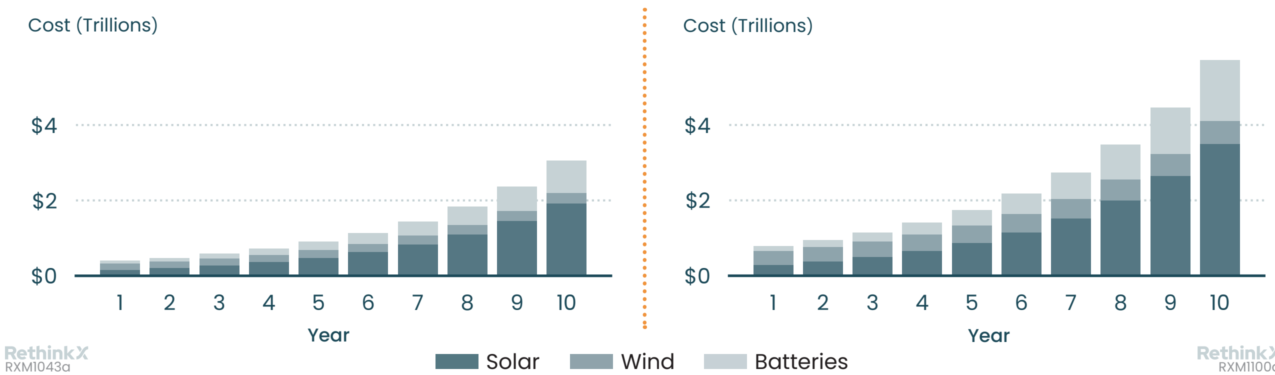
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data

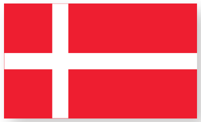


SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years





Denmark's path to *Stellar* Energy

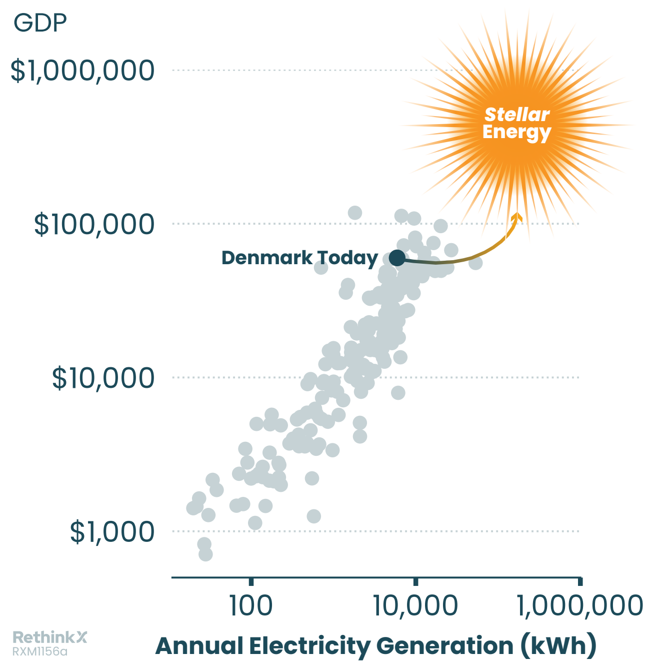
Population in 2040: **6,134,659**

Key Insights:

- Denmark generates 4-9 times more total electricity with a Stellar Energy system than it does today.
- Denmark will produce slightly more SWB Basepower than SWB Superpower in each of our scenarios
- SWB Superpower is available in Denmark throughout the year, but shows a seasonal pattern due to much greater solar abundance in the summer months.
- Despite its large existing wind power capacity, solar ultimately plays the largest role in Denmark's SWB mix.
- Battery capacity of roughly 97-114 average demand hours is required, which suggests Denmark could realize significant savings with a modest amount of alternative coverage as per the SWB Coverage Curve.

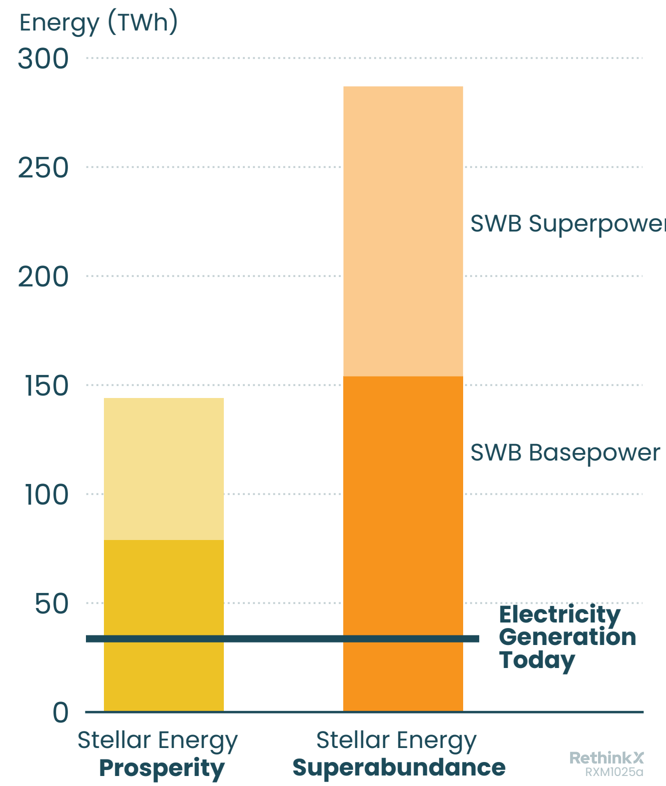
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Denmark

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$801 per year over 20 years
SWB Base power: 79 TWh
SWB Superpower: 65 TWh

Solar: 25 GW
Wind: 24 GW
Batteries: 1,028 GWh
(114 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$1447 per year over 20 years
SWB Base power: 154 TWh
SWB Superpower: 133 TWh

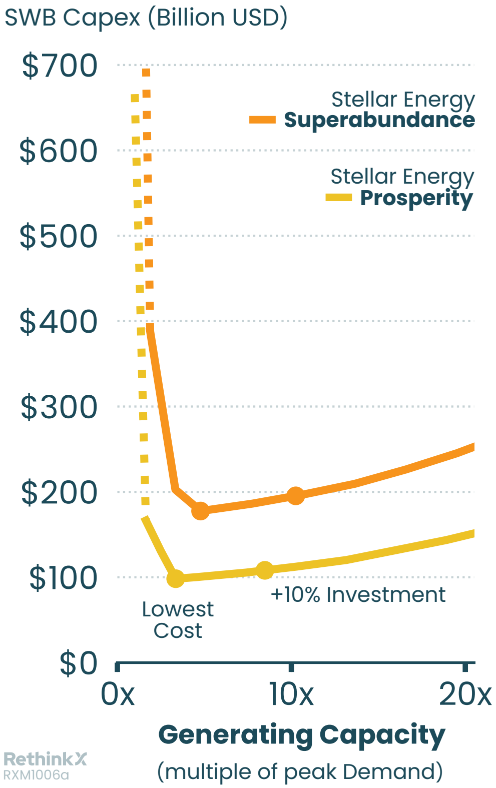
Solar: 67 GW
Wind: 44 GW
Batteries: 1,705 GWh
(97 average demand hours)

Denmark's path to *Stellar Energy*

Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

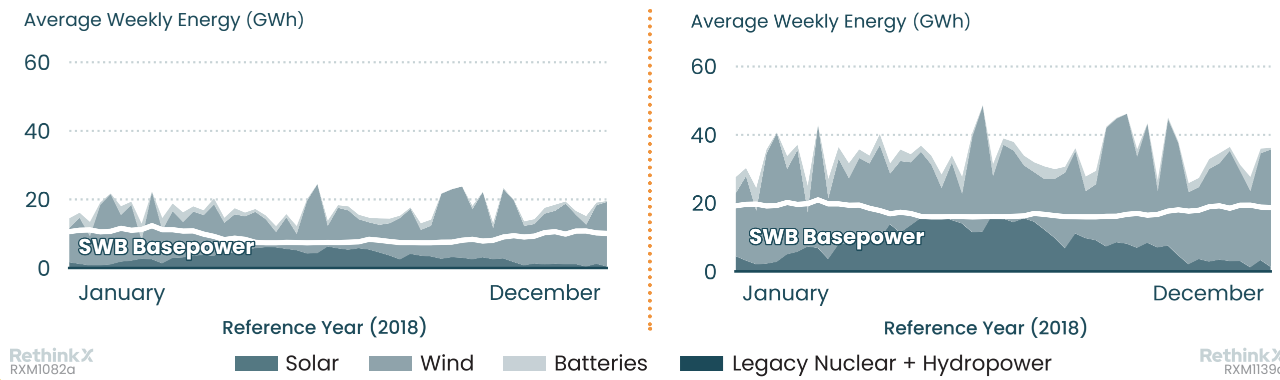
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



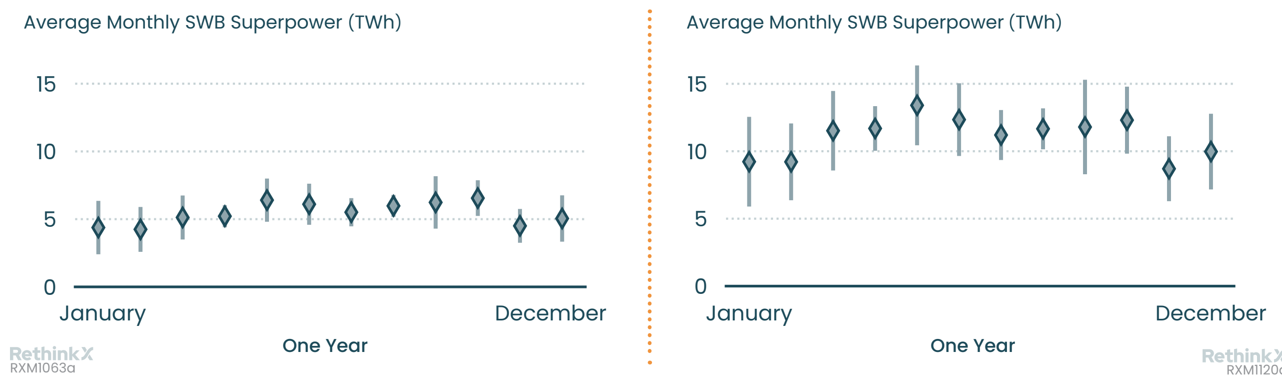
Learn more about this modelling go to https://go.rethinkx.com/R5BA

Denmark

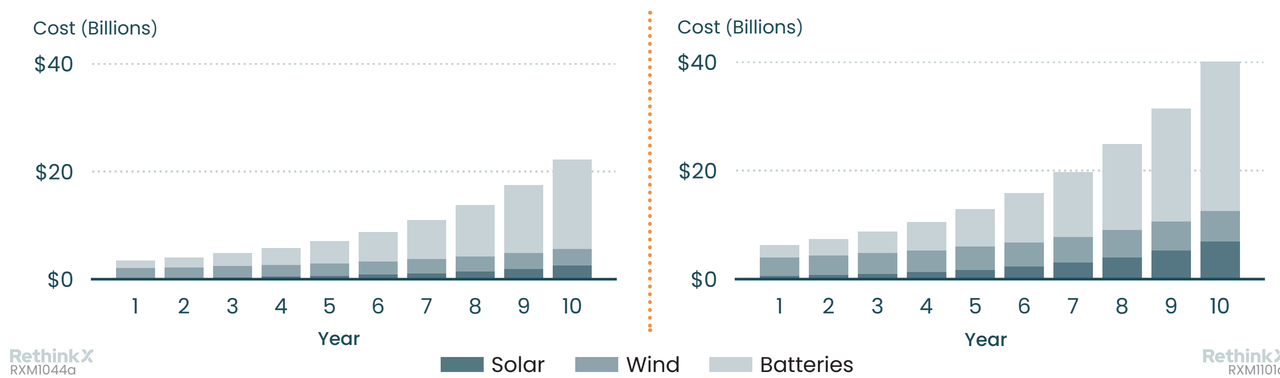
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data

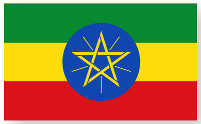


SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years





Ethiopia's path to *Stellar* Energy

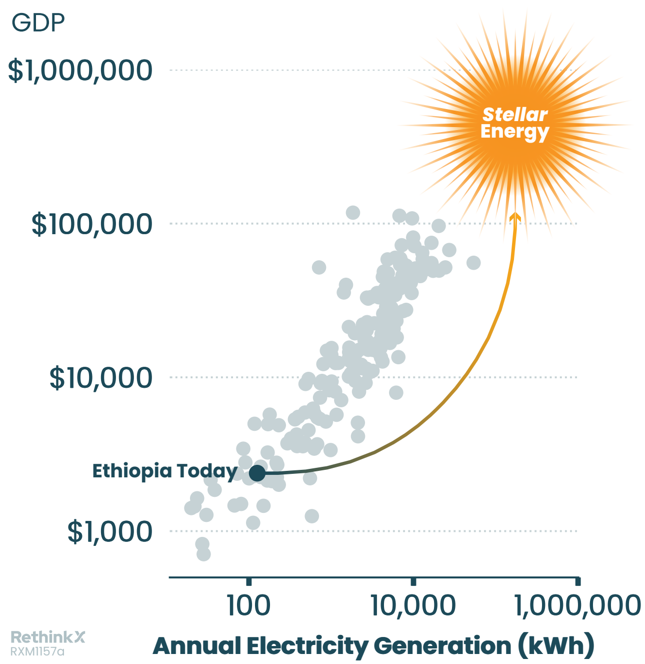
Population in 2040: **188,450,902**

Key Insights:

- Ethiopia generates 193-414 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Ethiopia produces roughly half as much SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is available in Ethiopia throughout the year, but shows a clear seasonal pattern with decreased solar availability corresponding to the summer rainy season.
- Despite significant existing hydropower capacity installed today, solar plays a dominant role in Ethiopia's future energy mix.
- Just 32 average demand hours of battery capacity is required, which reflects the consistency of Ethiopia's abundant solar and wind resources.

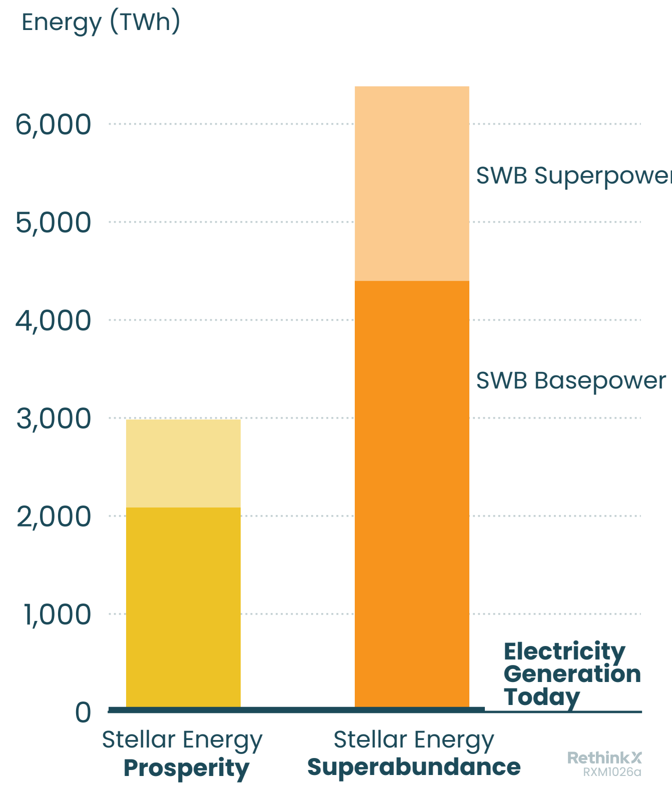
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Ethiopia

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$307 per year over 20 years
SWB Base power: 2,087 TWh
SWB Superpower: 896 TWh

Solar: 1,697 GW
Wind: 0.29 GW
Batteries: 7,584 GWh
(32 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$659 per year over 20 years
SWB Base power: 4,398 TWh
SWB Superpower: 1,986 TWh

Solar: 3,646 GW
Wind: 0.23 GW
Batteries: 16 TWh
(32 average demand hours)

Ethiopia's path to **Stellar Energy**

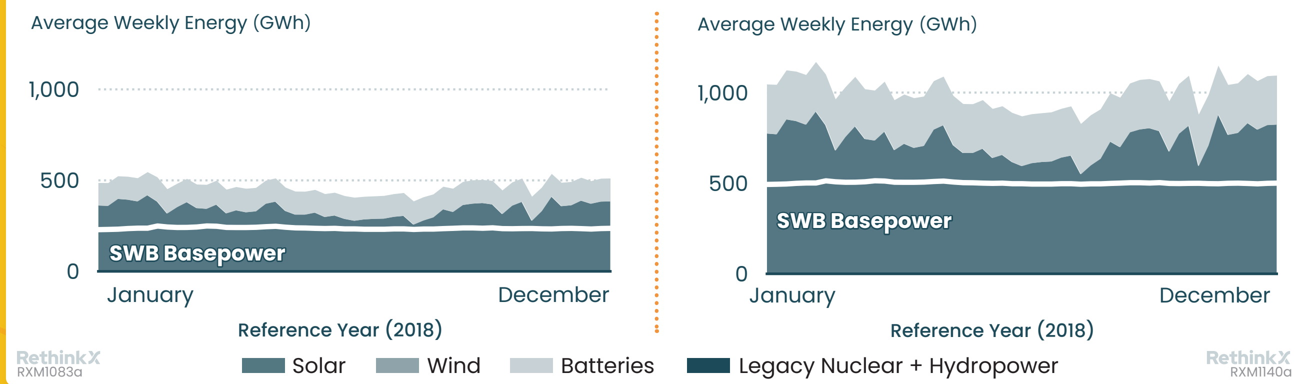
Clean Energy U-Curve

Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

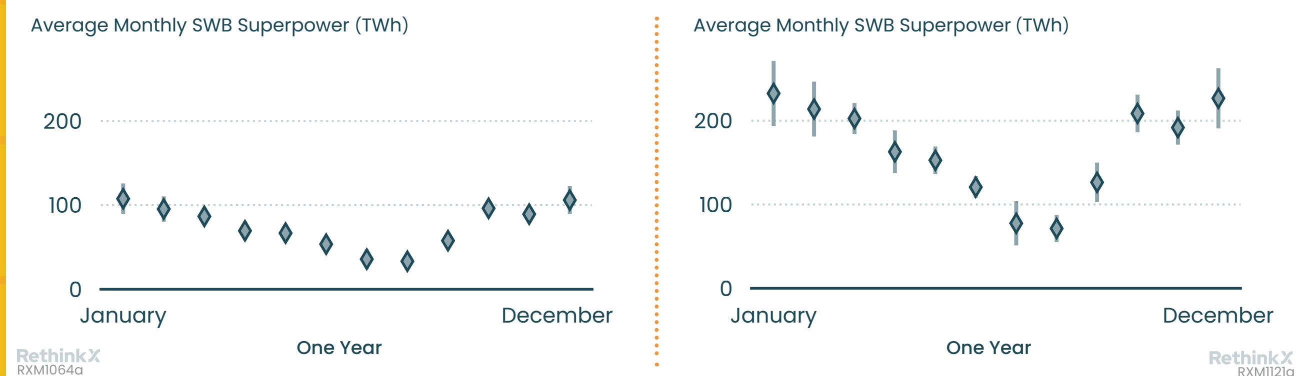
Learn more about this modelling go to https://go.rethinkx.com/W8RJ

Stellar Energy Prosperity | Stellar Energy Superabundance

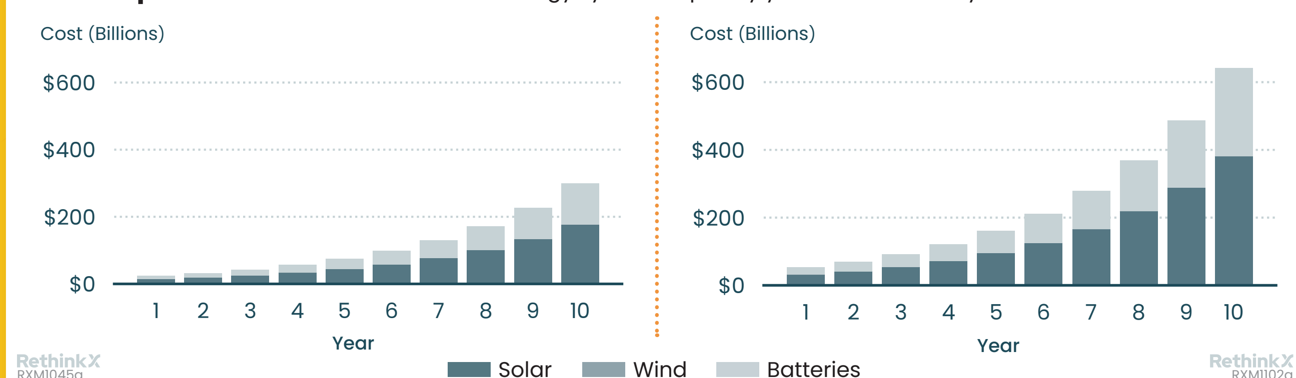
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Germany's path to *Stellar* Energy

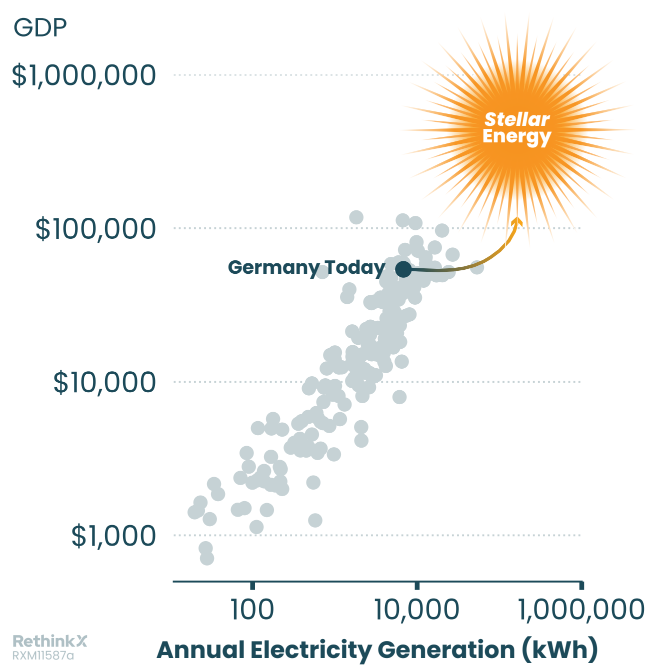
Population in 2040: **80,551,736**

Key Insights:

- Germany generates 5-9 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Germany produces slightly more SWB Superpower as SWB Basepower in each of our scenarios as a result of sizing to peak winter stress at high latitude.
- SWB Superpower is available in Germany throughout the year, with a modest seasonal pattern due to greater wind abundance in the winter months.
- Solar and wind play roughly equal roles in Germany's SWB mix.
- Battery capacity of roughly 55-57 average demand hours is required for Germany.

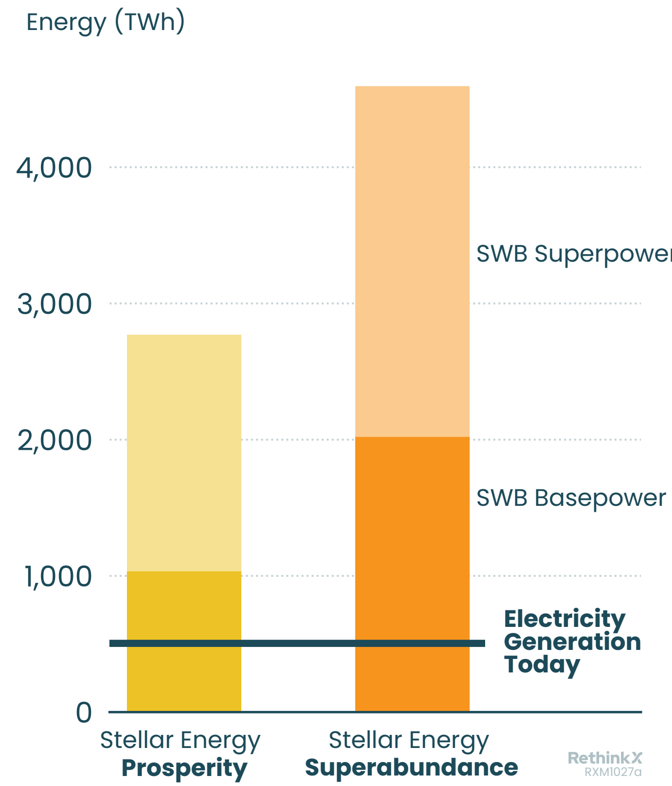
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Germany

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$769 per year over 20 years
SWB Base power: 1,032 TWh
SWB Superpower: 1,736 TWh

Solar: 573 GW
Wind: 580 GW
Batteries: 6,681 GWh
(57 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

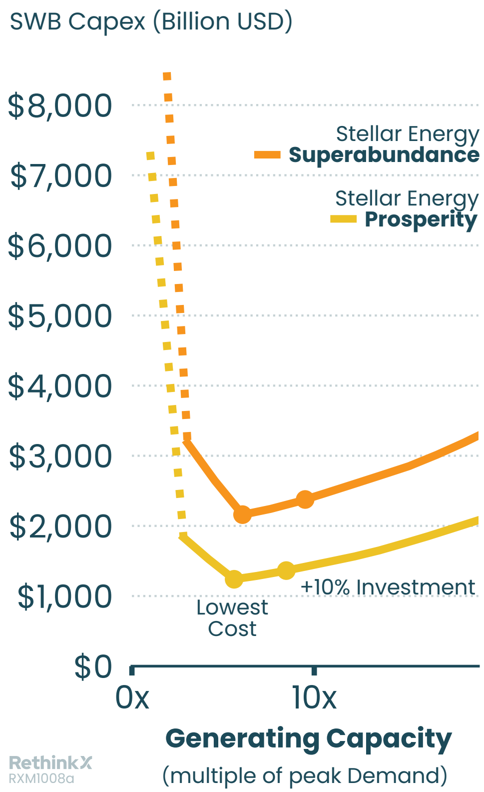
SWB Capex per capita:
$1341 per year over 20 years
SWB Base power: 2,020 TWh
SWB Superpower: 2,575 TWh

Solar: 964 GW
Wind: 969 GW
Batteries: 13 TWh
(55 average demand hours)

Germany's path to *Stellar* Energy

Clean Energy U-Curve

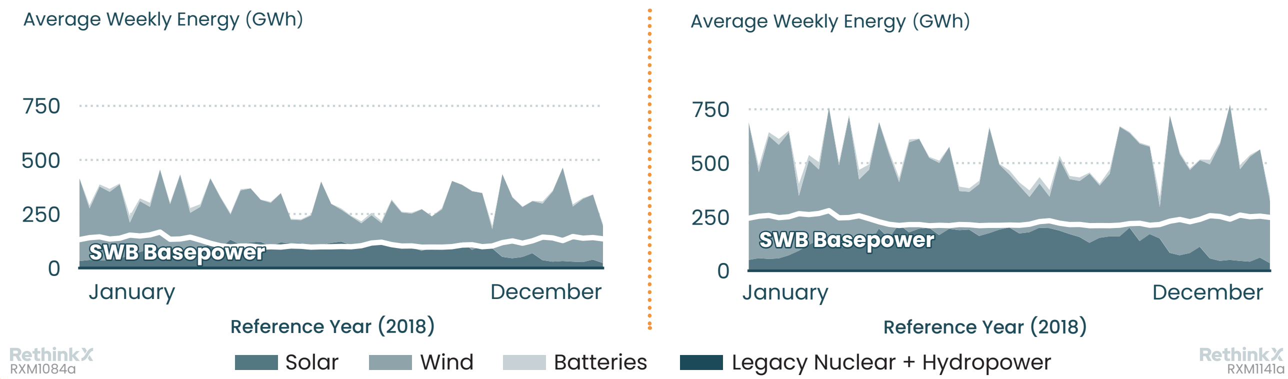
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



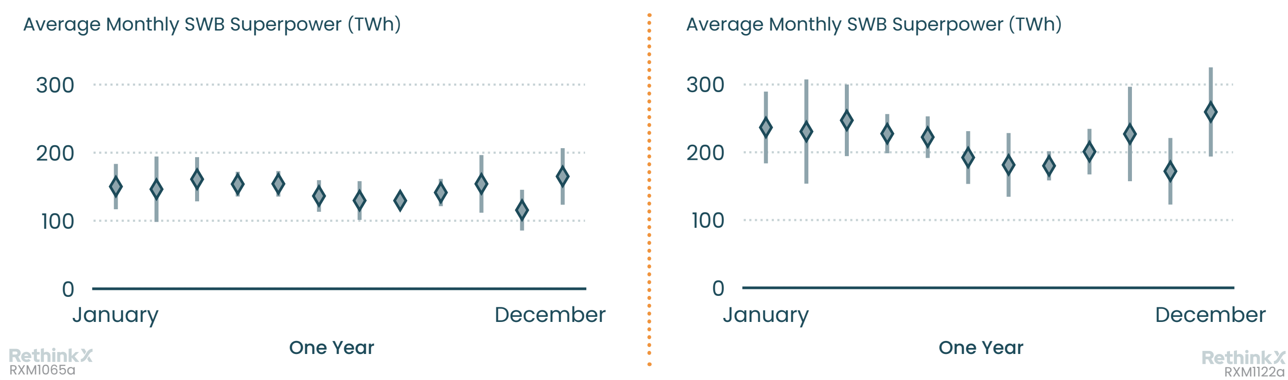
Learn more about this modelling go to https://go.rethinkx.com/Z8VX

Stellar Energy Prosperity | Stellar Energy Superabundance

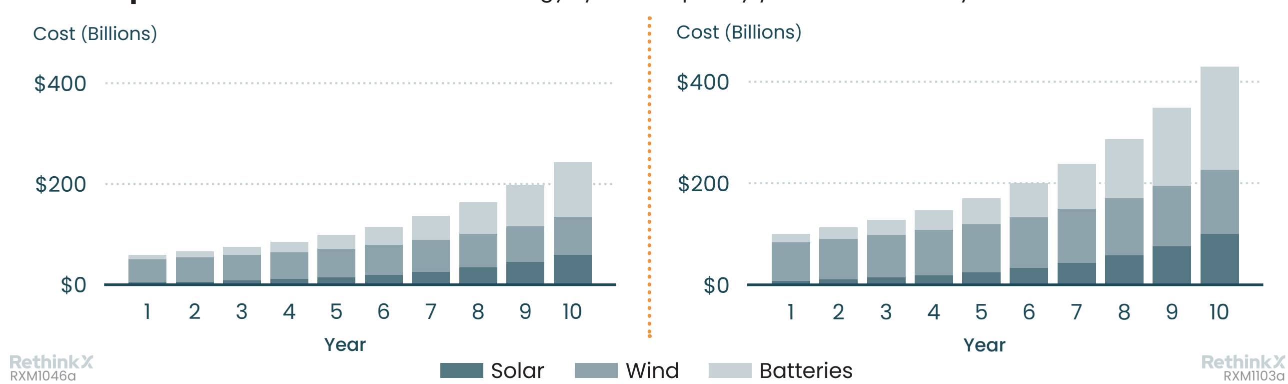
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Ghana's path to *Stellar* Energy

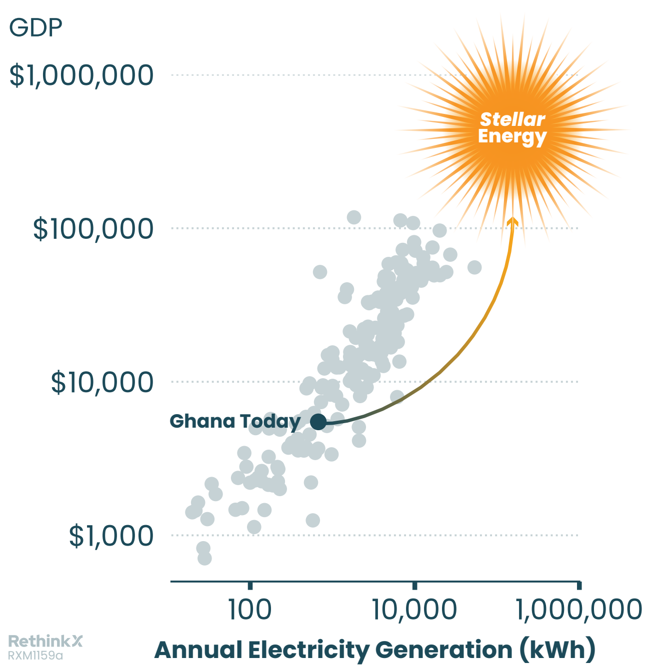
Population in 2040: **44,568,350**

Key Insights:

- Ghana generates 38-72 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Ghana produces less than half as much SWB Superpower as SWB Basepower in each of our scenarios as a result of its remarkably consistent solar availability all year long.
- SWB Superpower is available in Ghana throughout the year.
- Solar plays a dominant role in Ghana's SWB mix, with very little wind power.
- Battery capacity of 31 average demand hours is required for Ghana.

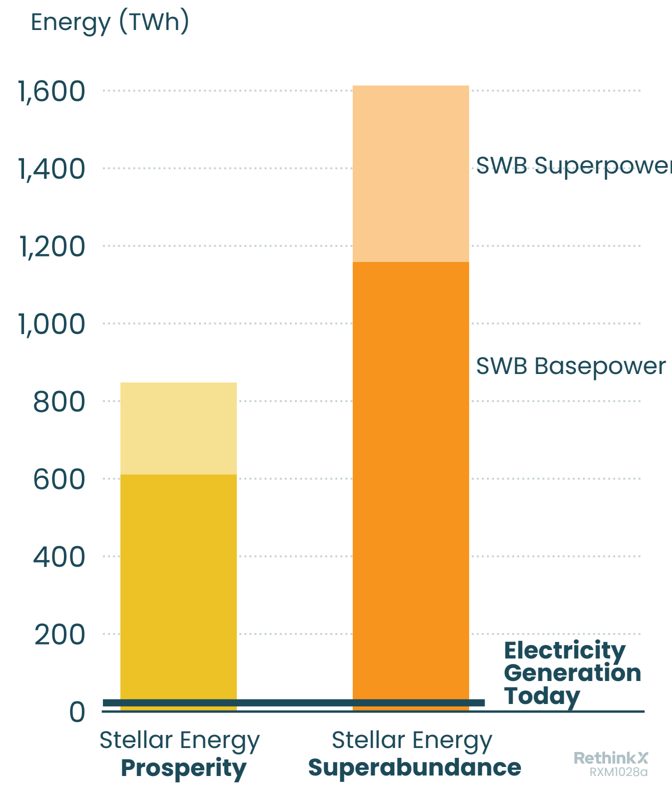
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Ghana

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$426 per year over 20 years
SWB Base power: 612 TWh
SWB Superpower: 236 TWh

Solar: 605 GW
Wind: 0.36 GW
Batteries: 2,161 GWh
(31 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

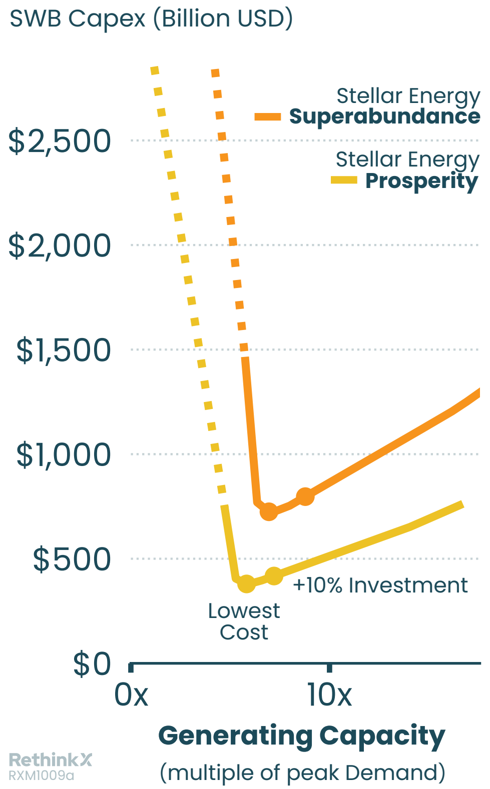
SWB Capex per capita:
$813 per year over 20 years
SWB Base power: 1,159 TWh
SWB Superpower: 454 TWh

Solar: 1,156 GW
Wind: 0.29 GW
Batteries: 4,128 GWh
(31 average demand hours)

Stellar Energy Prosperity | Stellar Energy Superabundance

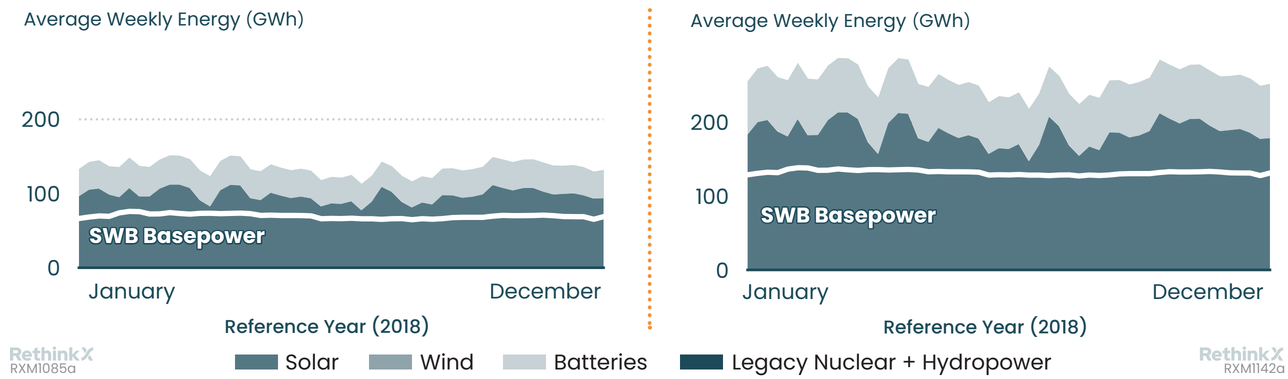
Clean Energy U-Curve

Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

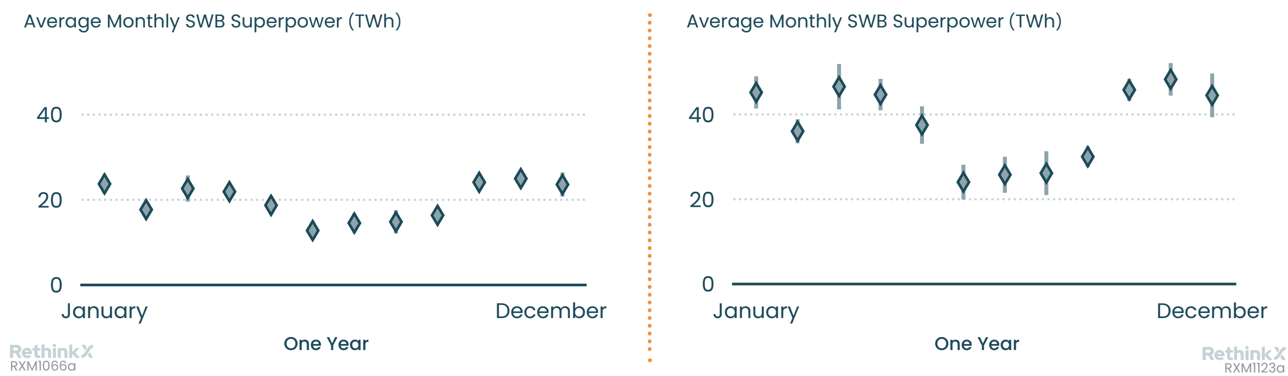


Learn more about this modelling go to https://go.rethinkx.com/K8AW

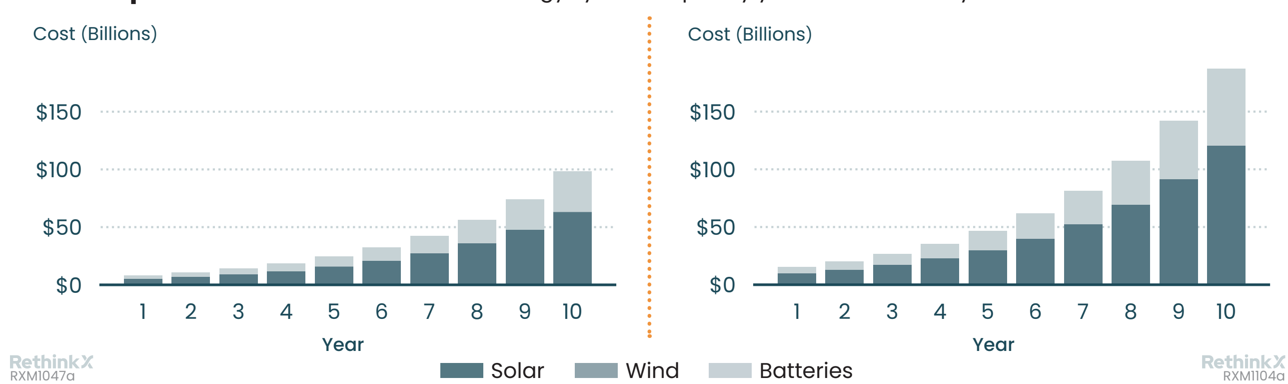
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Accra, Ghana’s path to *Stellar* Energy

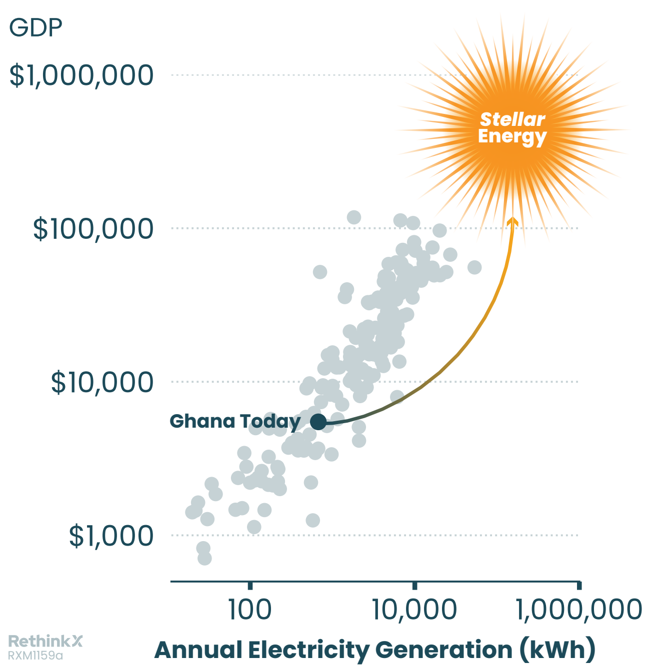
Population in 2040: **3,517,660**

Key Insights:

- Accra generates roughly 39-80 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Accra produces less SWB Superpower as SWB Basepower in each of our scenarios as a result of its steady solar availability all year long.
- SWB Superpower is consistently available in Accra throughout the year.
- Solar plays a dominant role in Accra’s SWB mix, with very little wind power.
- Battery capacity of 32-33 average demand hours is required for Accra.

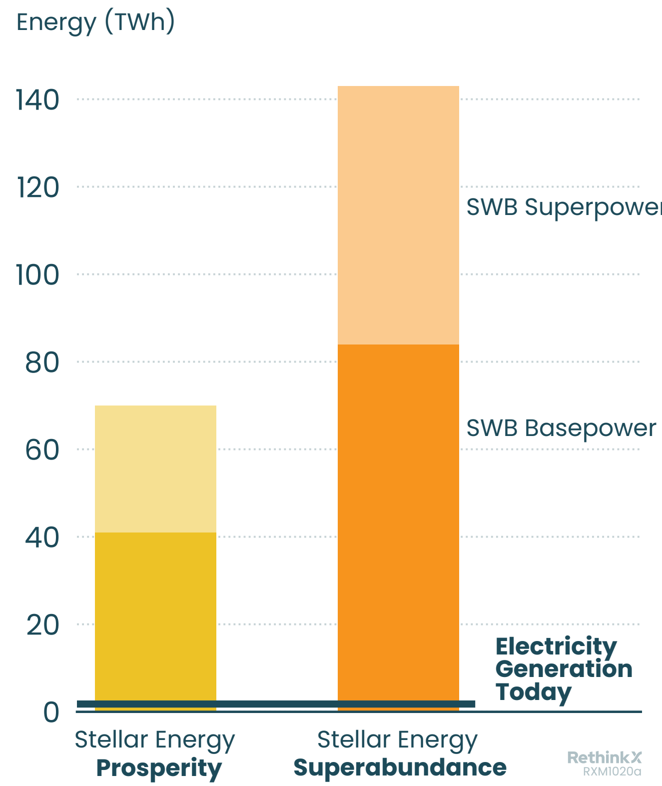
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy – Accra, Ghana

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$431 per year over 20 years
SWB Base power: 41 TWh
SWB Superpower: 29 TWh

Solar: 50 GW
Wind: 1 GW
Batteries: 155 GWh
(33 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$893 per year over 20 years
SWB Base power: 84 TWh
SWB Superpower: 59 TWh

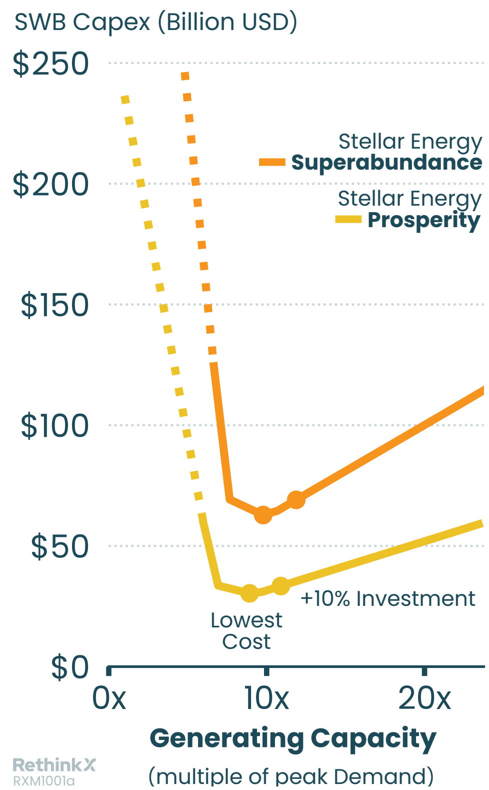
Solar: 100 GW
Wind: 4 GW
Batteries: 303 GWh
(32 average demand hours)

Accra, Ghana's path to *Stellar Energy*

Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

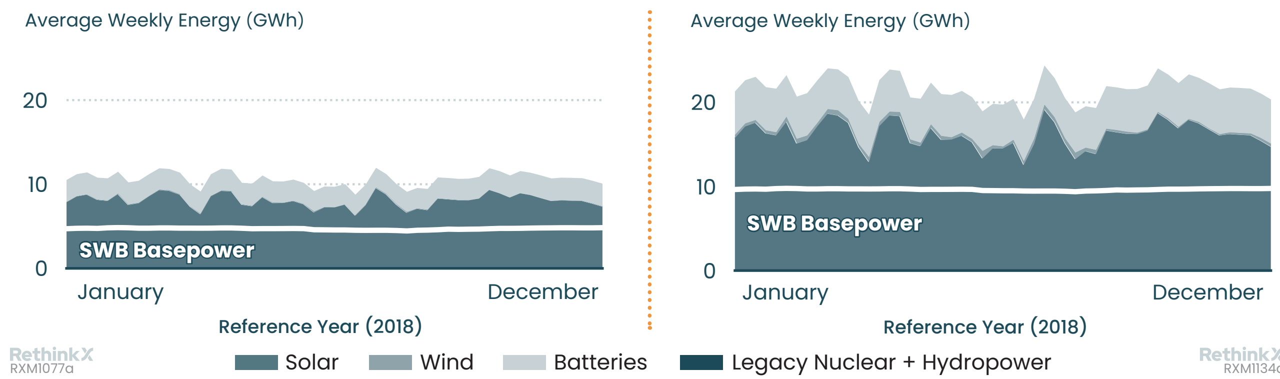
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



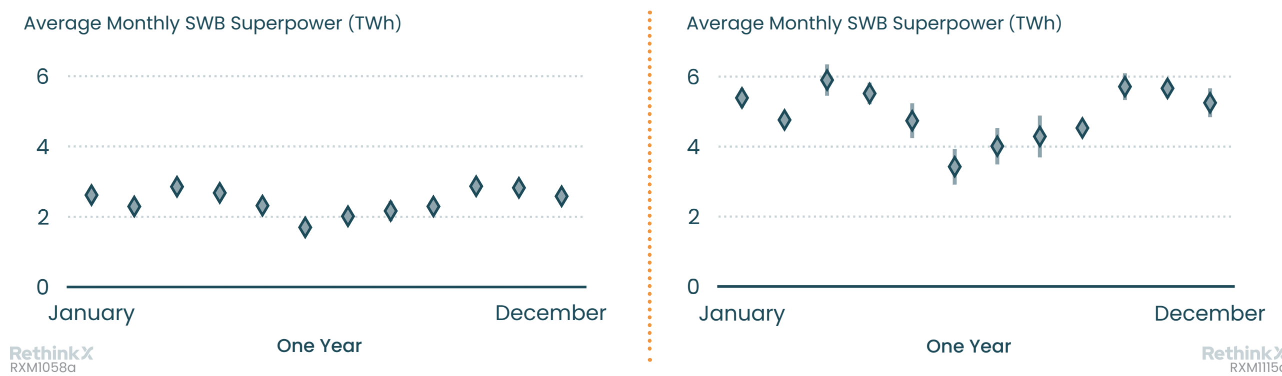
Learn more about this modelling go to https://go.rethinkx.com/H8JV

Accra

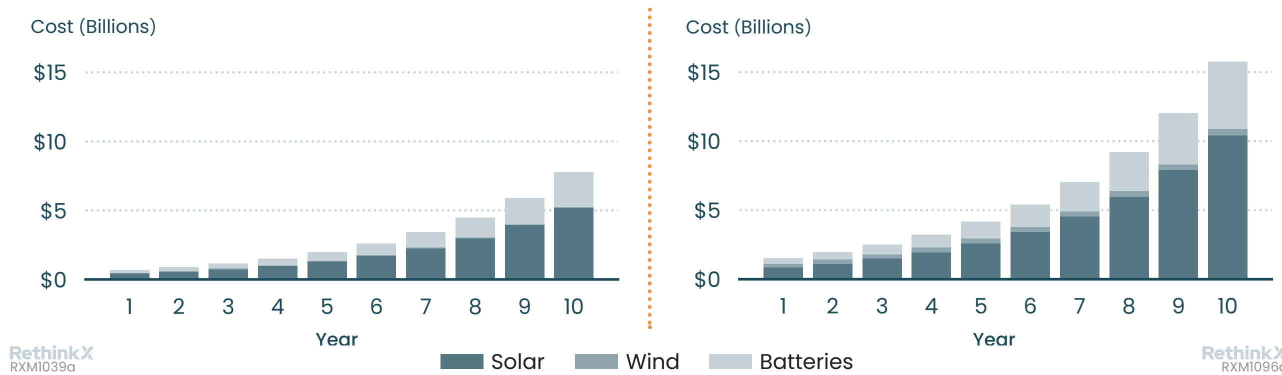
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



India's path to *Stellar* Energy

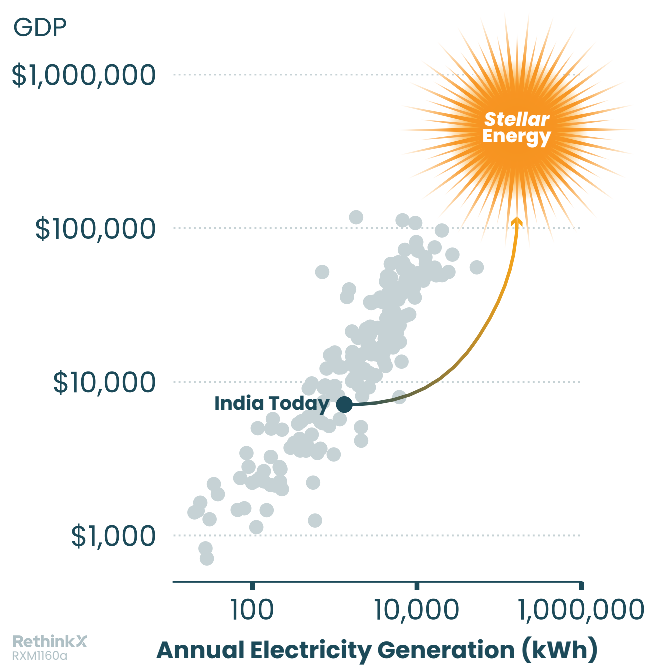
Population in 2040: **1,622,580,039**

Key Insights:

- India generates roughly 18-34 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- India produces about two-thirds as much SWB Superpower as SWB Basepower in each of our scenarios as a result of its steady solar availability all year long.
- SWB Superpower is available in India throughout the year, with a seasonal pattern of decreased solar availability corresponding to the monsoon season.
- Solar plays a dominant role in India's SWB mix.
- Battery capacity of just 17-18 average demand hours is required for the country as a whole, given the overall consistency of solar availability year-round that emerges when summed across India's very large geographic area.

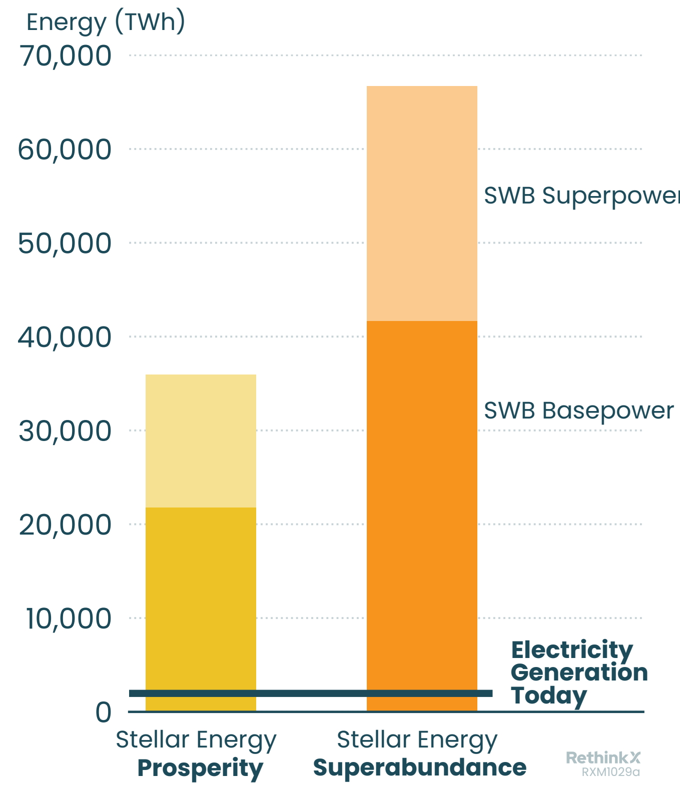
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - India

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita: $388 per year over 20 years
SWB Base power: 21,795 TWh
SWB Superpower: 14,150 TWh

Solar: 22 TW
Wind: 1 TW
Batteries: 42 TWh
(17 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita: $730 per year over 20 years
SWB Base power: 41,695 TWh
SWB Superpower: 25,003 TWh

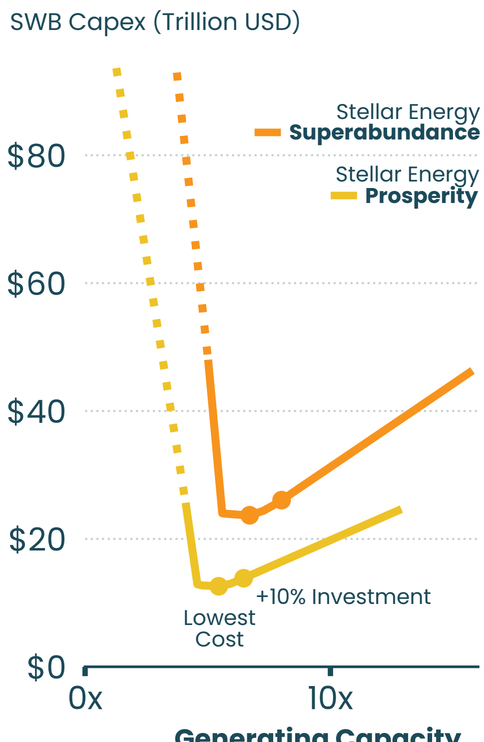
Solar: 41 TW
Wind: 2 TW
Batteries: 84 TWh
(18 average demand hours)

India's path to **Stellar Energy**

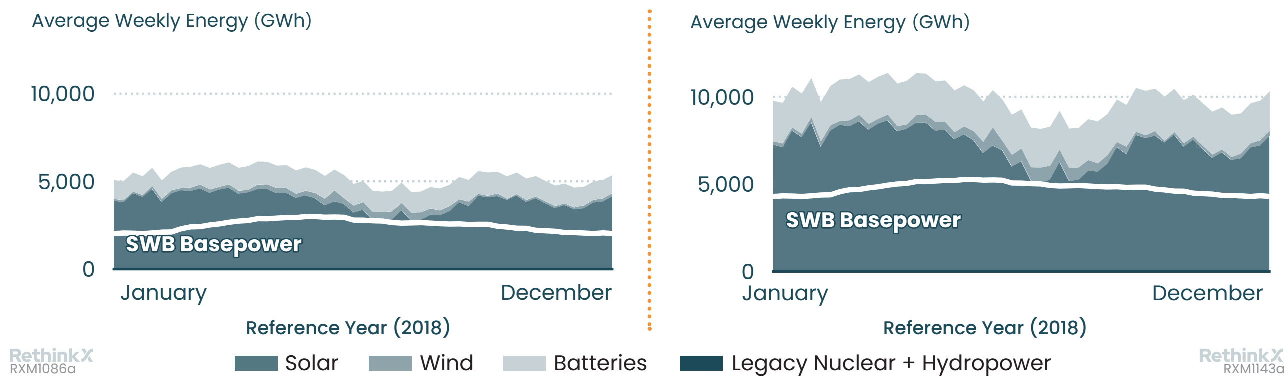
Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

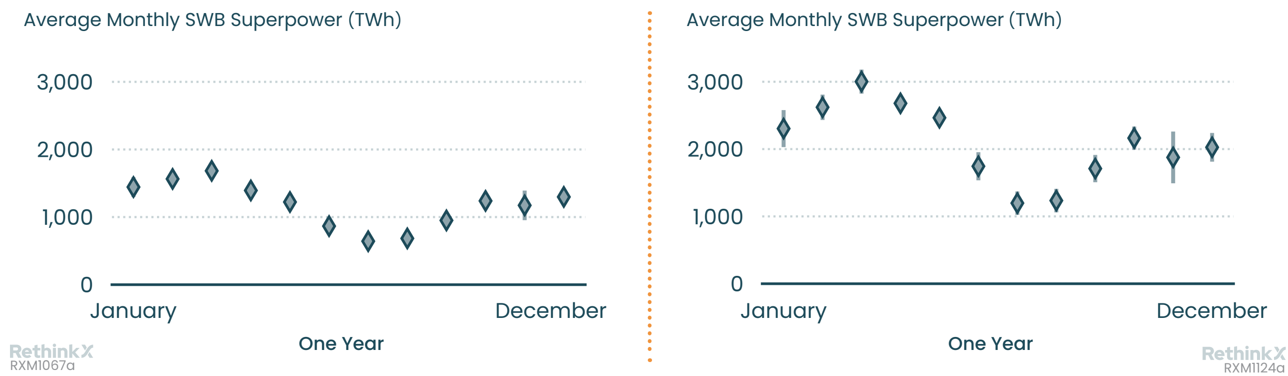
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



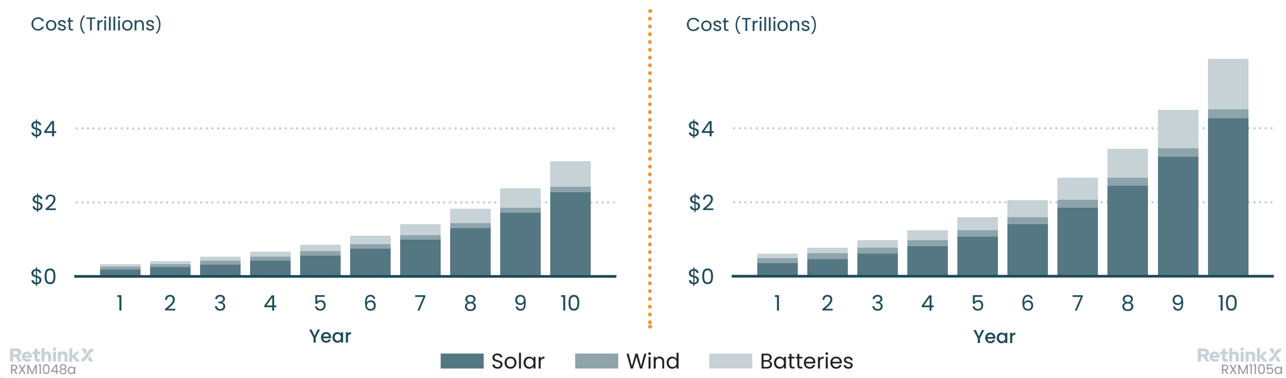
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Learn more about this modelling go to https://go.rethinkx.com/J6DU

India

Mumbai, India's path to *Stellar* Energy

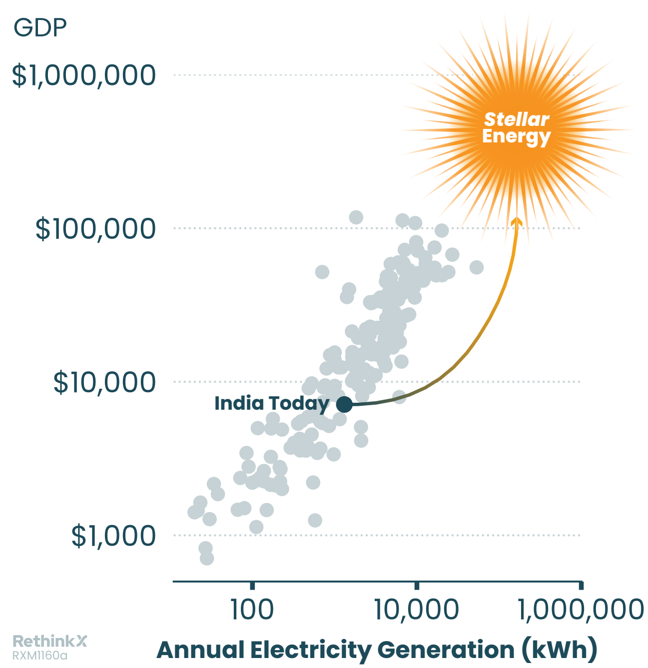
Population in 2040: **16,730,614**

Key Insights:

- Mumbai generates roughly 14-30 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Mumbai produces slightly less SWB Superpower than SWB Basepower in each of our scenarios as a result of its steady solar availability all year long.
- SWB Superpower is consistently available in Mumbai throughout the year, with a seasonal pattern of moderately decreased solar availability corresponding to the summer rainy season.
- Solar plays a dominant role in Mumbai's SWB mix, with wind power providing an excellent complement during the monsoon season.
- Battery capacity of just 34-35 average demand hours is required for Mumbai.

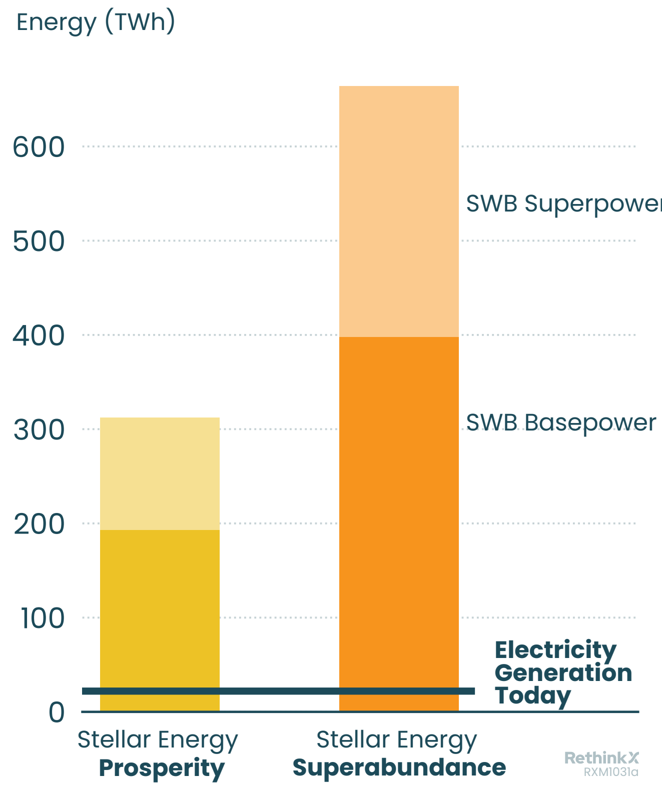
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Mumbai, India

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$462 per year over 20 years
SWB Base power: 193 TWh
SWB Superpower: 119 TWh

Solar: 161 GW
Wind: 41 GW
Batteries: 774 GWh
(35 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$953 per year over 20 years
SWB Base power: 398 TWh
SWB Superpower: 266 TWh

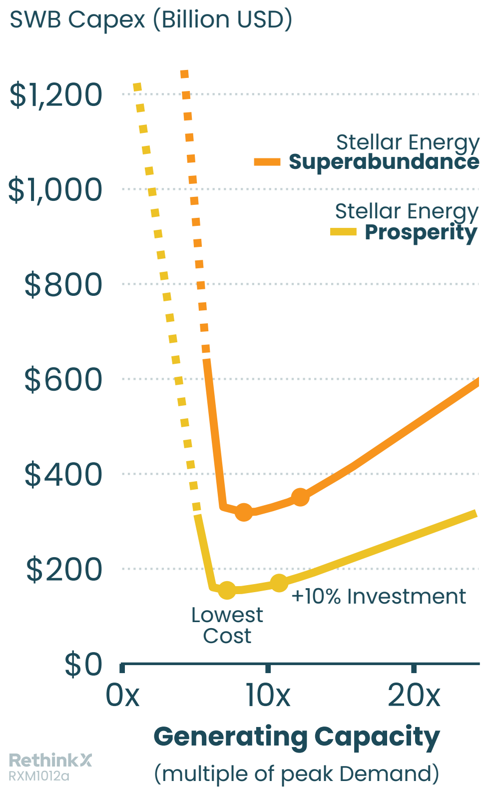
Solar: 350 GW
Wind: 79 GW
Batteries: 1,561 GWh
(34 average demand hours)

Mumbai, India's path to *Stellar* Energy

Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

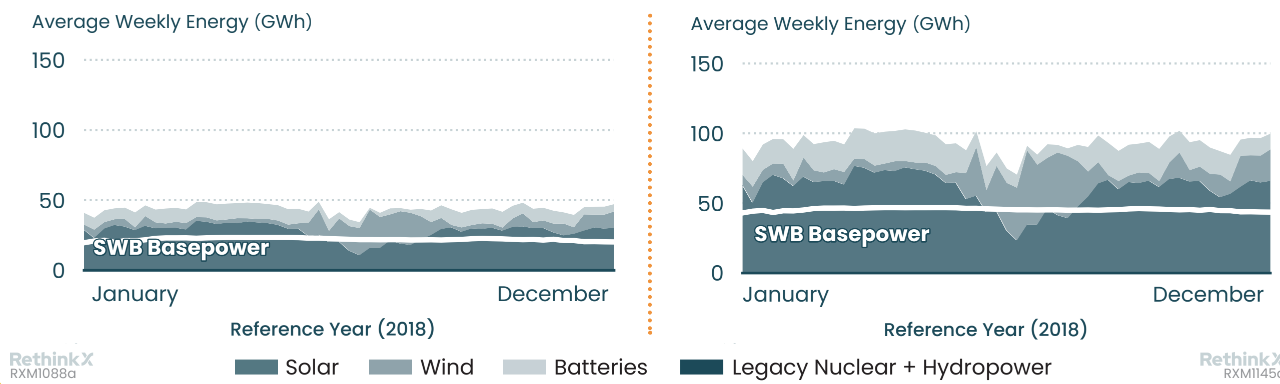
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



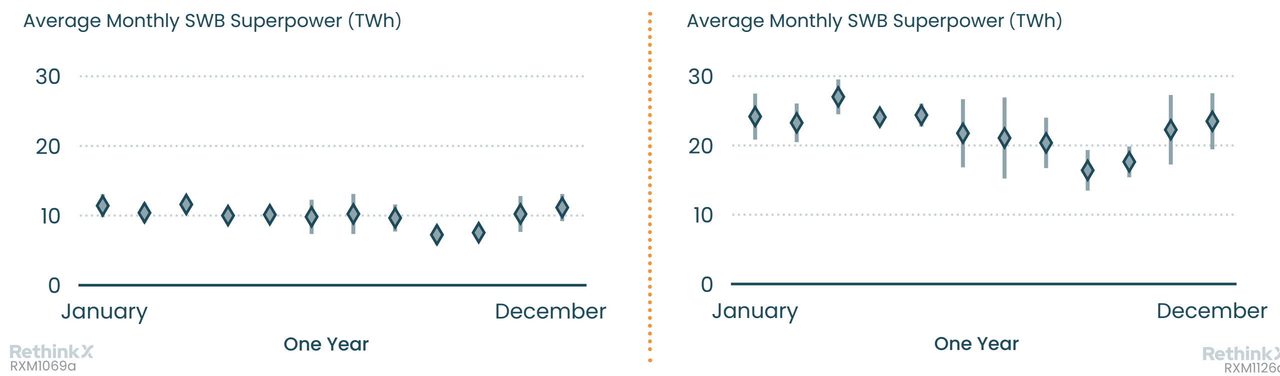
Learn more about this modelling go to https://go.rethinkx.com/H4DA

Mumbai

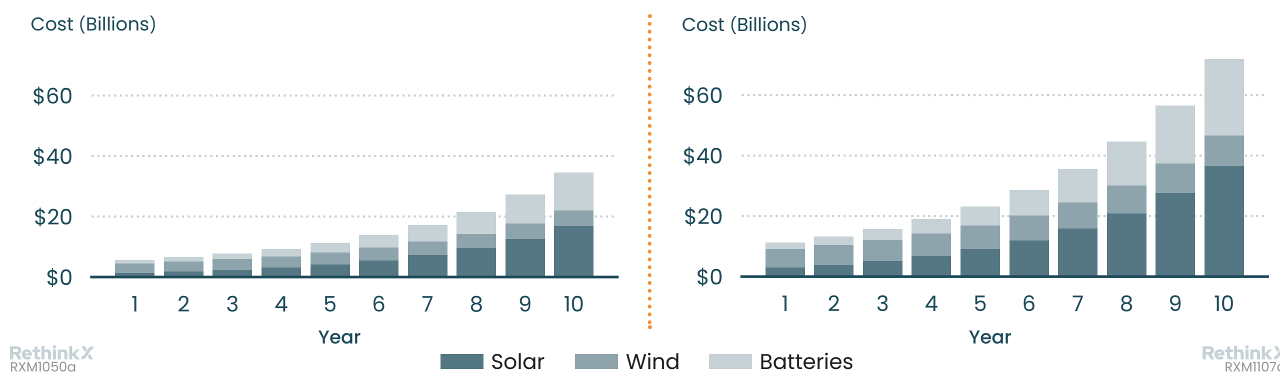
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Indonesia's path to *Stellar* Energy

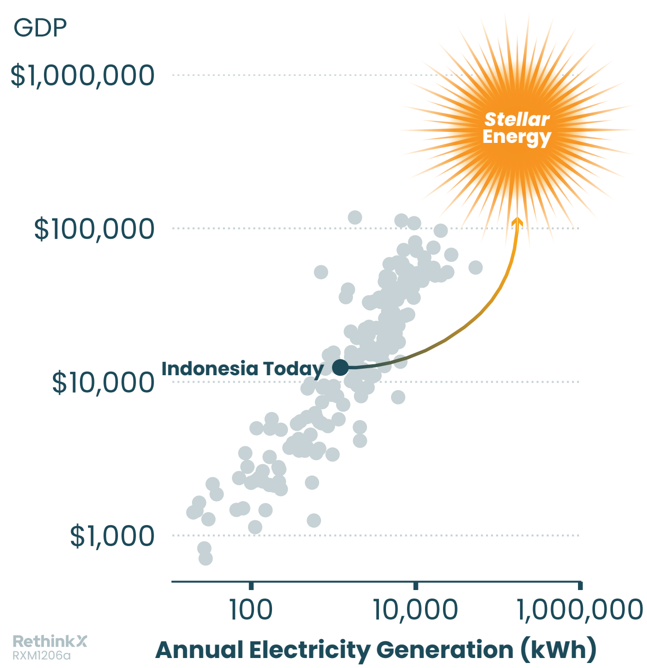
Population in 2040: **311,797,396**

Key Insights:

- Indonesia generates 18-36 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Indonesia produces about half as much SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is available in Indonesia throughout the year, with a seasonal pattern of moderately decreased solar availability corresponding to the summer rainy season.
- Solar plays the dominant role in Indonesia's SWB mix.
- Only 23 average demand hours of battery capacity is required for Indonesia.

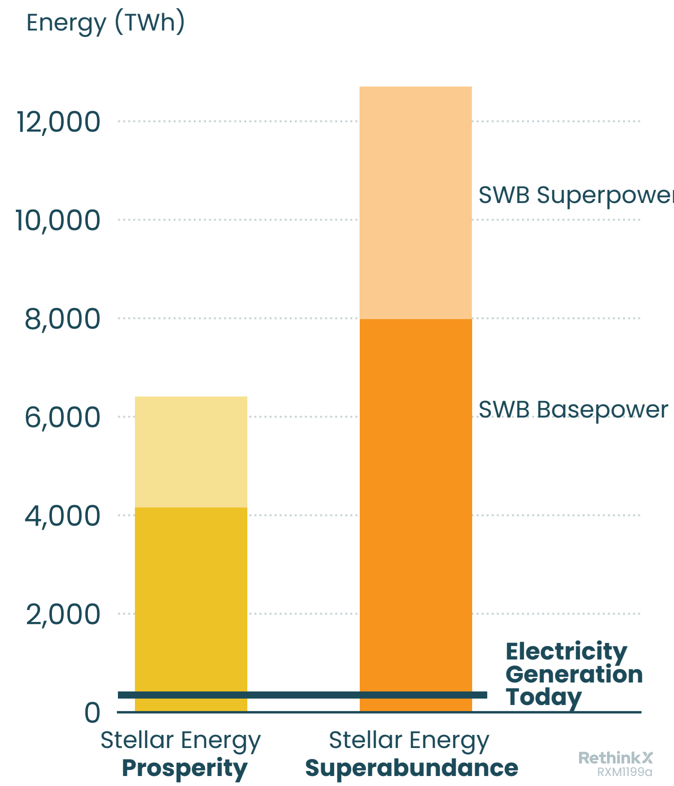
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Indonesia

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita: $399 per year over 20 years
SWB Base power: 4,159 TWh
SWB Superpower: 2,244 TWh

Solar: 4,468 GW
Wind: 7 GW
Batteries: 11 TWh
(23 average demand hours)

Stellar Energy Superabundance Scenario

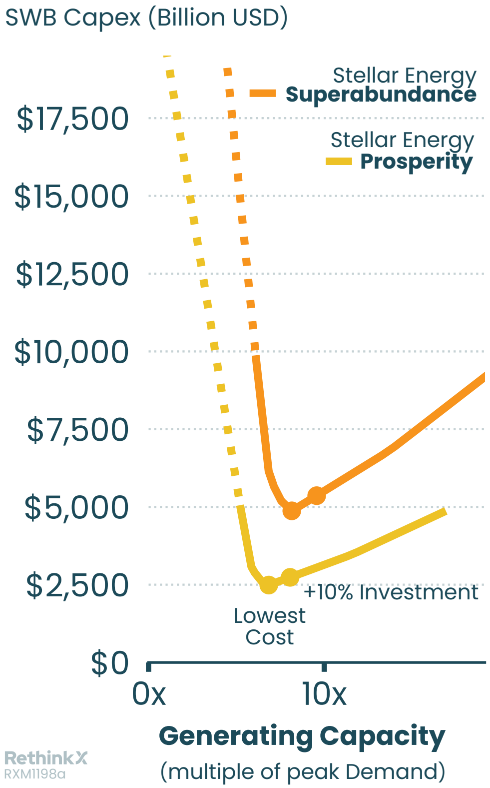
Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita: $782 per year over 20 years
SWB Base power: 7,983 TWh
SWB Superpower: 4,722 TWh

Solar: 8,889 GW
Wind: 0.47 GW
Batteries: 21 TWh
(23 average demand hours)

Clean Energy U-Curve

Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

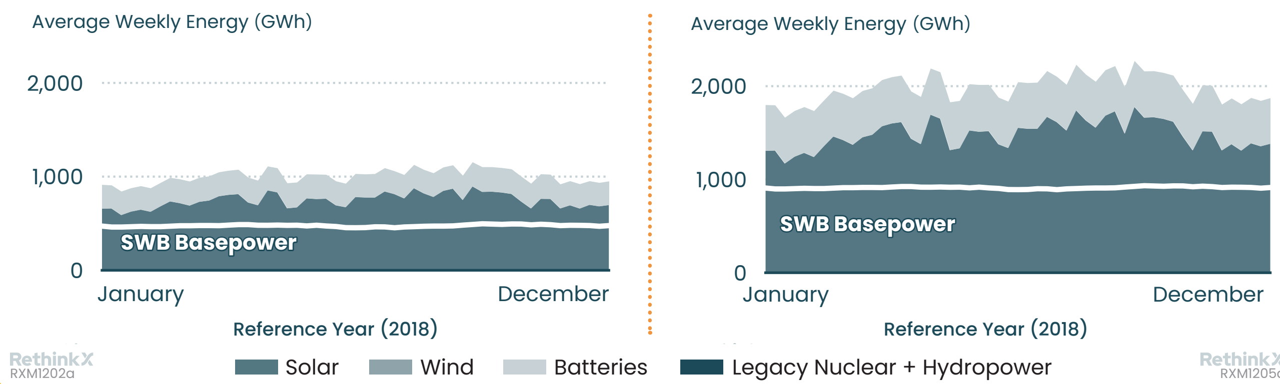


Learn more about this modelling go to https://go.rethinkx.com/F0FP

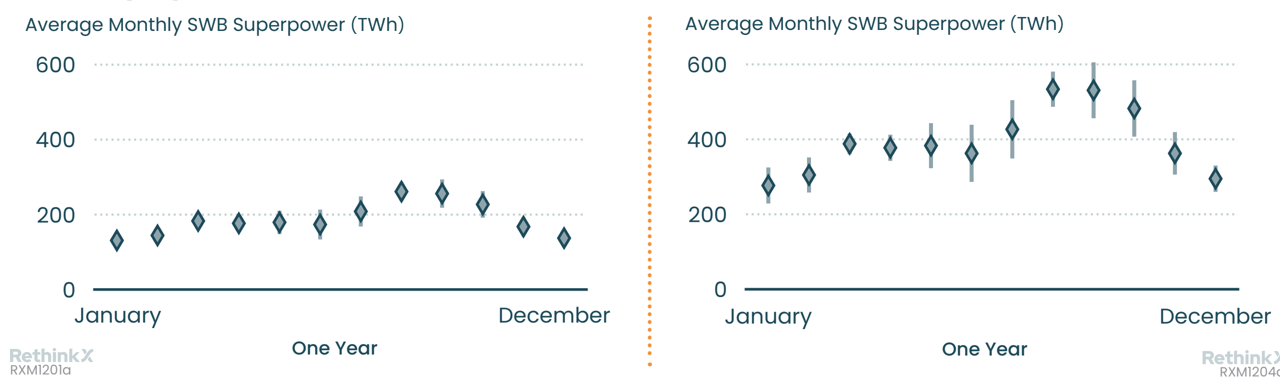
Indonesia

Stellar Energy Prosperity | Stellar Energy Superabundance

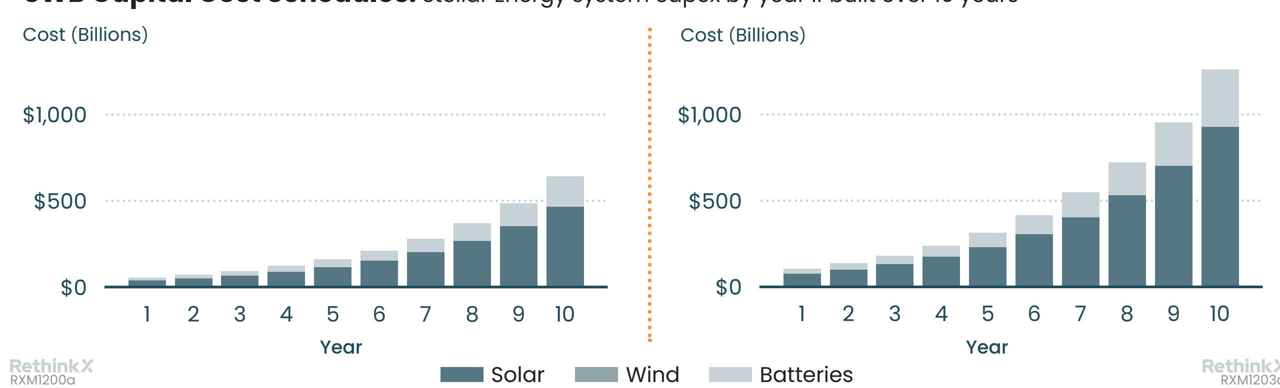
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Mexico's path to *Stellar* Energy

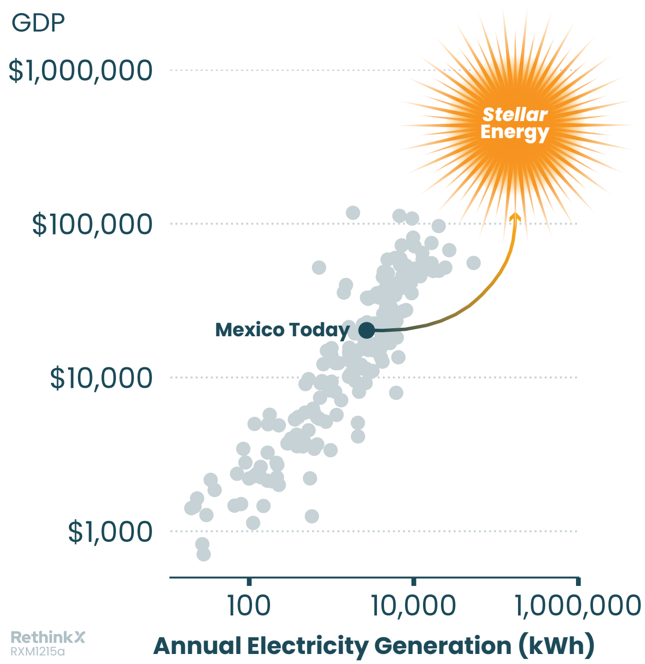
Population in 2040: **144,624,324**

Key Insights:

- Mexico generates 7-15 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Mexico produces about two-thirds as much SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is consistently available in Mexico throughout the year, with an increase in the spring associated with somewhat greater seasonal wind abundance and clear skies before the rainy season.
- Solar plays a predominant role in Mexico's SWB mix.
- Just 22-24 average demand hours of battery capacity is required, which reflects the consistency of Mexico's abundant solar resources.

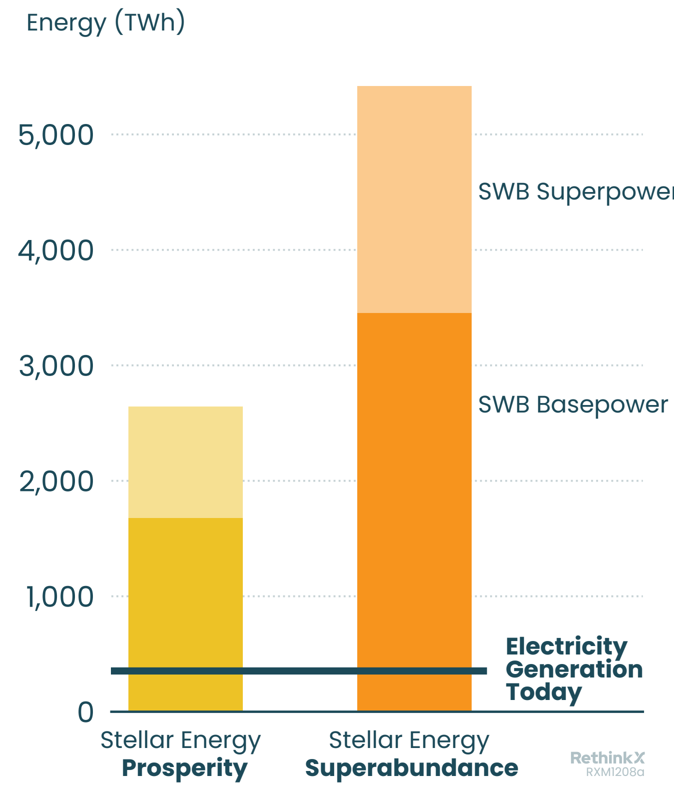
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Mexico

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$348 per year over 20 years
SWB Base power: 1,682 TWh
SWB Superpower: 962 TWh

Solar: 1,469 GW
Wind: 130 GW
Batteries: 4,513 GWh
(24 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

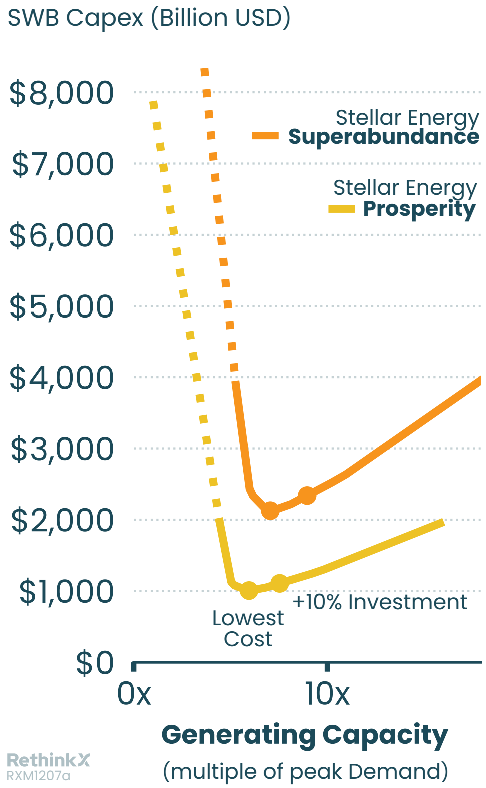
SWB Capex per capita:
$735 per year over 20 years
SWB Base power: 3,455 TWh
SWB Superpower: 1,964 TWh

Solar: 2,941 GW
Wind: 381 GW
Batteries: 8,827 GWh
(22 average demand hours)

Stellar Energy Prosperity / Stellar Energy Superabundance

Clean Energy U-Curve

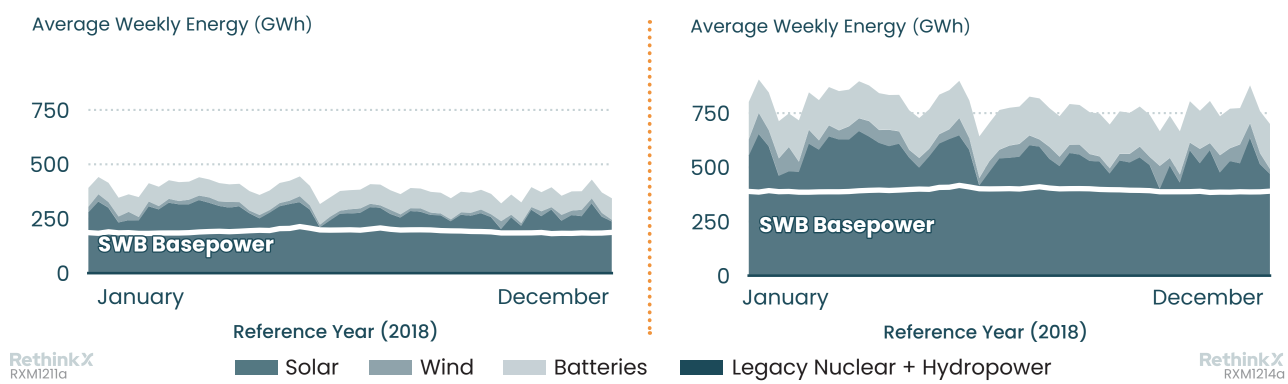
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



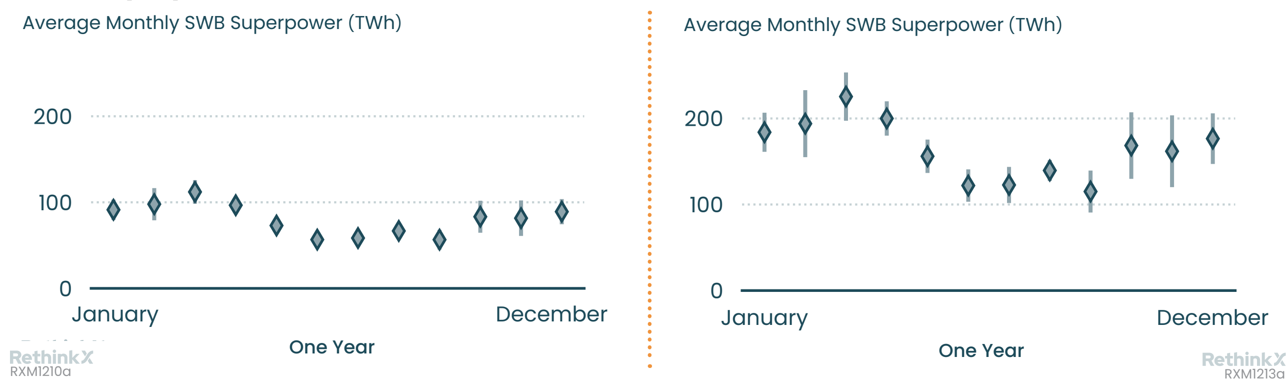
Learn more about this modelling go to https://go.rethinkx.com/W6CT

Mexico

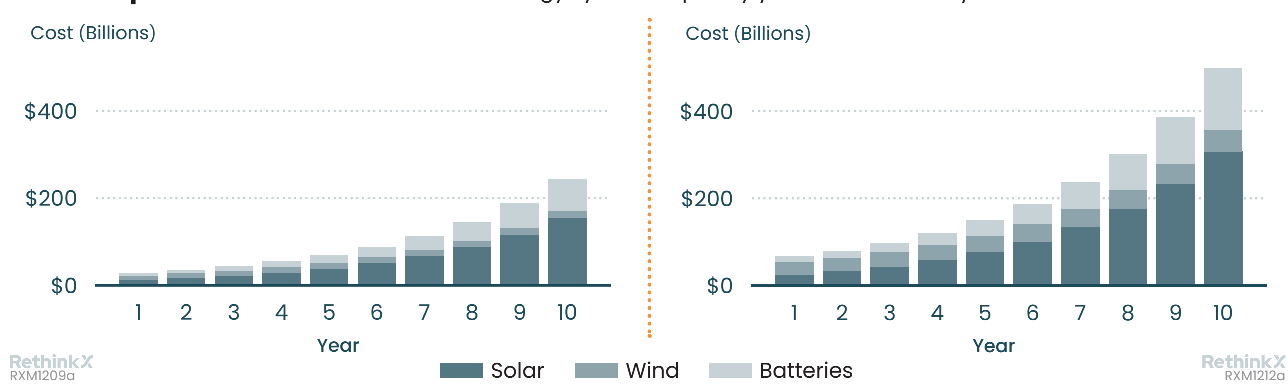
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



New Zealand's path to *Stellar* Energy

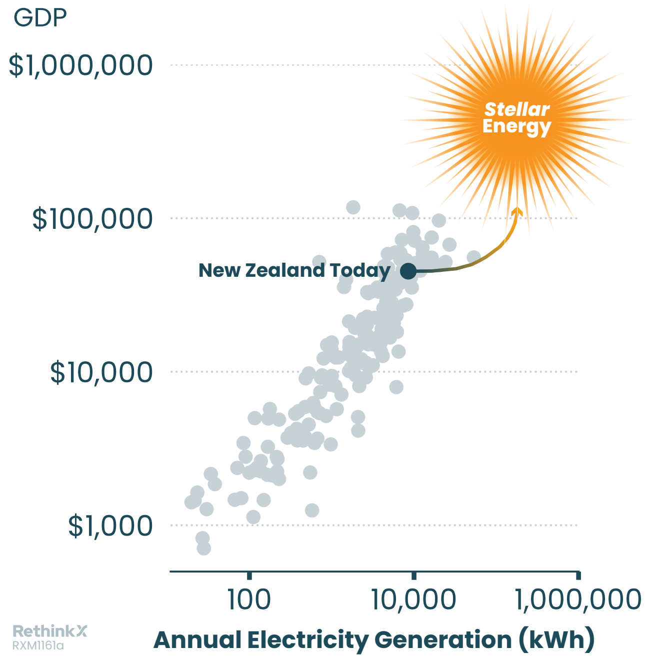
Population in 2040: **5,617,291**

Key Insights:

- New Zealand generates 2-5 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- New Zealand produces a third less SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is available in New Zealand throughout the year, with a seasonal pattern due to greater solar abundance in the summer months.
- Solar plays the dominant role in New Zealand's SWB mix.
- Battery capacity of roughly 28-34 average demand hours is required for New Zealand.

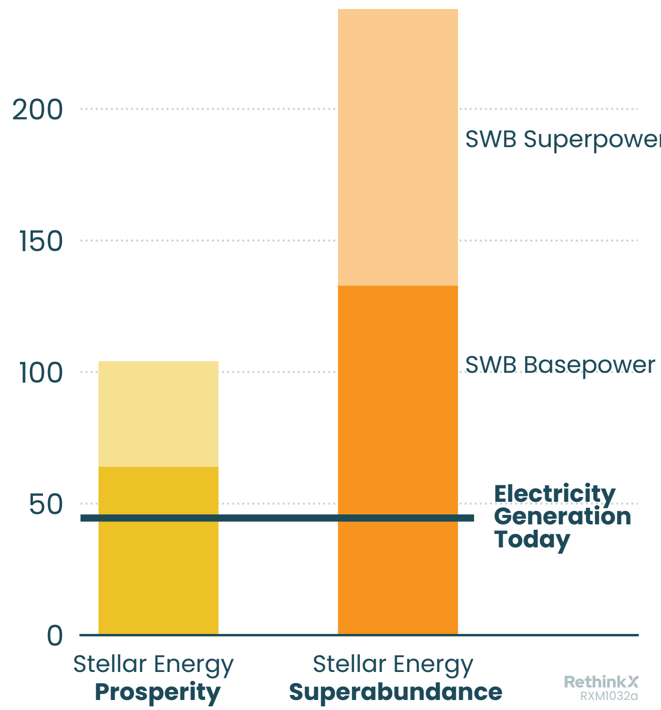
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy – New Zealand

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$308 per year over 20 years
SWB Base power: 64 TWh
SWB Superpower: 40 TWh

Solar: 35 GW
Wind: 8 GW
Batteries: 201 GWh
(28 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$821 per year over 20 years
SWB Base power: 133 TWh
SWB Superpower: 105 TWh

Solar: 92 GW
Wind: 23 GW
Batteries: 509 GWh
(34 average demand hours)

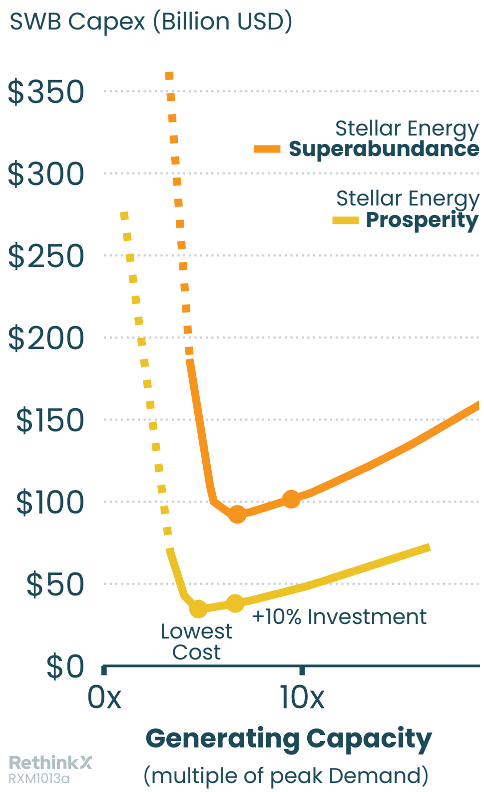
New Zealand's path to ***Stellar Energy***

Stellar Energy Prosperity

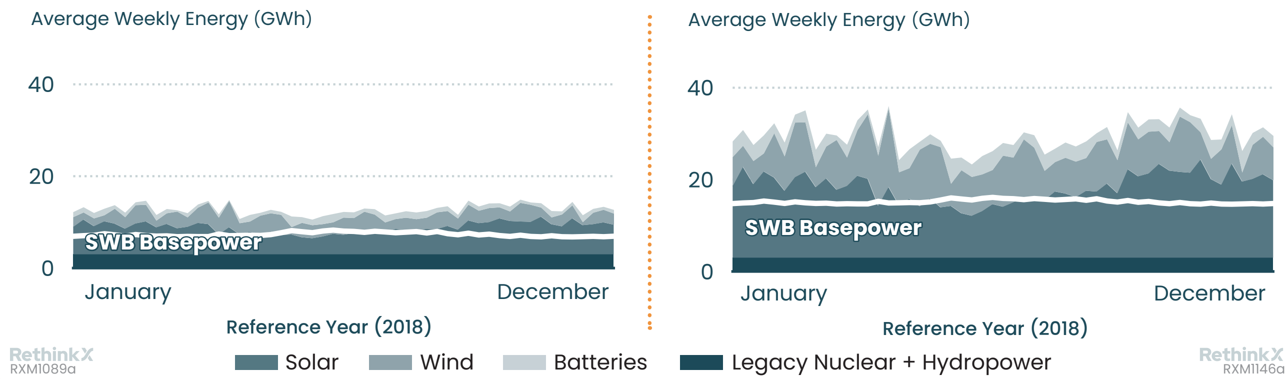
Stellar Energy Superabundance

Clean Energy U-Curve

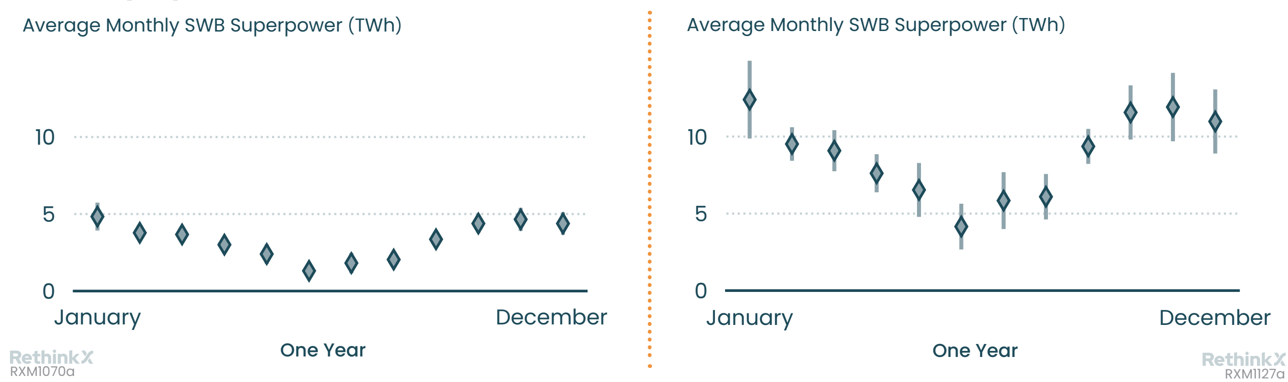
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



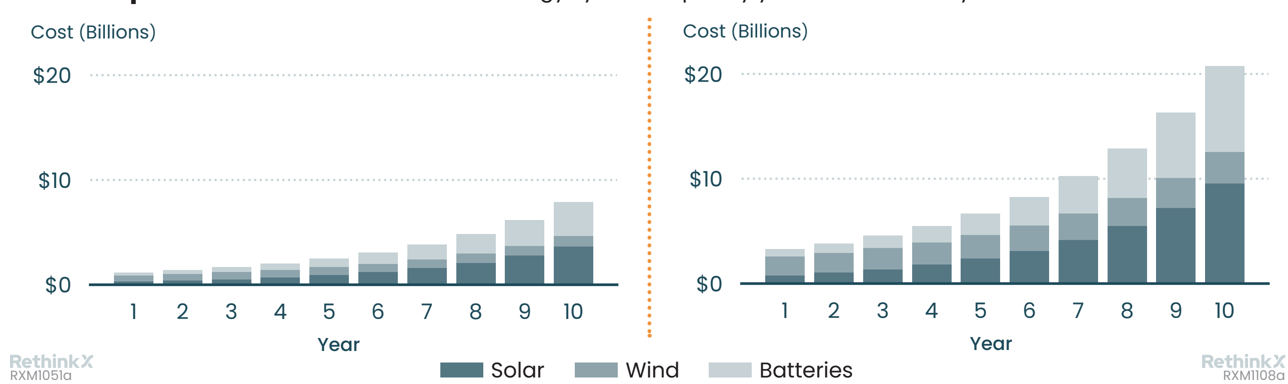
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Learn more about this modelling go to https://go.rethinkx.com/Y7YF

New Zealand

Saudi Arabia's path to *Stellar* Energy

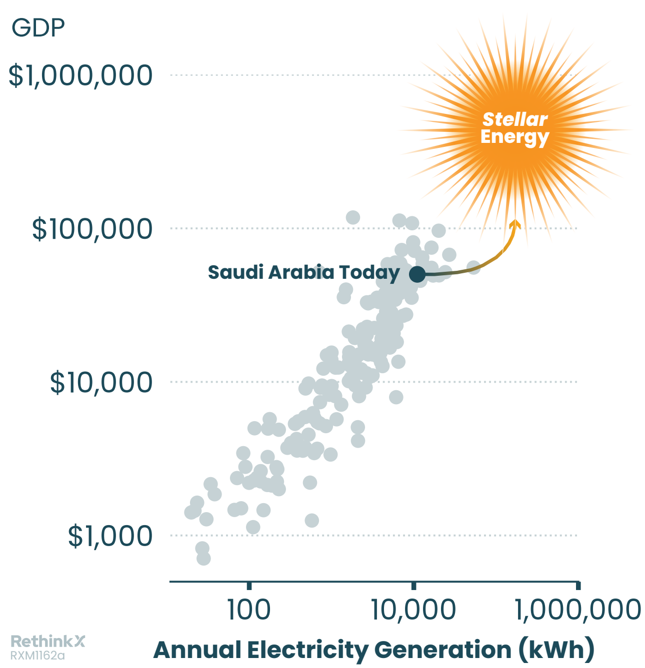
Population in 2040: **42,592,201**

Key Insights:

- Saudi Arabia generates 2-4 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Saudi Arabia produces half as much SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is available in Saudi Arabia throughout the year, but shows a seasonal pattern of higher availability during spring resulting from very large summer cooling requirements.
- Solar plays a dominant role in Saudi Arabia's future energy mix.
- Just 17-24 average demand hours of battery capacity is required, which reflects the consistency of Saudi Arabia's abundant solar resources.

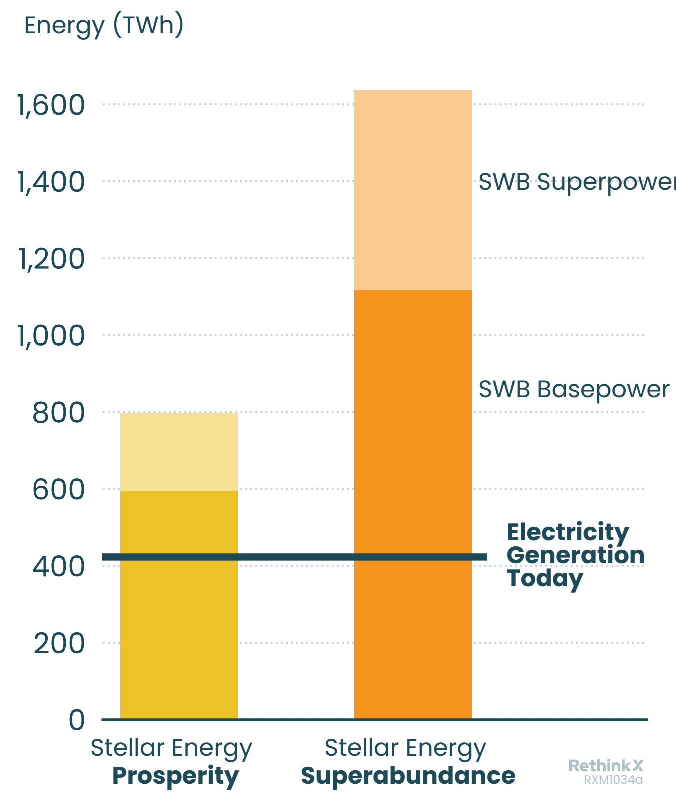
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Saudi Arabia

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$338 per year over 20 years
SWB Base power: 595 TWh
SWB Superpower: 202 TWh

Solar: 444 GW
Wind: 6 GW
Batteries: 1,641 GWh
(24 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

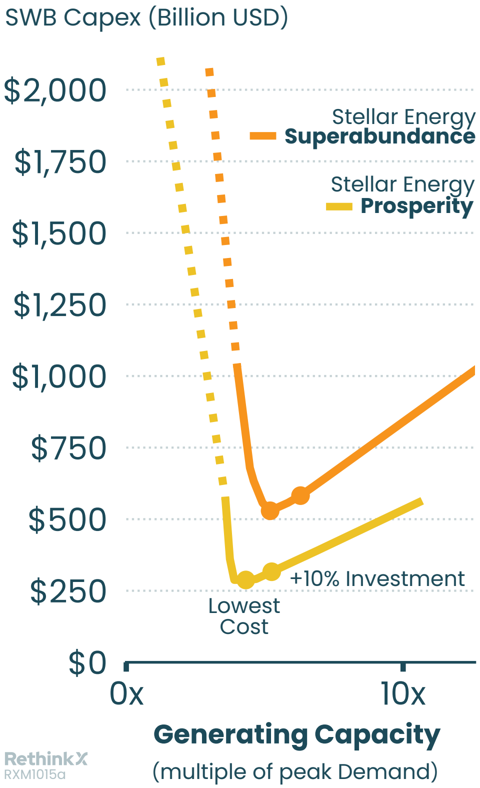
SWB Capex per capita:
$621 per year over 20 years
SWB Base power: 1,118 TWh
SWB Superpower: 520 TWh

Solar: 865 GW
Wind: 45 GW
Batteries: 2,157 GWh
(17 average demand hours)

Saudi Arabia's path to *Stellar* Energy

Clean Energy U-Curve

Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

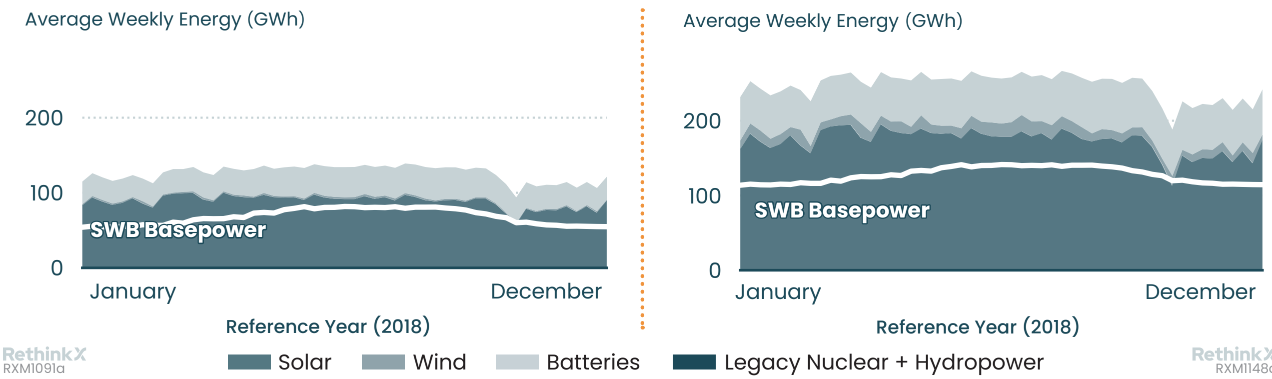


Learn more about this modelling go to https://go.rethinkx.com/C5TR

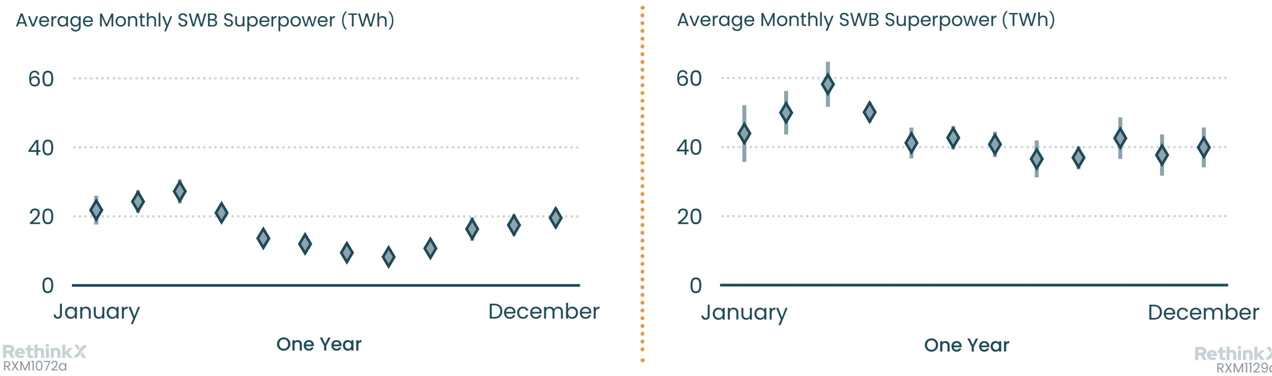
Saudi Arabia

Stellar Energy Prosperity | Stellar Energy Superabundance

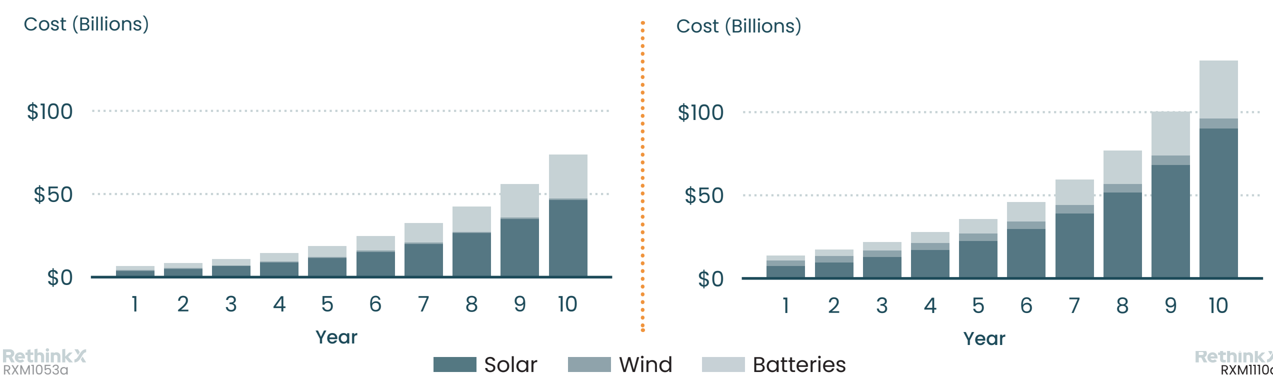
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



South Africa's path to *Stellar* Energy

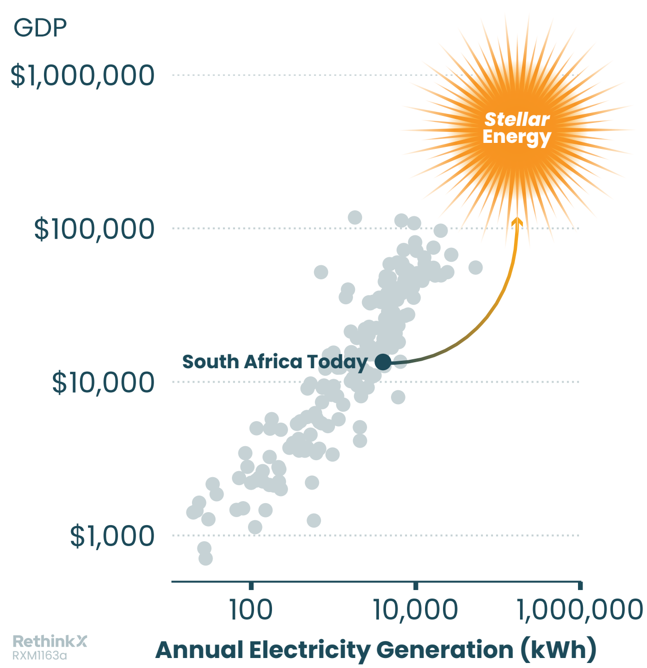
Population in 2040: **74,035,624**

Key Insights:

- South Africa generates 5-11 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- South Africa produces about half as much SWB Superpower as SWB Basepower in each of our scenarios.
- SWB Superpower is available in South Africa throughout the year, with a consistent seasonal pattern that peaks in September-October.
- Solar plays a dominant role in South Africa's SWB mix.
- Battery capacity of just 19-20 average demand hours is required for South Africa, which reflects the consistency of its solar and wind resources year-round.

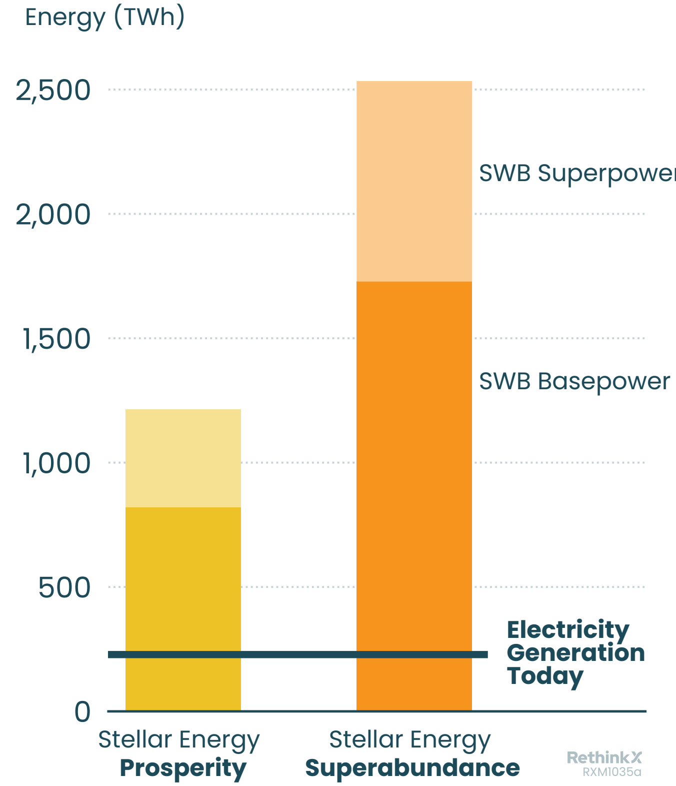
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - South Africa

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$292 per year over 20 years
SWB Base power: 820 TWh
SWB Superpower: 393 TWh

Solar: 572 GW
Wind: 90 GW
Batteries: 1,752 GWh
(19 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

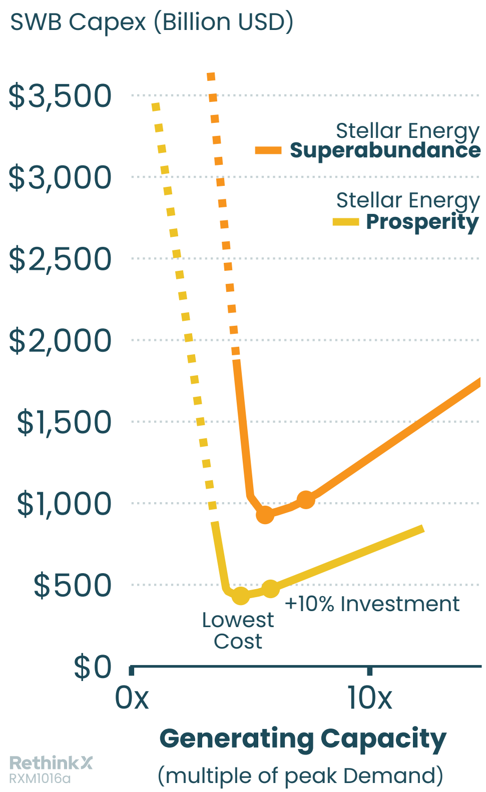
SWB Capex per capita:
$627 per year over 20 years
SWB Base power: 1,728 TWh
SWB Superpower: 806 TWh

Solar: 1,204 GW
Wind: 187 GW
Batteries: 4,025 GWh
(20 average demand hours)

South Africa's path to *Stellar Energy*

Clean Energy U-Curve

Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

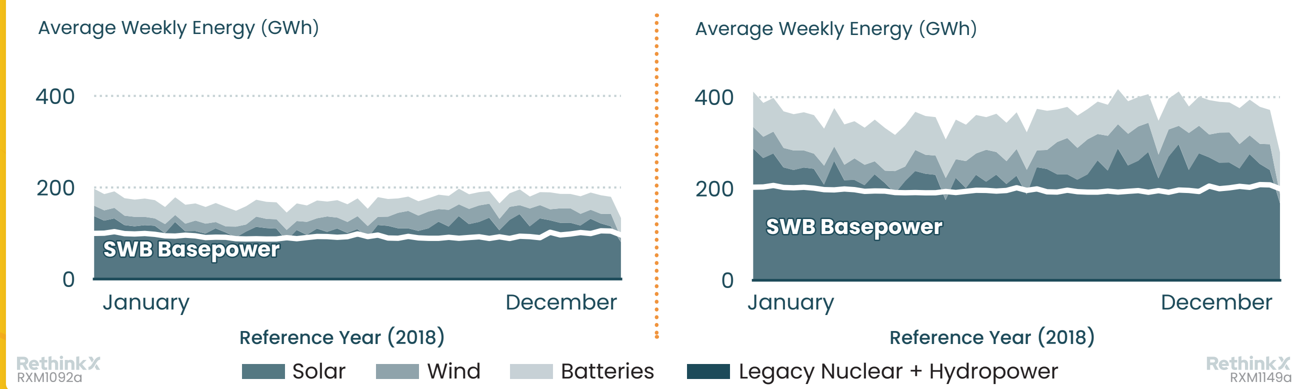


Learn more about this modelling go to https://go.rethinkx.com/O7NL

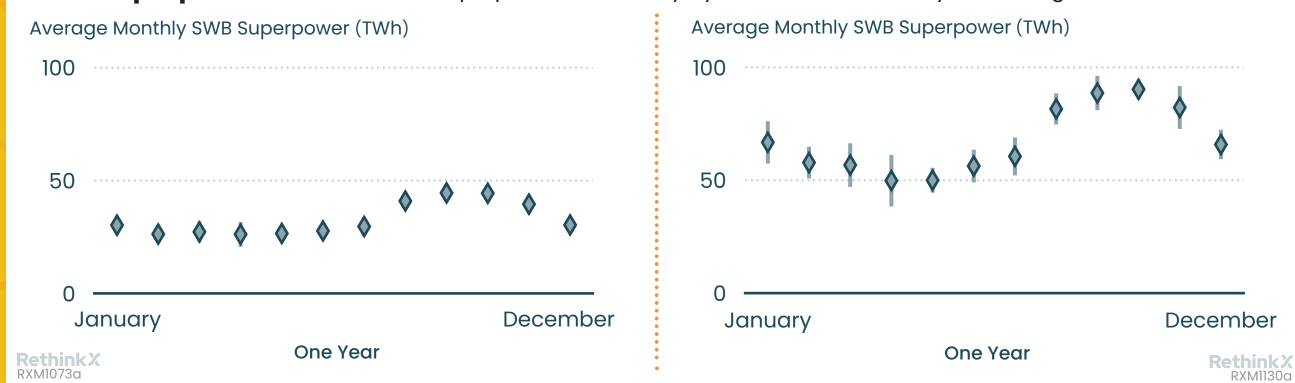
South Africa

Stellar Energy Prosperity | Stellar Energy Superabundance

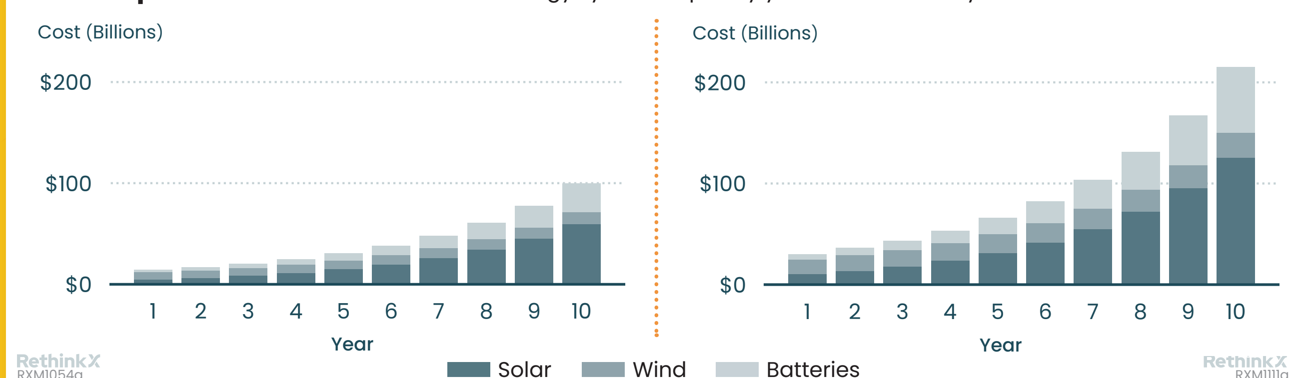
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Sweden's path to *Stellar* Energy

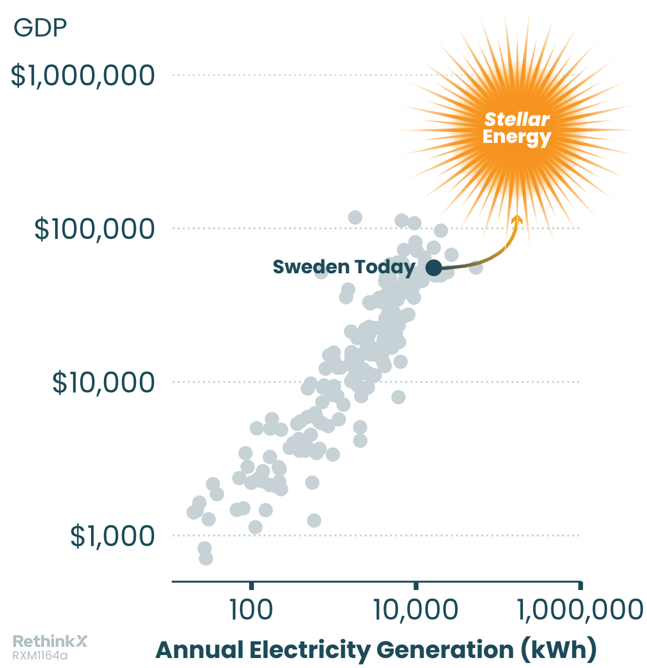
Population in 2040: **11,078,602**

Key Insights:

- Sweden generates 3 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Sweden produces about the same amount of SWB Superpower than SWB Basepower in each of our scenarios as a result of sizing to peak winter stress at high latitude.
- SWB Superpower is available in Sweden throughout the year, with a seasonal pattern due to greater solar abundance in the summer months.
- Wind plays a dominant role in Sweden's SWB mix, and these are complemented by a large amount of existing nuclear and hydropower capacity.
- Battery capacity of just 58-66 average demand hours is required, despite the country's high latitude, which is reflects the large amount of existing nuclear and hydropower capacity already installed in Sweden.

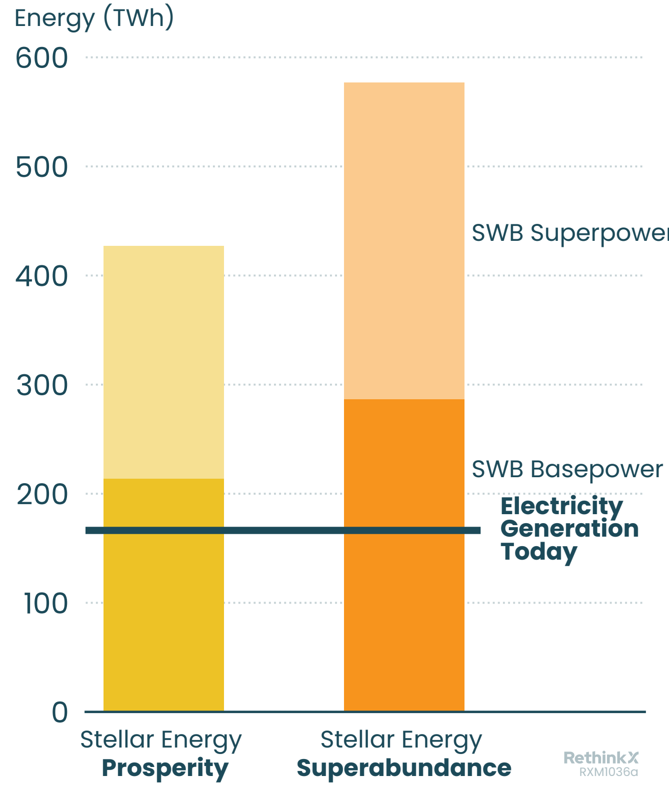
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Sweden

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita: $1196 per year over 20 years
SWB Base power: 214 TWh
SWB Superpower: 213 TWh

Solar: 87 GW
Wind: 139 GW
Batteries: 1,403 GWh (58 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita: $1817 per year over 20 years
SWB Base power: 287 TWh
SWB Superpower: 290 TWh

Solar: 117 GW
Wind: 217 GW
Batteries: 2,150 GWh (66 average demand hours)

Sweden's path to *Stellar Energy*

Clean Energy U-Curve

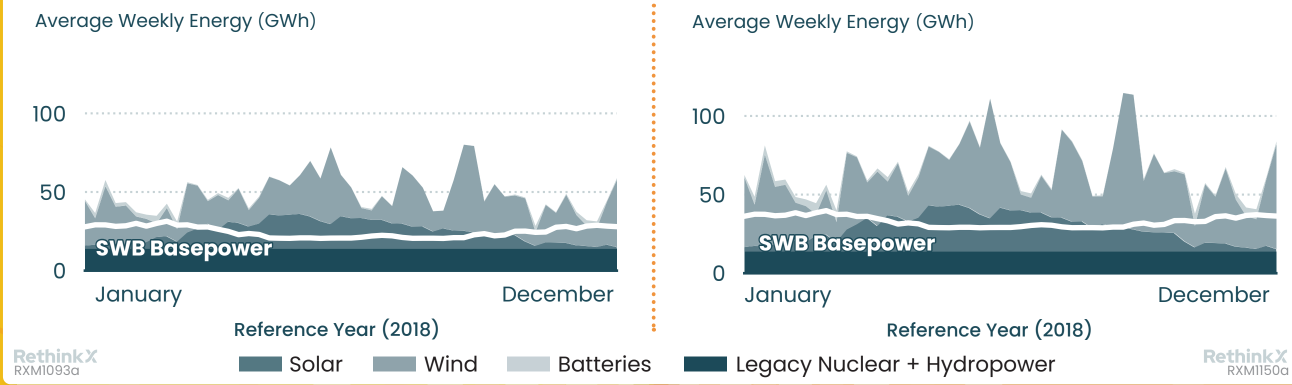
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

Learn more about this modelling go to https://go.rethinkx.com/Y8BH

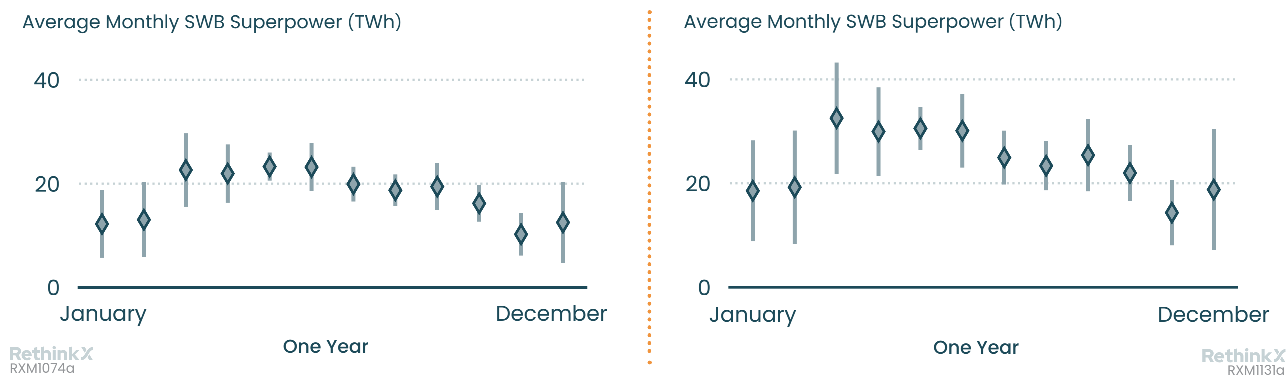
Sweden

Stellar Energy Prosperity | Stellar Energy Superabundance

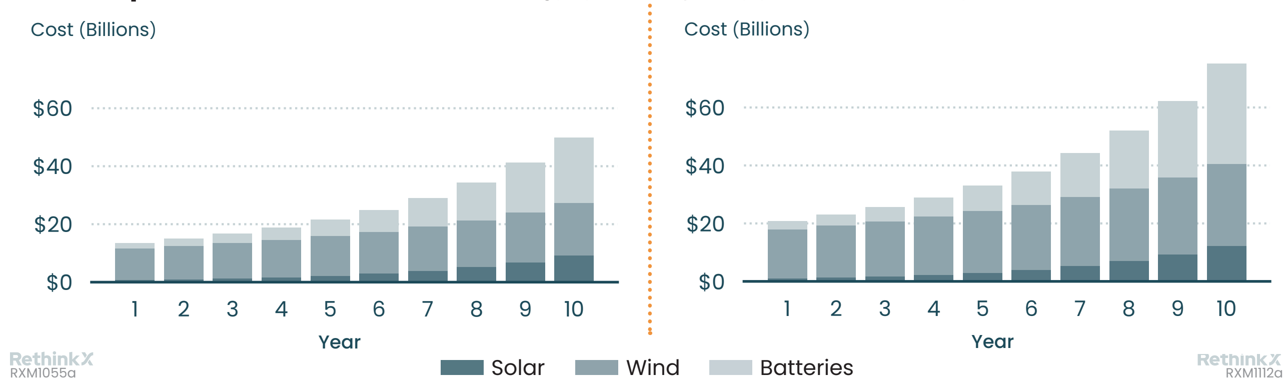
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Ukraine's path to *Stellar* Energy

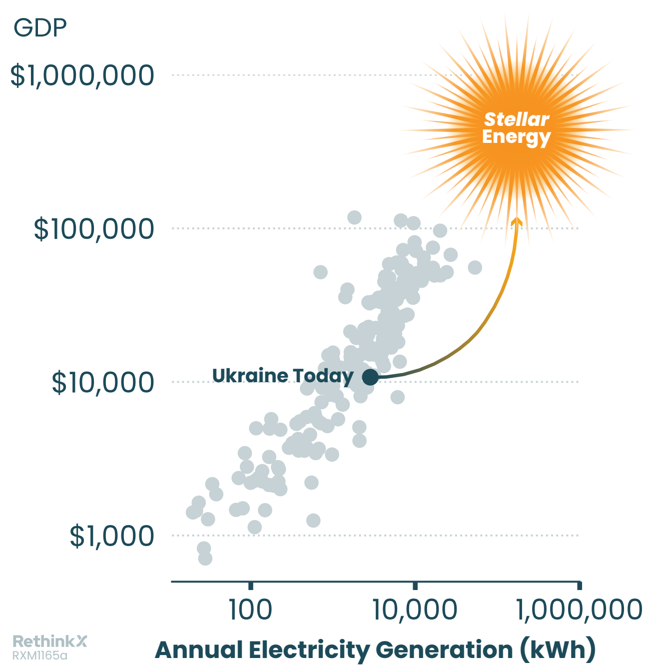
Population in 2040: **35,270,911**

Key Insights:

- Ukraine generates 11-19 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Ukraine produces slightly more SWB Superpower as SWB Basepower in each of our scenarios as a result of sizing to peak winter stress.
- SWB Superpower is available in Ukraine throughout the year, with a seasonal pattern corresponding to abundant wind resources during the spring season.
- Solar and wind play both play an important role in Ukraine's SWB mix.
- Battery capacity of 62-72 average demand hours is required, which suggests Ukraine could realize substantial savings with a modest amount of alternative coverage as per the SWB Coverage Curve.

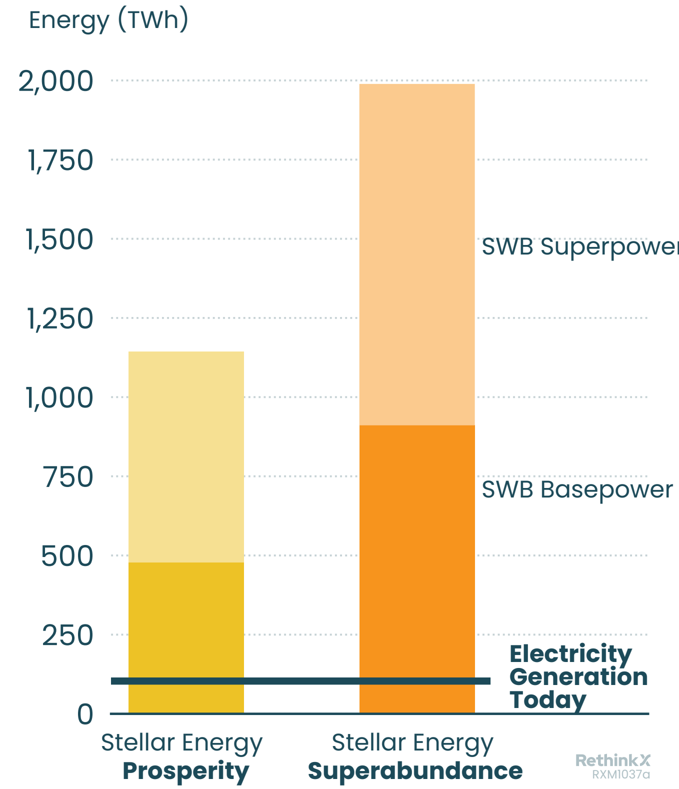
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy - Ukraine

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$917 per year over 20 years
SWB Base power: 478 TWh
SWB Superpower: 666 TWh

Solar: 294 GW
Wind: 278 GW
Batteries: 3,929 GWh
(72 average demand hours)

Stellar Energy Superabundance Scenario

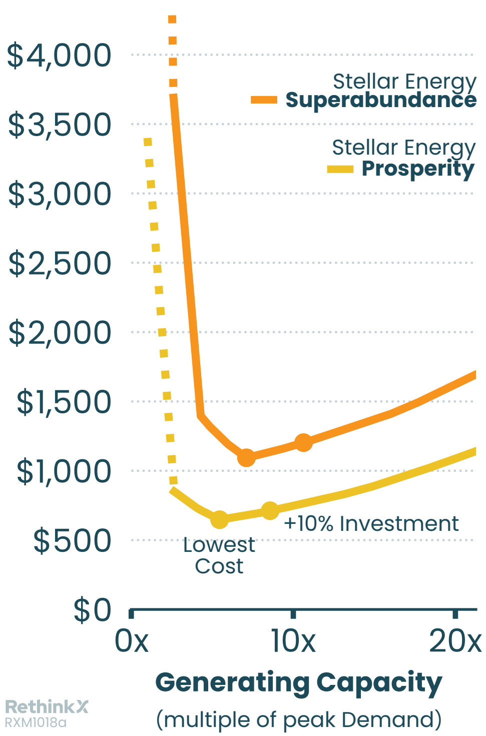
Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$1550 per year over 20 years
SWB Base power: 911 TWh
SWB Superpower: 1,078 TWh

Solar: 694 GW
Wind: 403 GW
Batteries: 6,464 GWh
(62 average demand hours)

Clean Energy U-Curve

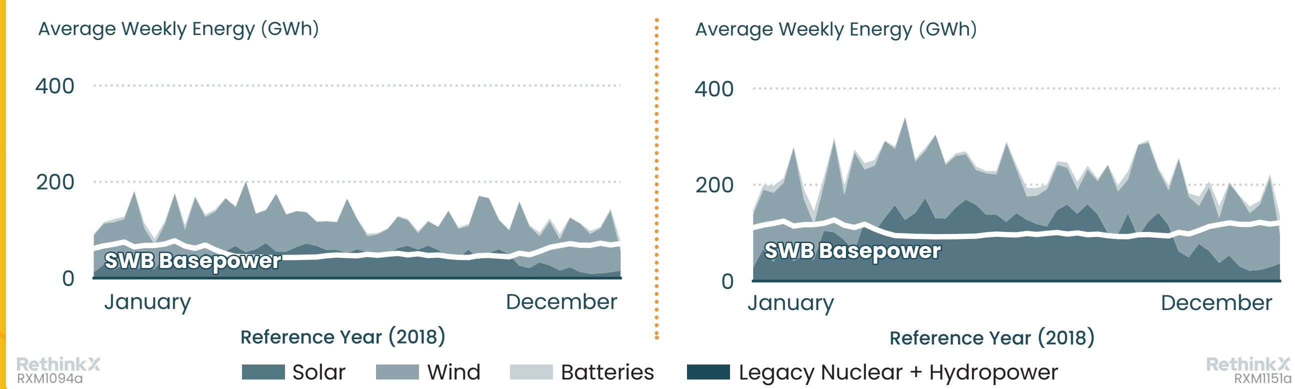
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



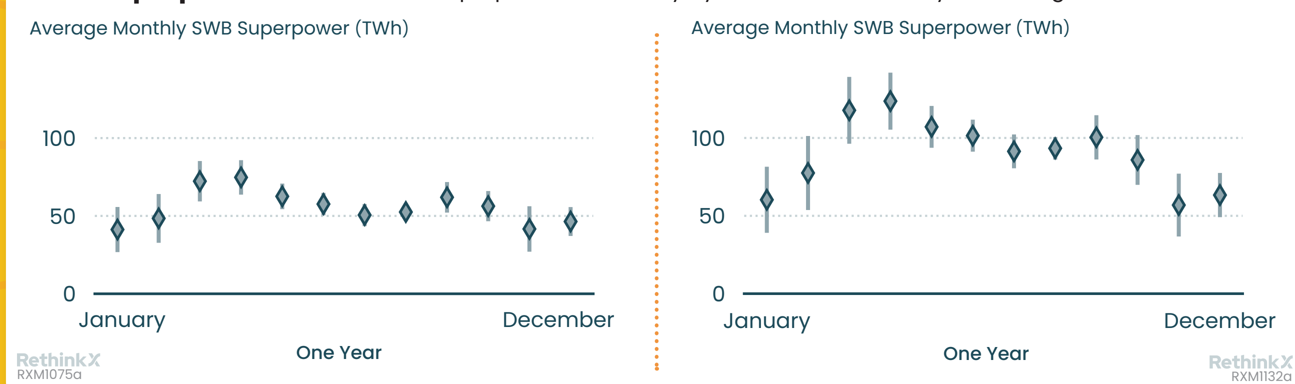
Learn more about this modelling go to https://go.rethinkx.com/L9WG

Stellar Energy Prosperity | Stellar Energy Superabundance

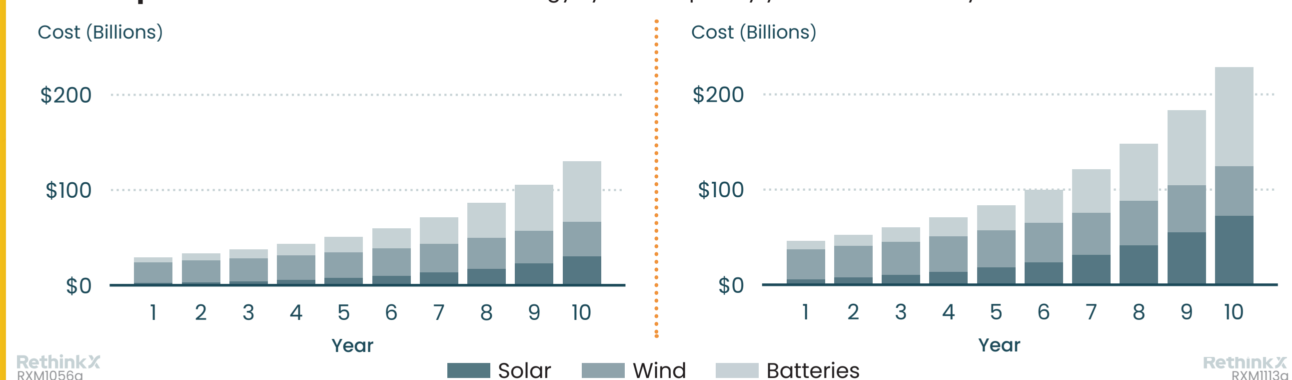
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data

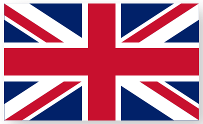


SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years





United Kingdom's path to *Stellar* Energy

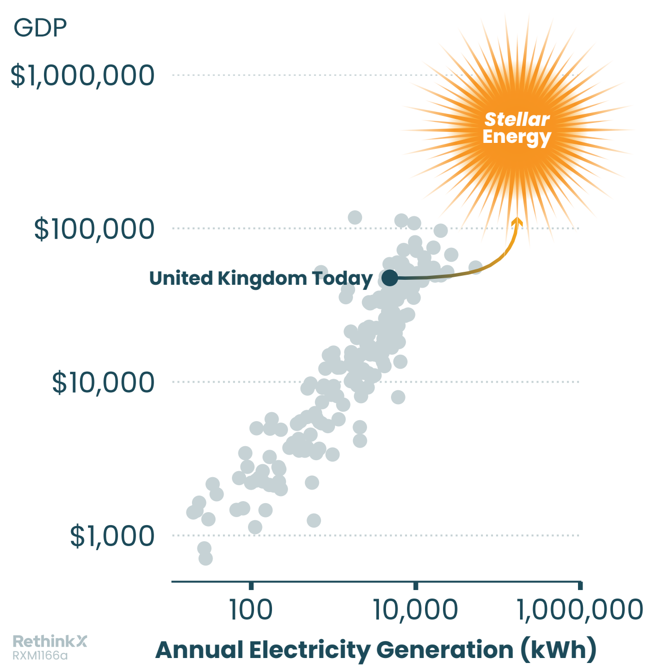
Population in 2040: **73,774,627**

Key Insights:

- The UK generates 8-14 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- The UK produces about one-third more SWB Superpower than SWB Basepower in each of our scenarios as a result of sizing to peak winter stress at high latitude.
- SWB Superpower is available in the UK throughout the year, with a seasonal pattern corresponding to greater wind resources during the winter season.
- Wind plays a dominant role in the UK's SWB mix.
- Battery capacity of 70-82 average demand hours is required, which suggests the UK could realize substantial savings with a modest amount of alternative coverage as per the SWB Coverage Curve.

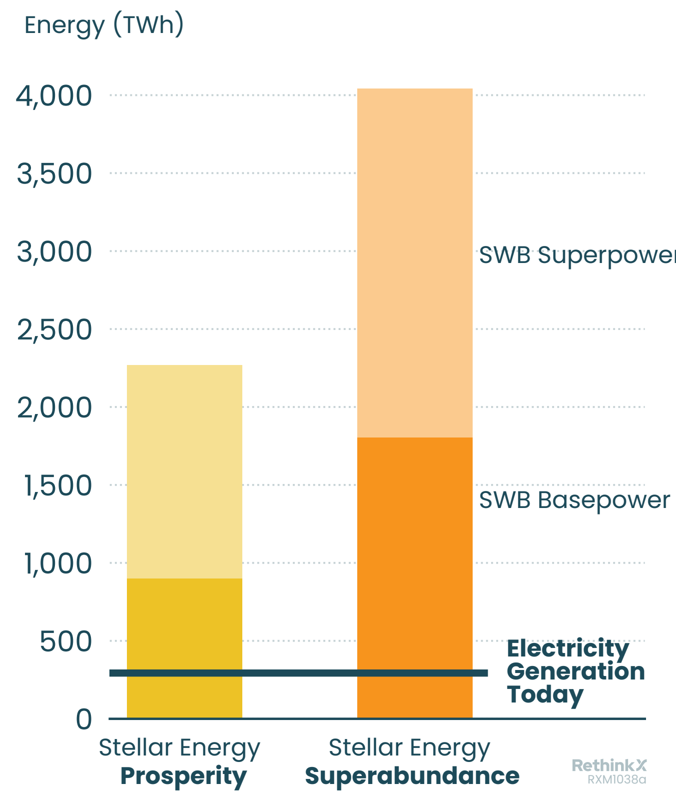
Energy Generation Per Capita

Energy availability per person is extremely strongly correlated with overall prosperity worldwide



Annual Energy – United Kingdom

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$747 per year over 20 years
SWB Base power: 899 TWh
SWB Superpower: 1,368 TWh

Solar: 223 GW
Wind: 479 GW
Batteries: 8,431 GWh
(82 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$1324 per year over 20 years
SWB Base power: 1,804 TWh
SWB Superpower: 2,236 TWh

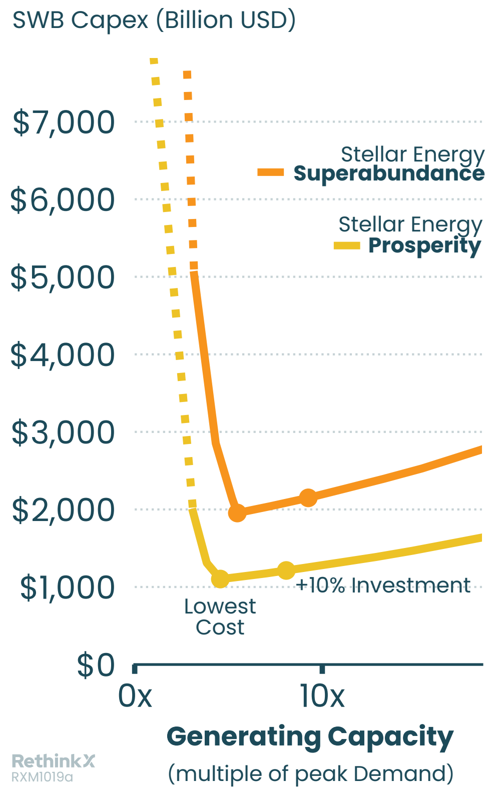
Solar: 606 GW
Wind: 800 GW
Batteries: 14 TWh
(70 average demand hours)

United Kingdom's path to *Stellar Energy*

Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

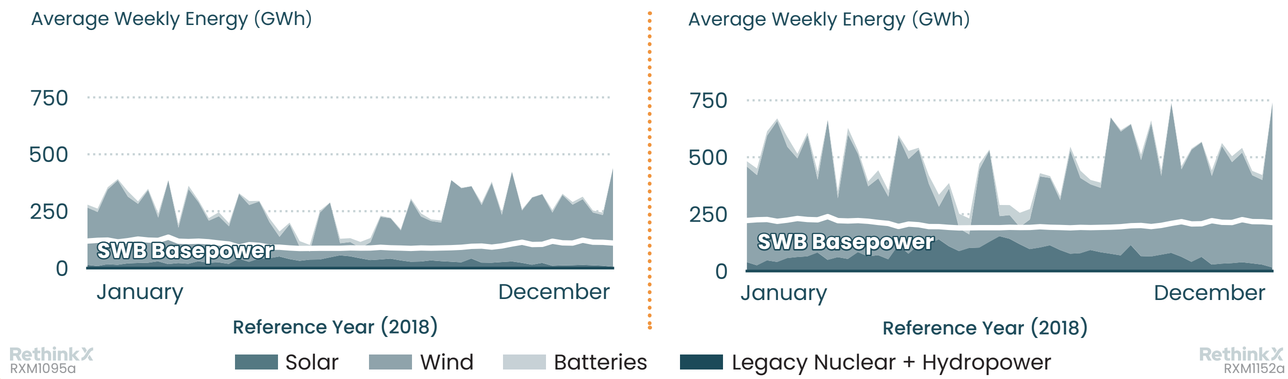
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



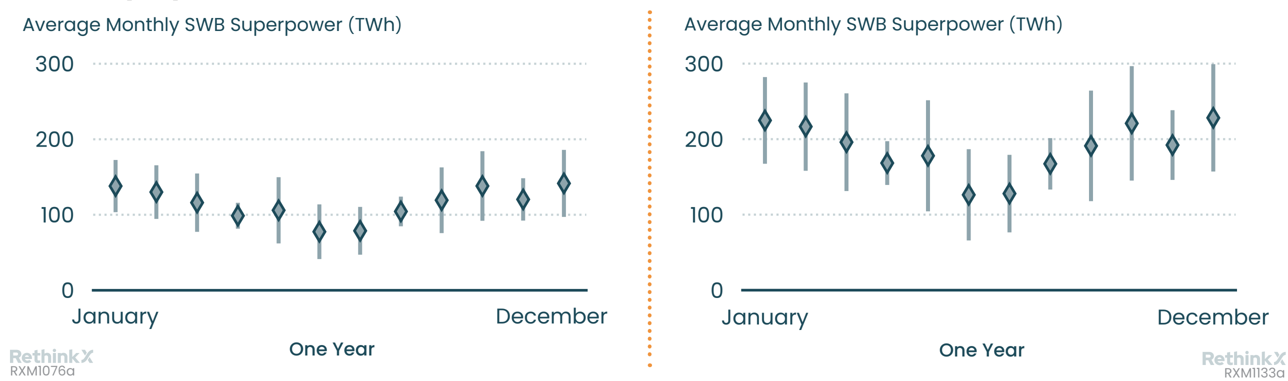
Learn more about this modelling go to https://go.rethinkx.com/O4OP

United Kingdom

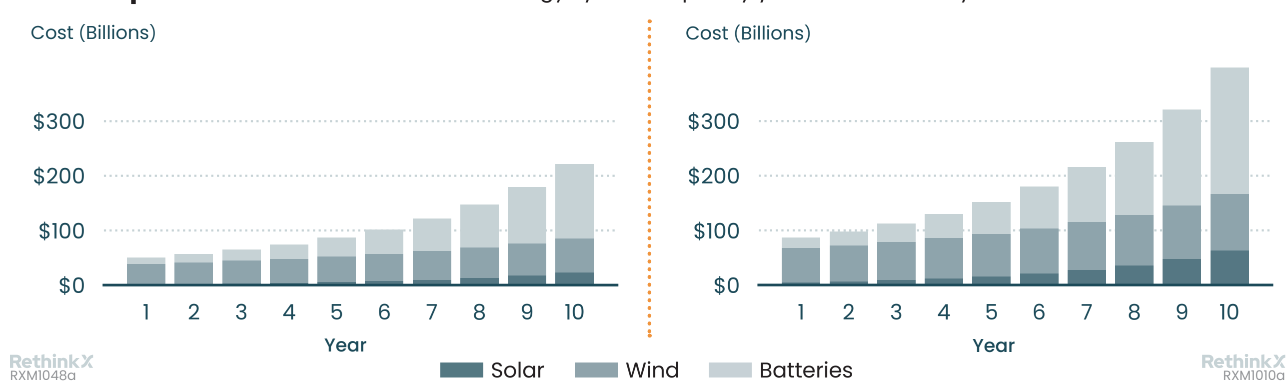
SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



SWB Superpower Curves: SWB Superpower availability by month based on 10-year averages



SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



U.S. Alaska's path to *Stellar* Energy

Population in 2040: **819,116**

Key Insights:

- Alaska generates 9-11 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Alaska produces an extremely large quantity of SWB Superpower in each of our scenarios as a result of sizing to peak winter stress at very high latitude.
- Despite Alaska's long winter season, SWB Superpower is consistently available on over two-thirds of all hours throughout the entire year.
- Solar and wind play roughly equal roles in in Alaska's SWB mix.
- Battery capacity of 196-233 average demand hours is required, which suggests Alaska could realize substantial savings with a very small amount of alternative coverage as per the SWB Coverage Curve.

Energy Generation Per Capita

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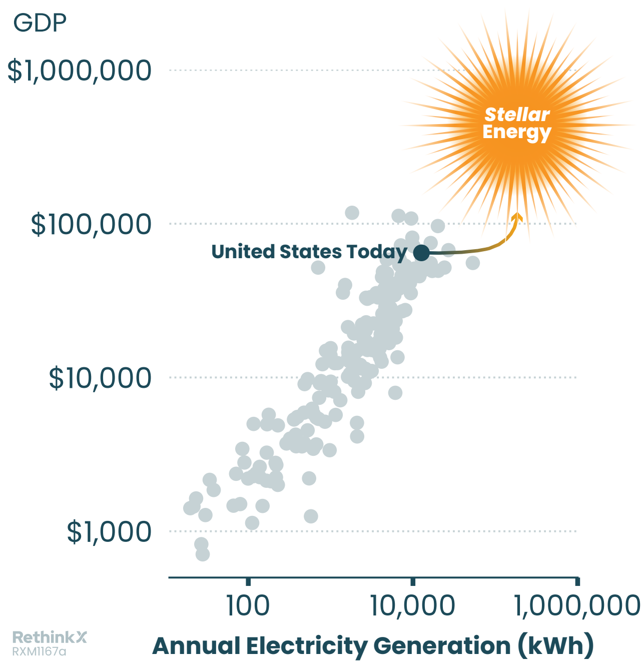
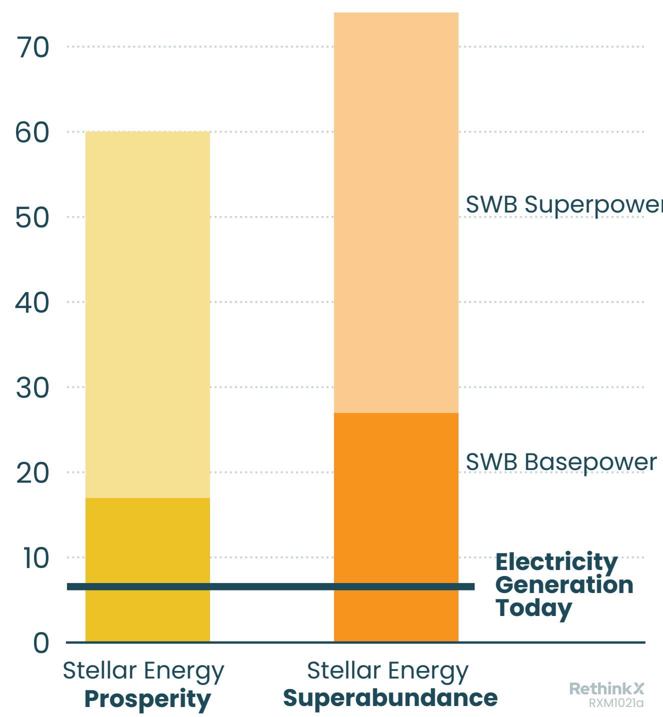


Annual Energy - Alaska, USA

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$3717 per year over 20 years
SWB Base power: 17 TWh
SWB Superpower: 43 TWh

Solar: 31 GW
Wind: 19 GW
Batteries: 463 GWh
(233 average demand hours)

Stellar Energy Superabundance Scenario

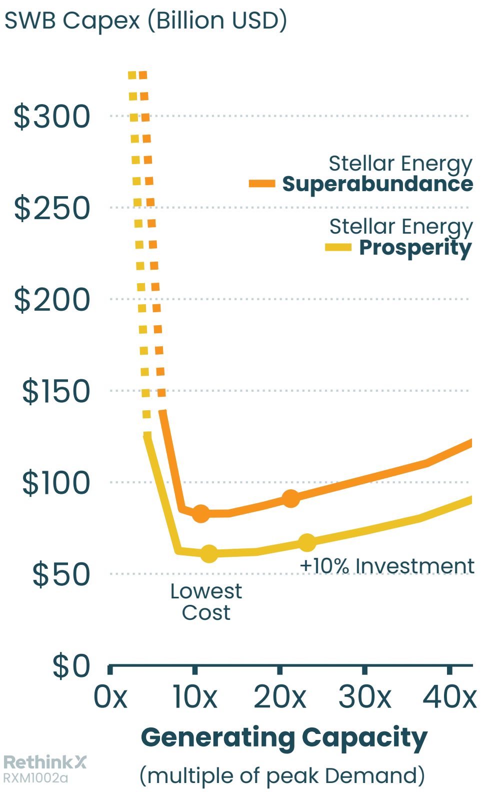
Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$5053 per year over 20 years
SWB Base power: 27 TWh
SWB Superpower: 47 TWh

Solar: 25 GW
Wind: 34 GW
Batteries: 615 GWh
(196 average demand hours)

Clean Energy U-Curve

Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function

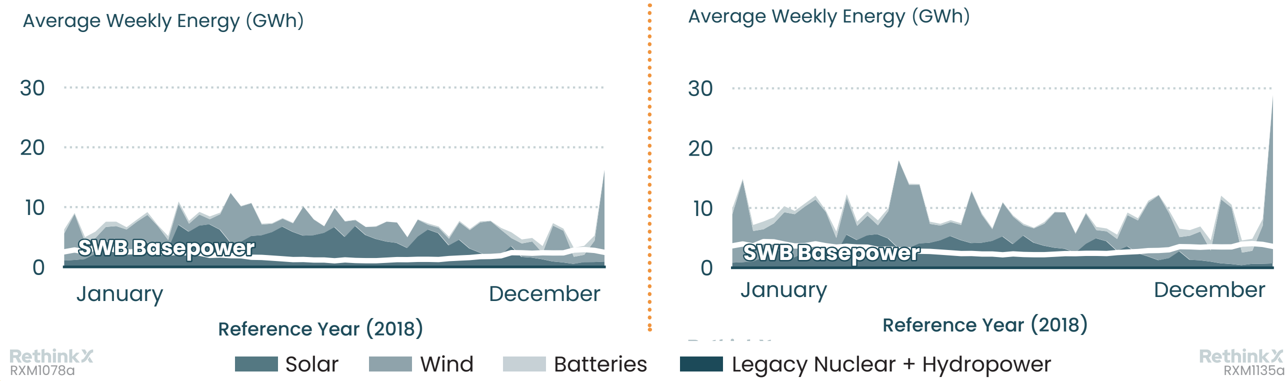


Learn more about this modelling go to https://go.rethinkx.com/Z7PK

Alaska

Stellar Energy Prosperity | Stellar Energy Superabundance

SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



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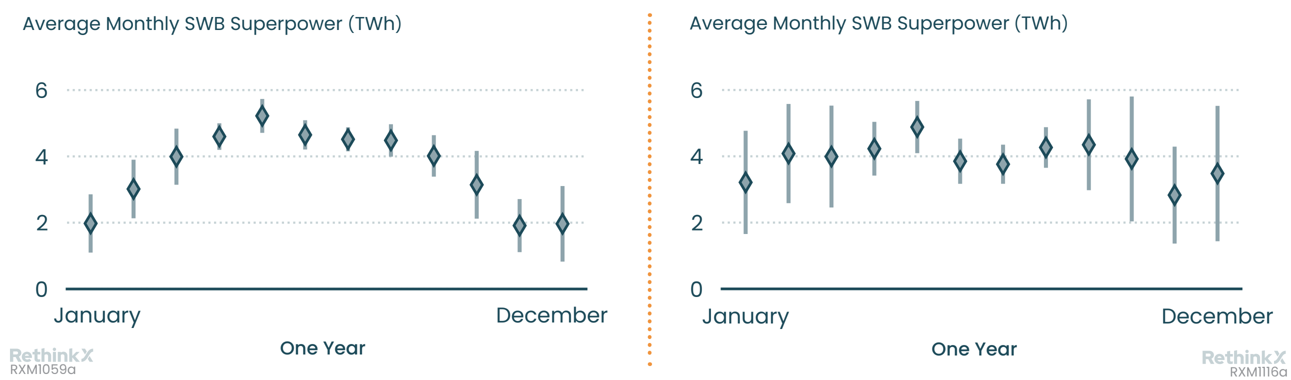
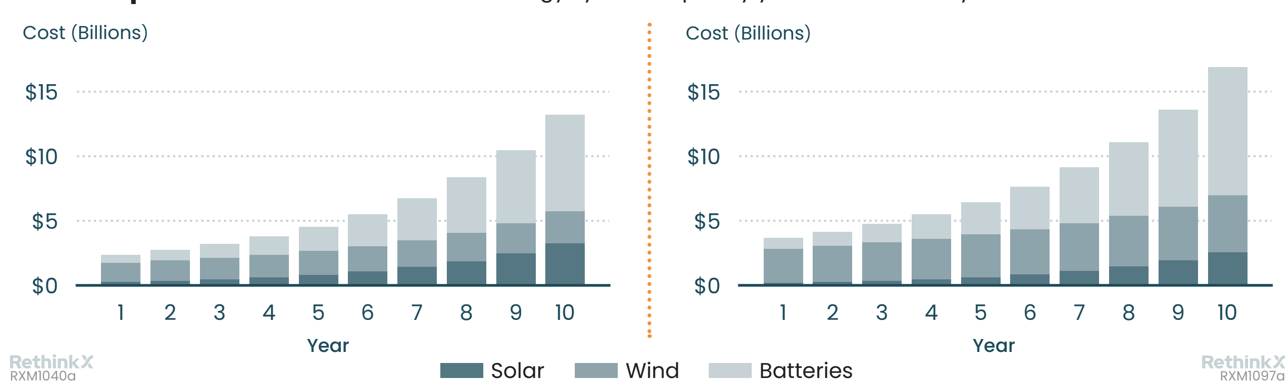


SWB Capital Cost Schedules: Stellar Energy system capex by year if built over 10 years



Kotzebue, U.S. Alaska's path to *Stellar* Energy

Population in 2040: **3,110**

Key Insights:

- Kotzebue generates 19-24 times more total electricity in our scenarios with a Stellar Energy system than it does today.
- Kotzebue produces an extremely large quantity of SWB Superpower in each of our scenarios as a result of sizing to peak winter stress at extremely high latitude.
- SWB Superpower is available in Kotzebue throughout the year, but shows a clear seasonal pattern due to greater wind abundance in winter – a pattern which fortunately matches the need for heating energy.
- Wind plays a dominant role in Kotzebue's SWB mix.
- Battery capacity of roughly 148-178 average demand hours is required, which suggests Kotzebue could realize very large savings with a very small amount of alternative coverage as per the SWB Coverage Curve.

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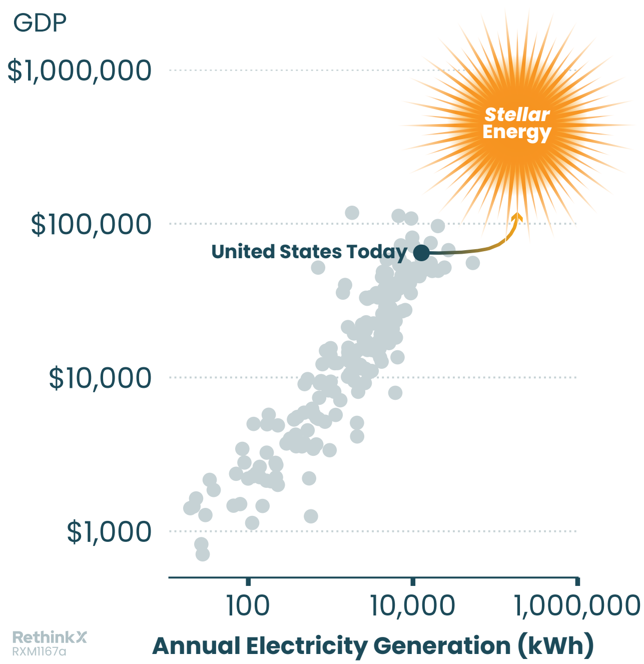
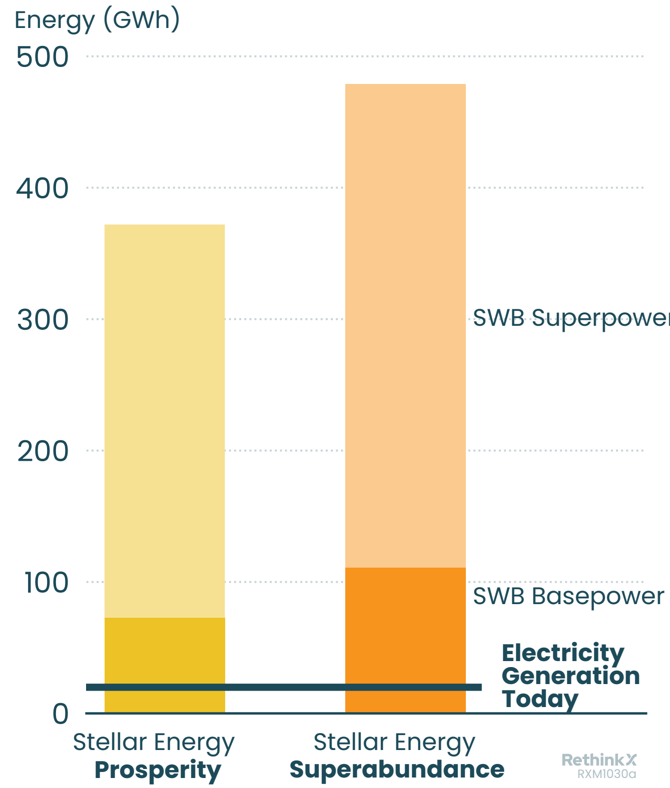


Annual Energy - Kotzebue, Alaska

SWB Superpower and SWB Basepower in Stellar Energy scenarios compared to current energy system



Stellar Energy Prosperity Scenario

Per-capita energy availability equivalent to Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$3299 per year over 20 years
SWB Base power: 73 GWh
SWB Superpower: 299 GWh

Solar: 20 MW
Wind: 102 MW
Batteries: 1 GWh
(178 average demand hours)

Stellar Energy Superabundance Scenario

Per-capita energy availability equivalent to three times Germany today, with heating to European standards and cooling to American standards of comfort

SWB Capex per capita:
$4214 per year over 20 years
SWB Base power: 111 GWh
SWB Superpower: 368 GWh

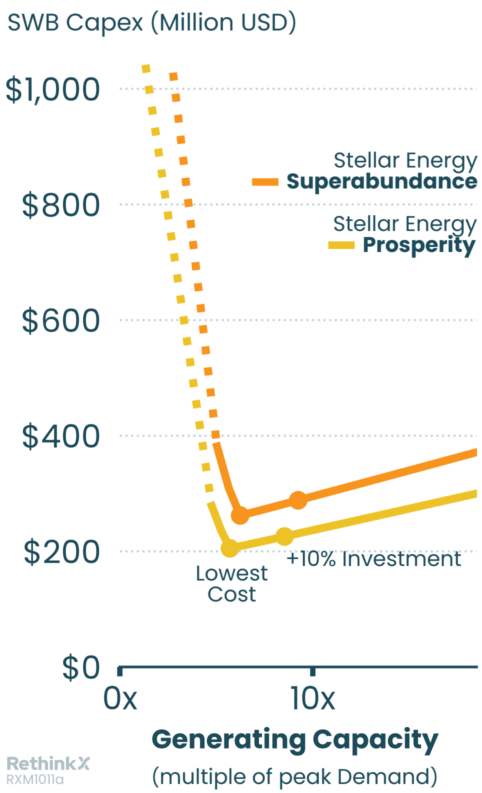
Solar: 31 MW
Wind: 130 MW
Batteries: 2 GWh
(148 average demand hours)

Kotzebue,U.S. Alaska's path to *Stellar* Energy

Stellar Energy Prosperity | Stellar Energy Superabundance

Clean Energy U-Curve

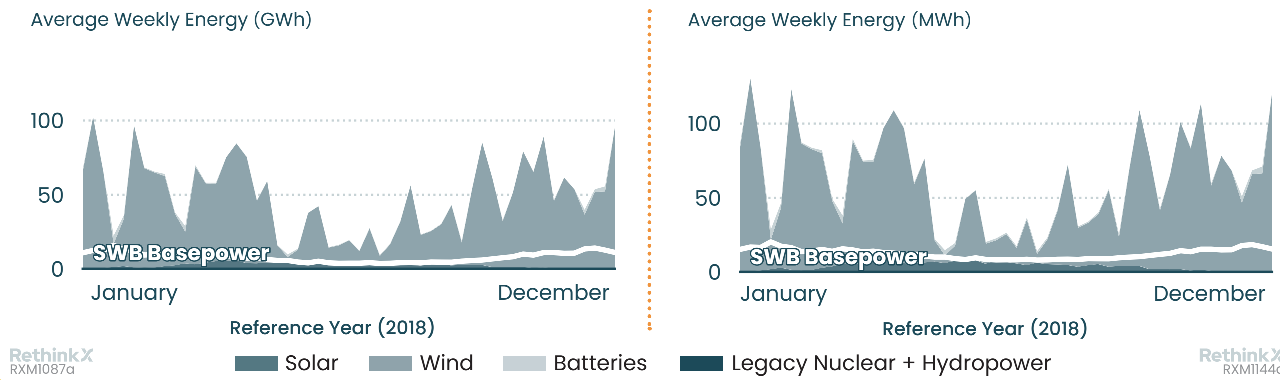
Many different SWB mixes could meet our energy needs, but their capex and generating capacity varies greatly according to a u-shaped cost function



Learn more about this modelling go to https://go.rethinkx.com/B2RA

Kotzebue

SWB Generation Profiles: Energy model output by source for one example year based on historical weather data



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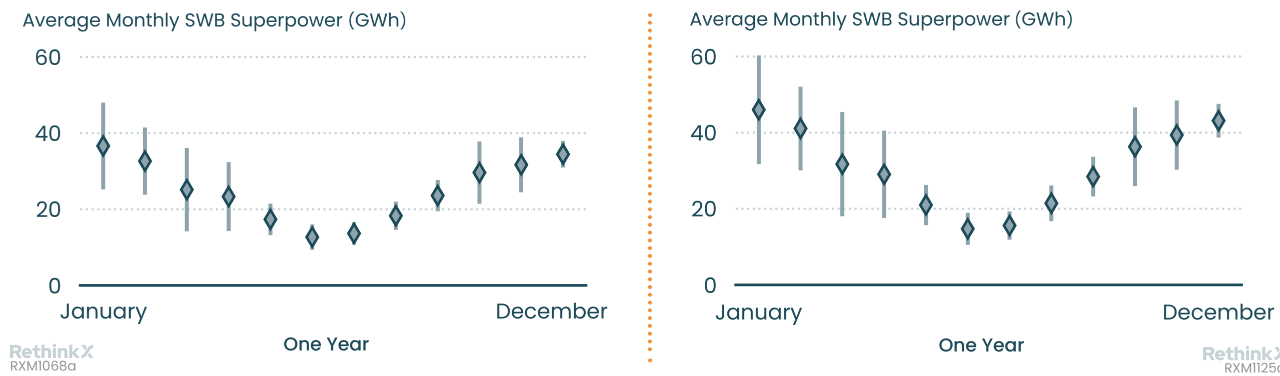

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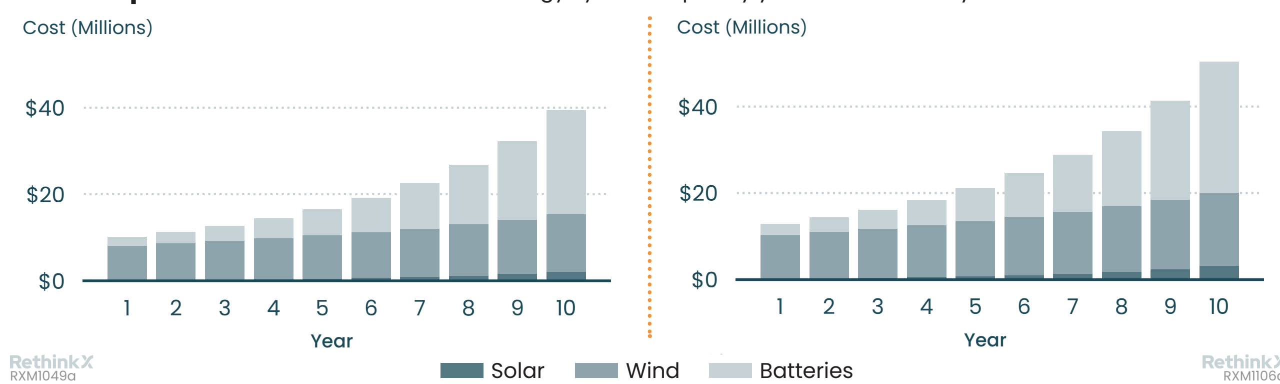

Data sources

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Demand Ninja github: https://github.com/renewables-ninja/demand-ninja

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United Nations, Department of Economic and Social Affairs, Population Division (2024). World Population Prospects 2024. https://population.un.org/dataportal/

RethinkX®

Understanding Stellar Energy

Adam Dorr

Adam Dorr is an environmental social scientist and technology theorist whose current research with RethinkX is focused on the disruption of the global energy sector by new energy generation and storage technologies, and its intersection with similar disruptions set to unfold across the economy.

He completed his MS at the University of Michigan's School for the Environment and Sustainability and his PhD at UCLA's Luskin School of Public Affairs, where he studied the environmental politics, policy, and planning around disruptive technologies. He has over a decade of teaching, lecturing, and presenting experience.

James Arbib

James Arbib is chairman of a UK-based family investment office with a diversified portfolio across all assets classes and a focus on the risks and opportunities of technology disruption. He is the founder of Tellus Mater, an independant philanthropic foundation dedicated to exploring the impacts of technology and its potential for solving some of the world's most challenging problems. He is the co-founder of RethinkX and has given keynote speeches at dozens of events including BlackRock, Goldman Sachs, governments, and corporations. He is the co-author of *Rethinking Humanity*: Five Foundational Sector Disruptions, the Lifecycle of Civilisations, and the Coming Age of Freedom (2020) and Rethinking Climate Change (2021).

A Graduate in history from Trinity College, Cambridge, he has a Masters in sustainability Leadership, also from Cambridge. He is a qualified chartered accountant and worked as an investment analyst covering utilities.

Tony Seba

Tony Seba is a world-renowned thought leader, author, speaker, educator, angel investor and Silicon Valley entrepreneur. He is the author of the #1 Amazon best-selling book "Clean Disruption of Energy and Transportation", "Solar Trillions" and "Winners Take All", and co-author of "Rethinking Transportation 2020-2030", "Rethinking Food and Agriculture 2020-2030", and "Rethinking Humanity".

He has been featured in several movies and documentaries including Bloomberg's Forward Thinking: A Sustainable World, 2040, and SunGanges. He is recipient of many awards including the Savvy Awards (2019), Solar Future Today's Visionary Influencer Award (2018), and Clean Energy Action's 2017 Sunshine Award. He is the creator of the Seba Technology Disruption Framework™. His work focuses on technology disruption, the convergence of technologies, business model innovation, and product innovation that is leading to the disruption of the world's major industries.

He has been a keynote speaker at hundreds of global events and organizations including Google, the European Commission, Davos, COP21, CLSA, J.P. Morgan, Nomura, National Governors Association, Conference on World Affairs, the Global Leaders Forum, Intersolar and China EV100. He has taught thousands of entrepreneurs and corporate leaders at Stanford Continuing Studies. He has a Stanford MBA and an MIT degree in Computer Science and Engineering.

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