From Constraint to Abundance:

CHARTING AN INNOVATION AGENDA FOR THE ENERGY TRANSITION

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THE ENGINE VENTURES

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INTRODUCTION

It's human to focus on constraints: barriers are always clearer than the winding pathways around them. And right now, the barriers to the transition to clean energy are not insignificant: from a depressed early-stage landscape, to clogged interconnection queues, to forecasts of coal plant extensions and new natural gas. But it's our job to take the long(er) view, and to keep our eyes trained on the art of the possible. And from where we sit, the energy transition is more than an ecological imperative: it remains the largest economic opportunity of our era. Comparable in scope to the industrial revolution, the transition affects nearly half of U.S. GDP, with required capital outlays of $7 trillion per year to net zero, and 27,000 terawatt-hours of electricity needed with demand increasing.[1, 2]

That opportunity is now accessible as a result of three intricately linked realities:

01 TECHNOLOGICAL BREAKTHROUGHS.

The current wave of innovations in fields ranging from plasma science and biological engineering to materials science and artificial intelligence is not just iterative, it is revolutionary. These technologies have the potential to push the boundaries of our resource constraints in a cost-effective way, reshaping our energy systems to be more efficient, resilient, and economically viable.

02 A NEW GENERATION OF INDUSTRIAL STRATEGY.

Government involvement in energy policy is not new, but the paradigm has shifted from making dirty energy expensive to making clean energy cheap. In the U.S. alone, the Inflation Reduction Act (IRA) is projected to unlock $3 trillion in capital by 2030 – the largest investment in climate-tech market creation in history.[3] The alignment of geopolitical imperatives with ecological ones is propelling unprecedented investment by countries in their own clean energy economies, opening up multiple markets through the imperatives of resiliency over integration.

03 EXPANDING GLOBAL MARKETS.

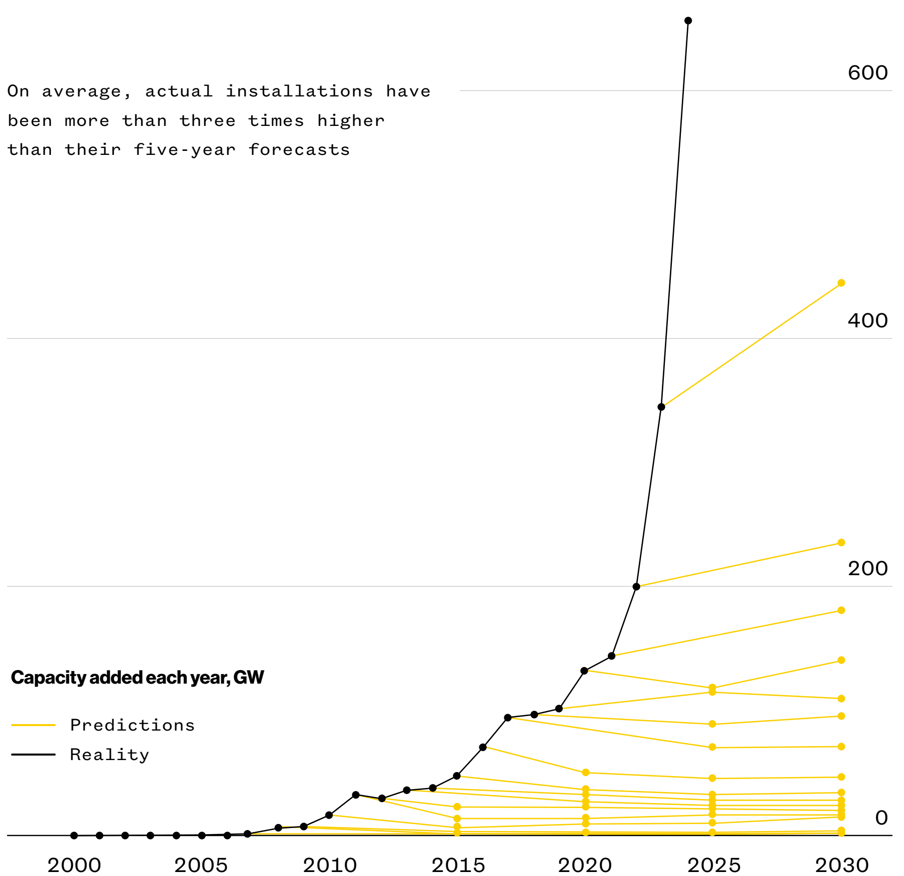
Private investment in clean energy technologies is at new records, surpassing oil and gas.[4] Electricity demand is expected to grow 15-20% over the next decade, as computing, electrification, and manufacturing generate market pull for energy technologies.[5] The general increase in energy intensity as the globe adopts air conditioning and other modern conveniences will only expand demand in the years to come, with global cooling alone forecasted to increase demand by an entire U.S. electricity sector's worth by mid-century.[6] While past forecasts have historically been revised down, total useful energy demand will begin to surprise to the upside as emerging markets and cost declines accelerate adoption.[7]

These forces have transformed the paradigm we find ourselves in, moving us from a demand-constrained world to a supply-constrained one. In the U.S., spending on clean energy technologies has shattered records each quarter and surpassed $280 billion in the last year, with investment in emerging clean technologies alone up tenfold.[8] Across technology spheres, including fusion, fission, and geothermal, technology is advancing toward market at rates heretofore unseen, pulled forward by the expansion of global markets and the need for increasingly power dense solutions. The challenge now is that unprecedented demand is running headlong into the physical, political, and financial infrastructure of our energy system that struggles to expand – with transmission and interconnection delays, permitting and siting opposition, outdated utility business models, and supply chain constraints limiting capacity.[9] Recently, much focus has rightly been on this "gauntlet."[10] But we believe it is just as important to look to what lies on the other side.

The positive feedback loop of innovation – where technological advancements begets market expansion and scale that further improves technological traits – enables exponential growth and unlocks the potential of an energy-abundant future.

The interplay between Wright's Law (the cost reductions associated with increased production) and Jevons Paradox (increased efficiency leading to higher demand) can drive rapid adoption of clean energy technologies. To illustrate this, look no further than solar energy: Installations have outperformed forecasts by 230% over the last decade, with each doubling of installed capacity linked to a 40% cost decline.[11] As British economist William Jevons

Forecasted versus actual solar installations[12]



‹ Installations for 2024 are an estimate from BloombergNEF for direct current solar capacity.
Source: IEA; Energy Institute; BloombergNEF

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postulated, the cheaper and better technologies get, the more demand increases: They expand their own markets, fueling their growth.

While non-market constraints pull the reins back on these S-curves today, close attention to the energy landscape paints a picture of gradual but accelerating erosion of frictions. Solar PV and battery storage indicate that S-curves are ever more present: Costs have declined by ~80% over the past decade, with a doubling in solar deployment every 2-3 years and battery storage capacity every year.[13] Increased demand from time-sensitive but cost-insensitive hyperscalers promises to pull new, power-dense technologies through common frictions related to first-of-a-kind project deployment and stagnant utility business models. Moreover, the national security imperative to win the competition for the energy and AI markets of the 21st century allows for emerging political consensus on hard issues, including scaling power-dense technologies like advanced nuclear, reforming permitting processes, and moving away from business as usual in electricity markets.[14] Together, these tailwinds will continue to build upon themselves in the years to come, accelerating the transition, and easing the gauntlet.

Importantly, the shift towards an energy-abundant future enables a positive argument about what the energy transition could be: No longer is it strictly about avoidance or subtraction of greenhouse gasses, but rather progress toward a world of increased productivity and growth enabled by the prevalence of unconstrained, affordable energy. It's become clear that an energy transition that demands citizens to make do with less is not a politically or economically viable one. Individuals and markets will not shift from the status quo unless the alternative offers the promise of something better - less expensive, high quality, more resilient, and more convenient. Innovation will be necessary to support the development of these substitutes and supplements to how we do things today, but abundance will always trump constraint.

These opportunities highlight an emergent reality: there has never been a better time to be investing into technologies and companies at the cutting edge of the energy transition. This doesn't mean the path to effective capital allocation is easy, however. Moving from a supply-constrained to an energy-abundant future will require navigating through non-linear waves of change.

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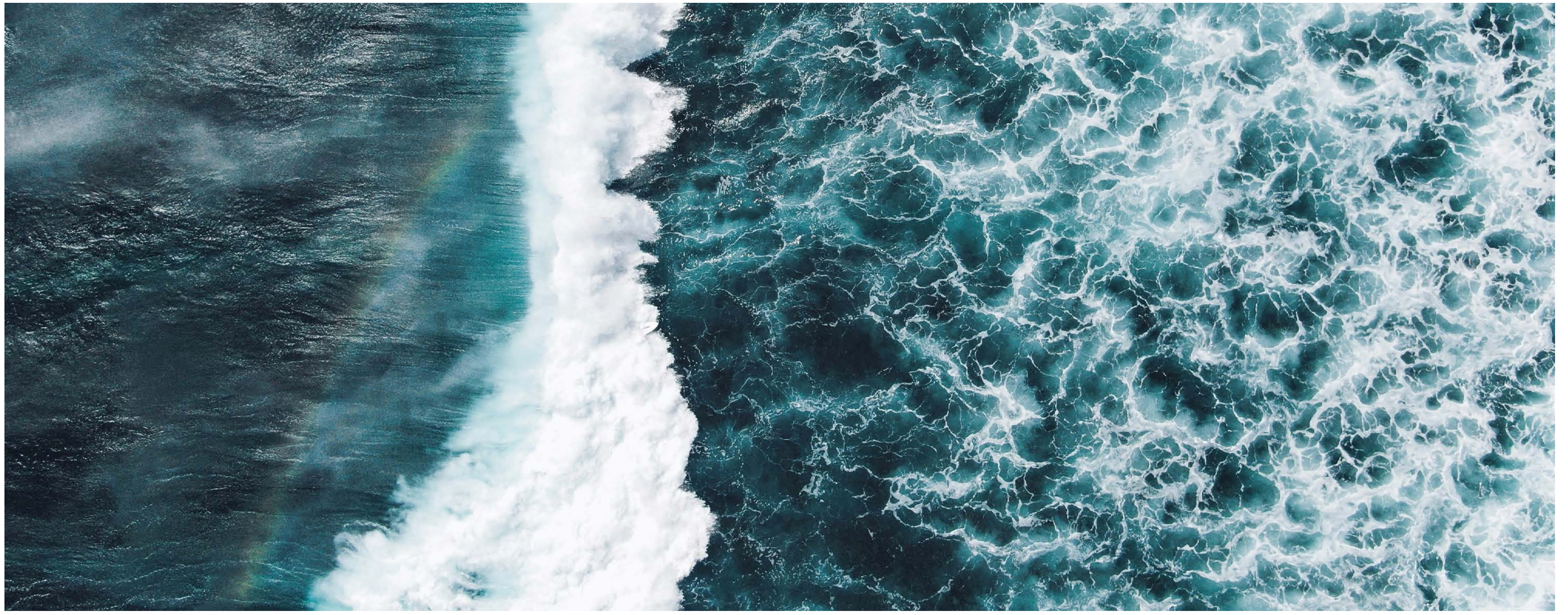
INVESTING THROUGH THE NEW ENERGY TRANSITION: DECADAL EVOLUTION WITH WAVES OF CHANGE



Since 1800, our industrial history can be tracked through a series of major shifts in energy production, beginning with thermal energy for light and propulsion, shifting in part toward electricity for particular use cases, with input materials and fuels evolving consistently throughout the last 200 years.[15] Changes over the last decade can be characterized by organic growth in renewable electricity production, vehicle electrification, and an expansion in natural gas capacity from hydraulic fracturing.

We are now entering a new paradigm. Between now and the 2050s, we expect three waves of economic activity that will culminate in a radically different energy paradigm as we navigate from scarcity to surplus. Importantly, these periods affect not only the technologies that will win, but also the business models that companies choose to pursue.

WAVE 1:

SUPPLY-CONSTRAINED REALITY

Despite unlocking demand for clean energy, we live in, and will continue to live in, a clean energy supply-constrained world for the next decade, where expanding capacity will be challenged by frictions across technology scaling, a growing yet insufficient capital stack, regulatory and permitting delays, and the architecture of an industry averse to change. The resultant reality is that the US is likely to see the buildout of additional natural gas capacity. But, technologies that take advantage of suboptimal market realities – smoothing out volatility, minimizing electricity costs via alternate feedstocks or efficiency improvements, improving electrical infrastructure while circumventing supply constraints – will scale.

WAVE 2:

SCALING OF HIGH-CAPACITY, ENERGY-DENSE RESOURCES.

Beginning in the 2030s, today's nascent but not-yet-scaled clean energy technologies like advanced nuclear and next-generation geothermal will be scale-ready, much like lithium ion and solar in the 2010s. Learning from the U.S.' failure to maintain early technological dominance in the solar PV and EV battery industry, this period instead will be marked by a buildout of the supporting ecosystem, supply chains, and manufacturing needed to productize and deploy clean and energy-dense power sources.

WAVE 3:

ENERGY ABUNDANCE UNLOCKS NEW ECONOMIC OPPORTUNITIES.

By the 2040s and beyond, a set of truly novel energy production technologies, including fusion and space-based solar, all in development today, reach commercialization, revolutionizing the energy landscape. These technologies will upend geopolitical dynamics and market structures that are ill-suited for their presence and the energy economy writ large as the paradigm shifts toward one of clean energy abundance. The possibilities of this are, in many cases, hard to fathom – access to energy resources has been linked to economic growth and geopolitical strife since the dawn of the Industrial Revolution. With plentiful, inexpensive energy, production and productivity growth accelerates progress across industrial verticals: unlimited computing power, transportation opportunities unconstrained by energy access, distributed manufacturing free from constraints of geographically dispersed natural resources, and more.

FROM SCARCITY TO ABUNDANCE

WAVE 1:
ADAPTATION: SUPPLY-CONSTRAINED REALITY

Themes
- Compute-fueled electricity demand
- Fractured grid infrastructure
- Volatility and congestion

Technologies
- Modular and load-following clean processes
- Longer-duration storage solutions
- Energy-efficient carbon capture technologies
- Alternative fuels
- CO_2-free reduction of methane
- Next-generation power electronics
- Energy-efficient heating & cooling

WAVE 2:
ADOPTION: SCALING HIGH-CAPACITY RESOURCES

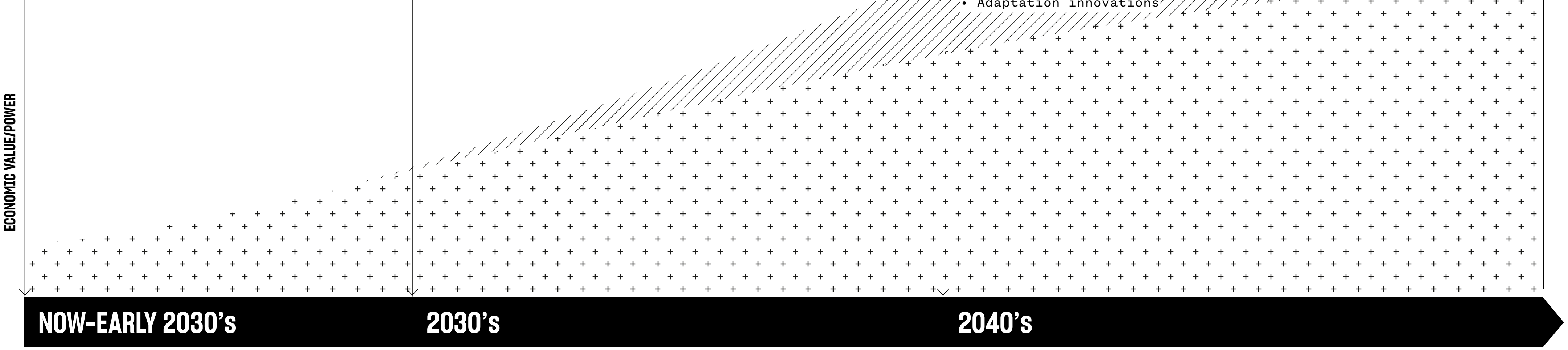
Themes
- Pressured supply chains
- Scaling of clean firm technologies
- Easing infrastructure constraints

Technologies
- Advanced nuclear fission
- Nuclear fusion
- Next-generation geothermal
- Space-based solar
- Manufacturing-to-productization of clean-firm
- Precision mining
- Organic and synthetic materials
- Midstream clean energy infrastructure

WAVE 3:
ABUNDANCE: EMERGENCE OF NEW ECONOMIC OPPORTUNITIES

Themes
- Near-zero marginal cost energy
- Changed physical ecosystem
- Mass electrification

Technologies
- Electrofuels & electrification of industrial end-uses
- Next-generation transportation
- Additive manufacturing innovations
- Automation of hard tech production functions
- Carbon-negative manufacturing processes
- Circular economy enablers
- Biomanufacturing
- Adaptation innovations



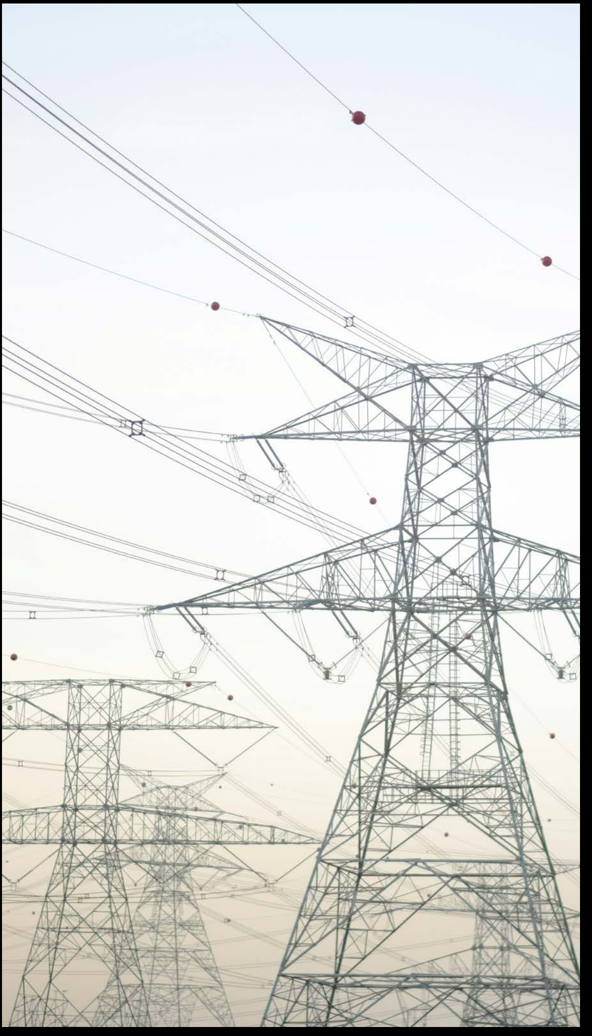
Effective capital allocation will require navigating across these three waves. We believe that investment in both the supply-constrained reality of today and the energy-abundant promise of tomorrow are critical levers for massive impact to mitigate the threats of climate change, and for significant returns to financing the foundational backbone of the next industrial paradigm. Here, we put forward a tripartite innovation agenda for investing through the new energy transition:

1.
Scaling technologies that meet demand in today's supply-constrained reality.

2.
Seeding the innovations and ecosystems that set the stage for energy abundance.

3.
Backing businesses that capitalize on the opportunity of an energy-abundant future.

INVESTING IN INNOVATION THROUGH THE NEW ENERGY TRANSITION



I.
MEETING DEMAND IN A SUPPLY-CONSTRAINED REALITY

The energy transition is entering a critical phase where electricity demand is surging 15-20% over the next decade.[16] Meanwhile, constraints on electricity infrastructure hamper the buildout of clean energy: interconnection queues swell to double current installed capacity and transmission timelines stretch into the decades, creating volatility in the temporal, geographic, and economic availability of clean electricity.[17] While innovation in industrial processes proliferates, the reality is many capital assets are early in their lifetime and clean energy transportation has yet to scale, necessitating that technologies be compatible with legacy infrastructure and long-lived assets. These challenges will not – cannot – prevent progress; Rather, strategic investments into a set of innovations can transform these constraints into opportunities. As a result, key themes inform our focus:

1. Strategic use of "pockets" of energy abundance – temporal and geographic areas where electricity is cheap and plentiful.

The inefficient buildout of the grid and the variability of renewables have contributed to global power price volatility, which has trebled in the past decade, with grid prices in the upper 20% of all hours doubling.[18] This necessitates flexible load-following technologies and modular industrial processes that can rapidly ramp up and down in response to power prices, and that can co-locate geographically with the limited highest-capacity-factor clean resources available before clean-firm baseload power scales. Storage solutions that temporally extend pockets of electricity that would otherwise be curtailed become increasingly important as renewables penetration increases: Indeed, in Germany, where renewables could account for 90% of all power generation by 2050, there would still be 75 days a year where backup generation will be necessary.[19] Looking ahead, we see significant opportunity in thermal energy storage, where high roundtrip efficiencies of >40% can make them increasingly cost competitive.

EVOLOH

Evoloh's technology enables the mass manufacturing of anion exchange membrane electrolyzers that can load-follow based on when electricity is cheap.

Form energy

Form Energy's iron-air batteries can overcome day-to-day variability by providing multi-day cost-effective storage systems.

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2. Reckoning with natural gas' enduring role in the energy transition.

As demand for 24/7 clean, firm electricity accelerates, with load growth of 2.5-2.75% p.a through 2030, projections suggest that natural gas generation will fill the gap in the near term – with some estimating ~10 bcf/day of incremental natural gas demand by 2030.[20, 21] Point-source carbon capture technologies that can overcome the energy penalty of carbon capture desorption to fall within economic ranges enabled by "carrots" such as the IRA's 45Q unlock the potential to decarbonize industry without massive infrastructure upgrades. Alternative fuels from diverse energy feedstocks, like biomass, are increasingly competitive economically and can offset significant portions of natural gas demand while avoiding the near-term electricity price penalties faced by electrolytic sustainable fuels. Looking ahead, technologies like pyrolysis present significant opportunities to leverage extant natural gas infrastructure and utilize lower-cost feedstocks.

Mantel

Mantel's point source carbon capture for industry leverages material innovation to reduce operating expenses common to carbon capture.

terragia

Terragia's consolidated bio-processing can convert inedible biomass into ethanol and other carbon-negative fuels at a cost competitive with petroleum.

3. **Energy-efficient technologies that enable us to do more with what we have.**

Against the backdrop of rising retail electricity prices and constraints on interconnection for industrial and commercial consumers, energy efficiency is back in vogue. Heat pumps are far from novel – dating back to the 19th century – but have renewed applicability where their efficiencies can make them cost-competitive with natural gas solutions. Advanced HVAC solutions – including breakthrough advances in dehumidification – can capture a growing market opportunity, with 3 billion additional AC units expected to be installed over the coming decades. In the data center context, for decades the energy required to execute a given amount of computation has declined by 50% every 2.5 years – but now, that trend, known as Koomey's Law, has slowed.[22] Now, demand-side breakthroughs in data center energy utilization – from chip architecture advances, such as photonics, to rethinking the infrastructure of data centers themselves – are needed.

ATMOSZERO

AtmosZero is commercializing an air-source heat pump to decarbonize industrial steam via a "drop-in" solution economical even for low-margin manufacturers.

PASCAL

Pascal is developing high-efficiency solid-state heat pumps for heating and cooling that leverage the existing industrial supply chain while eliminating HFCs.

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4. **A new generation of electrical infrastructure that circumvents supply constraints.**

The scale of grid buildout globally will need to accelerate by 40-50% over the coming decades, agnostic of the shape of the energy transition – and yet the current infrastructure struggles against non-market constraints, including permitting and siting and long supply-chain bottlenecks.[23] Advanced transmission technologies deployed at scale could increase effective transmission capacity of the *existing grid* by 20-100GW – sufficient to meet the expected 10-year peak in demand growth while sidestepping infrastructure challenges.[24] Technologies that are able to leverage near-term behind-the-meter demand as they work through the slow utility adoption cycle will be best-positioned to win. Innovations in power electronics hardware that address the supply-chain constraints in scaling the grid (e.g., ~48 month lead times for transformers) have large markets in which to scale. And, technologies that turn the grid from unidirectional to bidirectional enable further capacity increases, but will need to integrate with underlying hardware as well as utilities' staid operational processes. Leveraging the maturity of silicon carbide, and down the line gallium nitride and gallium oxide, can unlock benefits not only in the craved resiliency and reliability but also in providing more efficient, omnidirectional power flow.

VEIR

VEIR is developing superconducting transmission lines which are capable of operating with 5-10 times the transfer capacity of traditional lines at the same voltage, allowing for increased power transfer in existing transmission corridors.


II. SEEDING THE TECHNOLOGIES AND ECOSYSTEMS THAT DELIVER ABUNDANCE

Ultimately, solutions that leverage what we have are necessary but not sufficient – seeding investments in technologies that do not just integrate with, but overcome those limitations. Case in point: The "five-nines reliability" requirement of data centers isn't well-suited to the distributed and disruptable natural gas supply chain or variable renewable energy, making a new generation of 24/7 clean firm power technologies necessary. The alignment of public incentives, such as the ADVANCE Act and resurgent permitting reform, and time-sensitive but price-insensitive hyperscalers as novel customers, supports deployment of next-generation clean firm technologies in the 2030s.[25, 26] The scaling of these technologies, however, will also create new markets for a set of enabling innovations: cost-effective deployment solutions, critical inputs into their supply chains, and infrastructure to store and transport increasingly available clean electricity. Investing into the ecosystem to support energy abundance must take place now to avoid the supply-side constraints that have hampered deployment in the past, pointing to a set of investment areas for funding today:

1. Placing energy-dense sources of clean firm power on the same cost curves as solar and storage.

As growing demand comes into conflict with extant constraints on land and access to grid infrastructure, generation will shift towards denser sources of power. These resources will be valued for their geographic flexibility (deployable anywhere, potentially modularly) and high capacity factors – only the combination of these traits will begin to move the market toward energy abundance and enable broad electrification. Sources of dense, high-capacity supply include advanced nuclear fission, next-generation geothermal, nuclear fusion, and space-based solar. Core to scaling is not only innovation in underlying technologies – Lewis Strauss' 1954 prediction of "too cheap to meter" energy was premised on nuclear fission, and geothermal has been deployed sub-scale since the early 1900s.[27] Rather, it is in the ability to deliver in a cost-effective manner. In nuclear fission, construction makes up ~30% of the costs of deployment, with interest – a product of long build times – adding another ~35%.[28, 29] Drilling cost improvements could provide a ~50% reduction in overnight capital costs for enhanced geothermal systems.[30] Focusing investment on innovations in manufacturing, productization, and deployment will be particularly important in a new era of structurally higher interest rates.

Blue Energy: Small modular reactor development platform leveraging shipyard manufacturing techniques to reduce the costs of nuclear power from $10k/kW to $2.5/kW.

Commonwealth Fusion Systems: Accelerating the commercialization of nuclear fusion using high-temperature superconducting magnets to build smaller and lower-cost tokamak fusion systems.

Quaise: Pioneering a new gyrotron-powered drilling system that enables digging deeper to unlock more power density – available anywhere and capable of reusing fossil-fired infrastructure.

2. Scaling up the material world – and in particular critical minerals and materials – to feed abundant demand.

BNEF projects a fivefold increase in critical minerals usage by 2040 under a Net Zero scenario; Regardless of the shape of the energy transition, certain minerals – like copper – will need to significantly increase in supply.[31, 32] The constraints are most biting upstream, in mining itself, where timelines from discovery to production are into the multi-decadal.[33] From the Copper Crisis of the 1960s to the Oil Crisis of the 1970s, innovations in extraction – from fracking to open-pit mining – have significantly increased supply and obviated shortages. Now, innovations like precision ("laparoscopic") mining that minimize waste and address important regulatory and social license-to-operate concerns, and technologies that can yield more from brownfield distressed or waste-based assets are needed. Technologies that enable onshoring of processing and refining, where China controls upwards of 80% of capacity for critical value chains, will benefit from supportive industrial strategies.[34] A critical question will be whether innovations in sustainable extraction will outpace discovery of novel materials that can reduce the need for critical minerals in the first place. AI-enabled materials discovery promises further acceleration in innovation of materials that are abundant and low cost and can obviate upstream supply constraints by shifting demand.

Lilac Solutions: Novel ion exchange process for direct lithium extraction dramatically reduces land, water, and time relative to traditional brine extraction.

3. Building out the resilient supply chains of the future, today.

The deployment challenges that technically de-risked industries like wind and solar have faced over the past four years underscore the need for early ecosystem investment. Indeed, between 2020 and 2022, the price of polysilicon – the starting material for solar cell wafers – rose 350%.[35] In offshore wind, cost increases in the critical inputs to turbines, the lack of Jones Act-compliant vessels to transport those turbines, and the extended timelines for project deployment against the backdrop of higher interest rates rendered a viable technology economically impossible in many instances. Companies able to position themselves at the forefront of emerging supply chains stand to capture tremendous value. Look no further than the fusion supply chain, where developers' expenditures will already be in the billions when first of a kind power plants are being deployed, and could scale to trillions in the years to follow.[36] The development of specialized manufactured inputs, including fusion fuel isotopes such as Lithium 6 and Tritium, to ultra-efficient magnets and laser components, pose potential not only for fusion but for follow-on market creation. For instance, high-temperature superconductor capacity will scale manufacturing of advanced conductors; Isotope production could spill over into radioisotopes in the nuclear medicine industry. And though the nuclear industry is well-established, securing the fission supply chain for the next generation of advanced reactors will be critical – from on-shoring and expanding high assay low enriched uranium (HALEU) fuel production that is largely sourced from Russia to developing waste re-processing and disposal mechanisms.[37]

4. Innovating in the midstream.

The buildout of novel infrastructure to transport clean energy will run headlong into the chicken-and-egg constraint inherent in structural change: Will infrastructure precede and unlock demand formation, or vice versa? Today, storage and transportation costs contribute to stagnant demand for clean energy solutions – chief among them, hydrogen. Only 1,600 miles of hydrogen pipeline and 5,000 miles of CO2 pipeline are operational in the United States – ~0.3% of natural gas pipeline infrastructure. As a result, midstream solutions that leverage and transform existing infrastructure to its maximum capabilities are well-positioned, as are novel storage mechanisms that can complement inefficient transportation.

III. SEEDING THE TECHNOLOGIES AND ECOSYSTEMS THAT DELIVER ABUNDANCE

The effective growth of clean baseload capacity – both through the scaling of clean, firm power and the relentless global deployment march of solar and storage – leads to a world that looks fundamentally different from ours today. One where energy is abundant, bringing within reach that same 1954 prediction of energy that is "too cheap to meter." While inherently speculative, playing out the economic enablers and constraints associated with near-zero-marginal-cost, abundant energy is useful to probe which business models and technologies are positioned to both win and deliver long-term economic and productivity gains to society.

At core, the removal of supply constraints fundamentally changes production functions for goods across the economy – ushering in a full industrial transition where "electrification of X" is not a catchphrase but rather the economically optimal decision for industrial actors. Geographic distribution of energy becomes a function of speed of system expansion, rather than access to material resources like irradiance, wind, or liquid hydrocarbons. A set of novel practices and products become economically viable where they previously were not: from additive manufacturing, to fuels and products made of carbon sucked from the air, to methods of long-distance travel that today may be unfathomable.

As remarkable as this world sounds, the notable shifts in consumption from a world of energy abundance will bring its own constraints. Supply chain pressures grow as declines in production costs stimulate additional demand, shifting geopolitical advantage and corporate competition towards access to robust infrastructure and supply chains rather than co-location with cheap energy. Congestion will arise in economic arenas, chief among them land, and waste. We will need significant resources to store or consume abundant energy. Adaptation needs become more pressing, but also more feasible, as both sequestering carbon and utilizing it in materials and fuels becomes cost-competitive, as does water generation via desalination.

1. Electrifying everything – for real.

A set of novel practices and products become *economically* viable where they previously were not: from additive manufacturing, to fuels and products made of carbon sucked from the air, to methods of long-distance travel that today may be unfathomable. Already, process innovations that reduce energy consumption – such as low-temperature industrial electrochemistry – are beginning to challenge this assumption. Looking forward, a fundamental shift in cost functions opens up opportunity across industry. Electrofuels can scale to cover demands that cannot be met by biofuels, as the cost and carbon intensity of electricity declines, while leveraging existing pipeline infrastructure. A future of on-demand air transportation could be unlocked with electrification of aircraft – from electric commuter airplanes to vertical take off and landing aircraft. Technological development in battery density, distributed electric propulsion, and autonomy is needed to support: The development of portable nuclear reactor technology, for instance, could deliver a step change in higher energy densities.

Sublime Systems

Sublime Systems is producing zero-carbon cement via a low-temperature electrochemical approach to extracting calcium.

2. Rethinking the production function.

Reduced energy costs enable novel manufacturing processes to scale across goods: from additive manufacturing, to 3D printing, and beyond. Innovations in additive manufacturing that reduce waste are well-suited for a world where input costs are lower but materials are scarce, and enable localized production. As we reach the mid-century mark, the automation of manufacturing becomes increasingly important in advanced economies to sustain productive capacities against the backdrop of an aging workforce – acting as a complement rather than a replacement to human innovation. Integrating AI into the hard tech production function becomes feasible as low-cost energy drives unconstrained compute power for generative AI and quantum computing into applications across fields, including into the very act of problem-solving and prediction. The ability to automate actual hard tech experimentation, creating autonomous labs of the future, is the frontier.

Foundation Alloy

Foundation Alloy is creating a vertically integrated metal part production platform that is the enabling technology for the next generation of advanced manufacturing techniques.

3. Moving from a low-carbon economy towards a new carbon economy.

The current high costs of removing CO_2 from the air and regenerating, purifying, and pressurizing it before utilization pose barriers to building out a new set of products and materials from captured carbon. As energy costs related to capture and utilization decline, carbon-negative manufacturing processes become feasible. Similarly, as costs of electrolytic hydrogen production decline, electrochemical pathways for CO_2-to-X become increasingly explored and competitive. Currently, many sequential carbon capture and reaction processes produce reduced carbon products that can be converted to higher-value hydrocarbons. CO_2 recycling process innovations that reduce complexity and hardware needs and address other impacts (byproducts, wastes, water utilization) will support higher utilization across end markets. These forms of CO_2 utilization also minimize infrastructure needs involved in a sequestration-based regime.

sora fuel

Sora Fuel provides the most economical route to carbon-neutral chemicals and fuels by integrating direct air capture with conversion to syngas, reducing carbon capture energy by 90% relative to standard approaches.

4. Building a circular economy that alleviates resource competition for fundamental inputs.

As the economy grapples with meeting new markets expanded by sub $10/MWh electricity, supply chains will become increasingly taxed, requiring rapid expansion of inventories and access to critical materials. At the same time, the world of *more stuff* also generates *more waste:* from tailings generated by mining critical minerals, to spent nuclear fuels, to a change in what we consider "garbage" when producing more is so much cheaper. Technologies that enable recycling, particularly of critical metals and minerals, will be important for avoiding a new generation of supply constraints and alleviating congestion. Specific opportunities include advanced plastic recycling technologies that can utilize waste streams as cost-advantaged feedstocks, and biomanufacturing that enables the conversion of agricultural residues and other organic materials into bio-based chemicals, fuels, and products — reducing the need for virgin resources and in turn minimizes waste.

Foray

Foray is bioengineering grown-to-order tree and plant products for supply surety.

For the better part of the last century, the energy industry, and the global economic and security order alongside it, has ebbed and flowed with humanity's ability to find and extract fossil resources. Only in the last decade has this reality begun to shift, and only in the last five years can we begin to see real data points of companies scaling clear technological advances that serve as pathways to an unconstrained, energy abundant future. No longer is the emergence of an energy abundant future a question of "if" but rather it is a question of "when." But, that slight linguistic shift should induce significant variation in capital expenditure in the energy industry and the economy writ large. Surely, if you knew that an energy abundant future was on the horizon, investing into that future would be a core piece of every portfolio, and consideration of the macroeconomic effects of energy abundance, a requirement for financial stewardship.

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As a General Partner, Michael spends his time working to accelerate the deployment of new technologies to solve some of the world's greatest challenges, with a particular focus on Climate Change mitigation. He serves as a Board Member for AtmosZero, Copernic, Mantel, Osmoses, Pascal, Sora Fuel and VEIR, and as an observer for Terragia.

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