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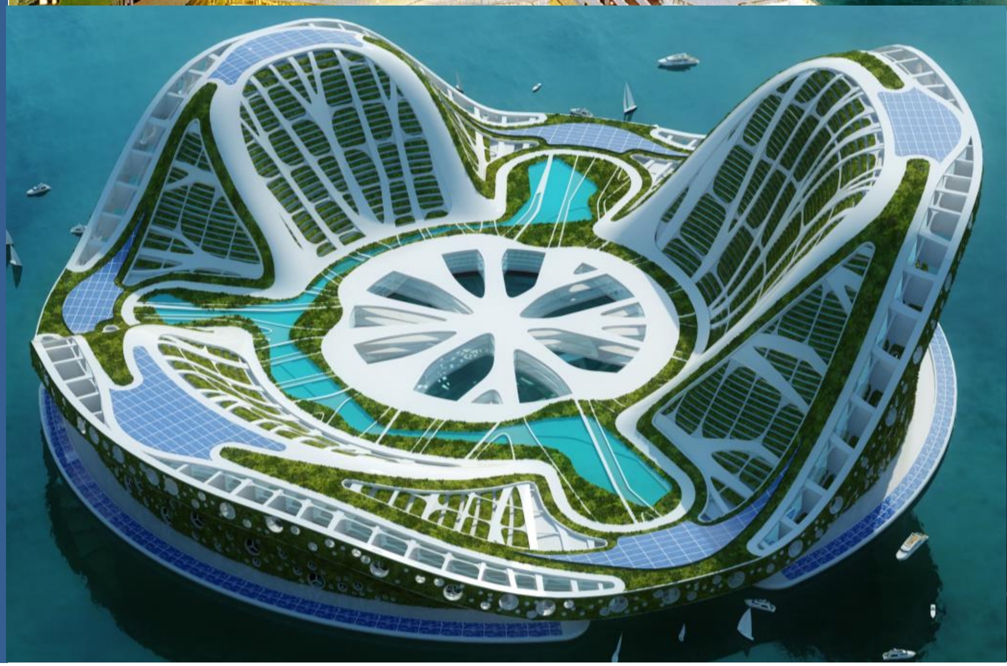
Energy Transition Fast Forward!

Scouting the Solutions for the 80-100% Renewable Economy

The Exergeia Report

Dr. Maximilian Martin

Impact Economy



This report asks how investing in early-stage renewable energy breakthroughs could accelerate the energy transition, given the goal to converge on a global economy powered 80-100 percent by clean energy within our lifetime.

The full report is available on the Impact Economy website:
http://www.impacteconomy.com/en/primer4.php

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Executive Summary

Current events ranging from California facing one of the most severe droughts on record—likely exacerbated by climate change—to geostrategic tensions between Russia and Ukraine over the price of natural gas and territorial borders remind us that the availability of and affordable access to energy is the biggest challenge of our times. With the advent of fracking, additional fossil energy is entering the market. However, only clean and renewable energy can play a lasting role in providing energy security and in combatting climate change.

In 2012, world total primary energy supply was 13,371 MTOE (Million Tons of Oil Equivalent).[1] 17.2 percent was produced from biofuels and waste, hydro, and nuclear energy sources. Given population growth, economic development, and the rise of Asia, global energy consumption is expected to keep rising. To reduce the adverse CO_2 and environmental impact of fossil fuel production and consumption, numerous initiatives are under way to enable a so-called energy transition to a global low carbon economy. There has been significant progress in increasing renewable sources of energy in the global energy mix. However, under a business as usual scenario, advancements are neither sufficient to deliver on a vision of cheap energy for all (to enable global development), nor to decelerate climate change by significantly cutting CO_2 emissions. We are on a track to lose our generation's race against time.

Can this be turned around? This report asks how investing in early-stage renewable energy breakthroughs could accelerate the energy transition, given the goal to converge on a global economy powered 80-100 percent by clean energy within our lifetime. The following questions informed the analysis:

- How to move to a sustainable energy paradigm providing energy on a massive scale?
- How to accommodate rising primary demand due to population growth (even if energy intensity per unit of GDP decreases)?
- How to locate the appropriate energy solutions?
- Which investments to back?
- How to scale up these solutions so they matter in the grand scheme of things?

Providing answers to such wide-ranging questions requires turning many stones. To this effect, we established the Exergeia Project and considered over 9,238 startups and clean energy projects since August 2014. Our search process for the leading breakthrough opportunities around the world included:

- Creating a dedicated website in 5 languages (www.exergeia.com);
- Running 14 online and print op-eds in 5 languages;
- Placing 18 advertisements in a range of specialized media calling for inventors to submit their work and ideas, reaching over 7,800,000 readers in the science space; and
- Conducting site visits to numerous energy clusters and incubators, as well as attending energy conferences and visiting promising labs and startups.

The following report summarizes our findings. We focused our search for breakthroughs on the key areas where progress is needed:

- Energy use/waste reduction (energy efficiency);
- Energy generation (considering all possible sources of renewable energy, but excluding nuclear power which is neither safe nor unlimited nor clean when waste disposal is considered);
- Energy storage;
- Energy transmission; and
- Energy distribution to end consumers.

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ABBREVIATIONS

ARPA-E	Advanced Research Projects Agency-Energy
BC	Before Christ
bcm	billion cubic meters
BoP	Base of the Pyramid
BP	British Petroleum
°C	degree Celsius
CdTe	Cadmium Telluride
CEO	Chief Executive Officer
CIS	Copper Indium Selenide
CIGS	Copper Indium Gallium (Di)Selenide $[Cu(In_xGa_{1-x})Se_2]$
cm	Centimeter
CO_2	Carbon dioxide
CPV	Concentrated Photovoltaics
CSP	Concentrating Solar Power
DARPA	Defense Advanced Research Projects Agency
dB	Decibel
DIN	Deutsches Institut für Normung
DOD	US Department of Defense
DOE	US Department of Energy
EDI	Electric Drive Italia
EEG	Renewable Energy Law (in German, "Erneuerbare Energien Gesetz")
EIA	US Energy Information Administration
EIT	European Institute of Innovation and Technology
EU	European Union
EUR	Euro
EV	Electrical Vehicle
FCEV	Fuel Cell Electric Vehicles
FOA	Funding Opportunity Announcement
GBP	Pound Sterling
GDP	Gross Domestic Product
GPS	Global Positioning System
GW	Gigawatt
HAW	High Altitude Wind
H_2O	Water
IEA	International Energy Agency
IRENA	International Renewable Energy Agency

IPO	Initial Public Offering
IT	Information Technology
ITER	International Thermonuclear Experimental Reactor
kg	kilogram
KIC	Knowledge Innovation Community
Km	Kilometer
KSU	Kite Steering Unit
kWh	Kilowatt-hour
LCICG	Low Carbon Innovation Coordination Group
LCOE	Levelized Cost of Energy
LED	Light Emitting Diode
LENR	Low Energy Nuclear Reactions
MA	Master of Arts
MIT	Massachusetts Institute of Technology
MJ	Megajoule
MPA	Master of Public Administration
MTOE	Million Tons of Oil Equivalent
MW	Megawatt
MWh	Megawatt hour
NASA	National Aeronautics and Space Administration
n.d.	Not dated
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Co-operation and Development
PhD	Doctor of Philosophy
R&D	Research and Development
SFCO	Solar Fire Concentration Oy
TPES	Total Primary Energy Supply
TRL	Technology Readiness Level
TWh	Terawatt-hours
UK	United Kingdom
US	United States of America
USD	United States Dollar
VC	Venture capital
W	Watt
Wh	Watt-hour
WHO	World Health Organization

1. Introduction: Scouting for Disruption

"People who have achieved all their objectives have probably set them too low."

—Herbert von Karajan (1908-1989)[2]

New paradigm wanted

Availability of and affordable access to clean and safe energy is the biggest challenge of our times. In connection with the upcoming United Nations Climate Change Conference (COP21/CMP11) to be held in Paris, France from 30 November to 11 December 2015, the topic of clean energy is increasingly moving up on the international agenda. Even many major oil and gas companies who are at home in the fossil business are currently reviewing their policies on climate change; some are considering renewing their previously unsuccessful participation in the renewables industry dating back to a decade ago.[3]

After the 250-year interlude of the fossil fuel age, the questions are:

- How can humanity move to a sustainable energy paradigm that will provide energy on a massive scale?
- How can we accommodate rising primary demand due to population growth (even if energy intensity per unit of GDP decreases)?
- How can our technological and financial prowess enable us to locate the appropriate clean energy solutions?
- Which investments should we back?
- Moreover, how can we scale up these solutions so they matter in the grand scheme of things?

For the past nine months, we have been looking for precisely these game changers. We considered over 9,238 startups and projects, were primarily interested in investable opportunities, and found over 100 that merit further assessment and investment.

Energy investments need to be grasped in their wider geopolitical and regulatory context

Nevertheless, to assess their promise it is important to grasp the wider context. For nations and regions, access to energy is also a question of competitiveness and geostrategic positioning. Take the EU, the largest energy importer in the world: the European Union (EU) imports 53 percent of its energy, spending around EUR 400 billion per year.[4] The European Commission talks about establishing energy as the EU's "fifth freedom"—next to the free movement of goods, people, services and capital, which are all central to the EU and its global competitiveness.[5] There is work to do: 75 percent of the EU's housing stock is considered energy inefficient. 94 percent of transport relies on oil products (90 percent of which are imported).[6] Important for businesses and consumers, wholesale electricity prices in Europe are 30 percent higher and wholesale gas prices over 100 percent higher than in the US.[7] To secure its long-term competitiveness, Europe needs to solve this—and this will cost money. Estimates indicate that over EUR 1 trillion need to be invested into the EU energy sector by 2020 alone.[8]

Compared to the end of the 18th century—when the previous renewable and "low" energy era ended—, the sheer amount of energy consumed has increased by several orders of magnitude. At the time of the French Revolution in 1789, Europe was mainly powered by animals—14 million horses and 24 million cattle with a total power of 7.5 billion Watts, or equivalent to the power of about 100,000 mid-size cars today.[9] 600,000 water mills and firewood complemented the largely renewable energy mix two hundred years ago.

The subsequent fossil fuel revolution rendered economic development and modernity, as we know it, possible. Now we need to take the next qualitative leap forward. Building on previous work, we set out to uncover the technologies and solutions that can help to achieve this.[10]

Energy is the mother of all markets

Throughout history, access to energy has ranked at the same level of importance as basic human priorities such as food, housing, health, or education. Energy is foundational to the ability to provide all of the former. Access to energy will remain central to the definition of geopolitical fault lines, as haggling over pricing of natural gas exports from Russia or wars over oil fields in the Middle East remind us nearly every day.

In 2010, world total primary energy supply was 13,113 Million Tons of Oil Equivalent (MTOE).[11] About 13 percent was produced from renewable energy sources (excluding nuclear power). This share has remained unchanged since 2000, but with changing contributions of the different renewable sources. Global energy consumption is expected to rise by about 45 percent, with a growth averaging 1.5 percent per annum from 2012 to 2035.[12] Fully 95 percent of the growth in demand is expected to come from the emerging economies. Energy use in the advanced economies of North America, Europe and Asia as a group is expected to grow only very slowly—and begin to decline in the later years of the forecast period. In other words, the centers of growth are shifting, but energy demand keeps growing. As it has thus far, with a 52 percent rise in demand over the last twenty years, and a 30 percent rise over the last ten years.[13]

Global warming is literally raising the temperature

Further accentuated by global warming—which to be addressed will require retiring fossil energy sources on a massive scale over the next two decades—it is fair to say that the world of energy is now again in the middle of another epic energy transition. This results in both creative destruction and fresh opportunities. The until recently stable and profitable business models of major utilities such as German energy giants E.ON or RWE—which relied on fossil fuels and oligopolistic market structures—are becoming obsolete fast.

Without some breakthrough, and taking into consideration the energy landscape and current trends, the pace of rise of clean energy will be too feeble to mitigate global warming, or even to provide access to the 1.3 billion people without access to energy (see **Figure 1**), and to the 2.6 billion without access to clean cooking facilities.[14]

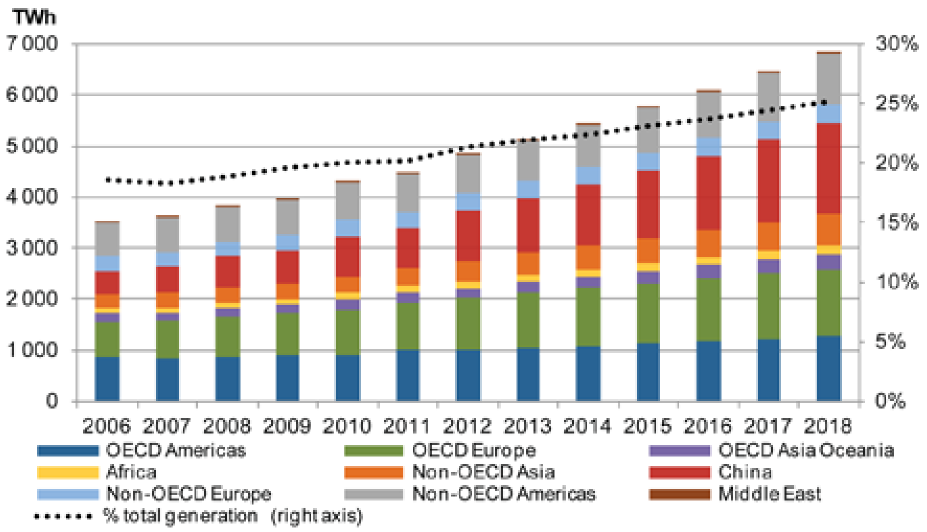


Figure 1: Global Renewable Electricity Production by Region as a Percentage of Total Electricity Generation (Source: IEA)[15]

We need to invent our way out of the problem

Turning back the clock is not possible. The only logical way forward is to therefore invent our way out of the bottleneck we are racing toward—just as humanity has always successfully addressed the obstacles standing in its development path, until now. What needs to happen is pretty clear; the estimated costs have also been mapped.[16] It is however less obvious how a full energy transition can happen fast. To succeed, we need to take our cues from science—and be ambitious.

Amazing breakthroughs are in the wings, waiting to be taken from the lab to becoming commercial products. Take silicene, also dubbed "graphene's cousin," and made of one-atom thick sheets of silicon atoms. In the mid-2000s, scientists theorized that silicon atoms could form sheets similar to graphene—or pure carbon in the form of a one atom thick, nearly transparent sheet that is about 100 times stronger than steel, and that in spite of its low weight, conducts heat and electricity with high efficiency.[17] However, even if graphene is the world's most conductive substance, it is missing a crucial characteristic: unlike semiconductors, which are used in computer chips, graphene misses a band gap. This is the energy hurdle that electrons must overleap before they can carry current, thereby enabling semiconductor devices to switch on and off, performing 'logic' operations on bits. Now given its properties, if silicene could be used to build electronic devices, it could enable the semiconductor industry to achieve the Holy Grail in miniaturization. Until three years ago, this could have been a theorist's fantasy. However, in 2012, Guy Le Lay, a French materials scientist at Aix-Marseille University, managed to create silicene in the lab.

It's time to take science's amazing new possibilities out of the lab

Many developments in chemistry, nanotechnology, and material science allow ideas from theoretical physics to be translated into practice. An obvious conclusion is this: we need to bring them to bear on solving the problem, and fast. To search for such new and unconventional sources of renewable energy, at Impact Economy we launched a dedicated initiative to set out to find fresh and potentially game-changing clean energy solutions and technologies, on which we are now reporting back.

To take a fresh perspective and uncover the leading opportunities, we bundled our talent scouting and idea sourcing activities under a dedicated new roof. We even coined a new term for this scouting effort, calling it **The "Exergeia" Project**: when ancient Greek philosopher Aristotle first came up with the concept of "*energeia*" (ἐνέργεια), he had in mind the connection between energy and the good life—or a principle that creates possibilities. In physics, the usable energy in which we are interested, is referred to as exergy—hence the neologism "Exergeia."

We have conducted the most ambitious ground sweep we know of

The energy industry is complex, highly regulated and can be confusing. If we are serious about the energy transition, we need to make progress along all energy frontiers: energy generation, storage, transmission and efficiency. Disruption is the name of the game. The transition to an 80-100 percent renewable economy over the next 35 years can only succeed if solutions move into place for all areas in which progress is needed. This is where we focused our search for breakthroughs:

- Energy use/waste reduction (energy efficiency);
- Energy generation (considering all possible sources of renewable energy, but excluding nuclear power which is neither safe nor unlimited nor clean when waste disposal is considered);
- Energy storage;
- Energy transmission; and
- Energy distribution to end consumers.

For the past nine months, we have been looking for game changers. Able to draw on a team to power the search process, we looked pretty much everywhere. In what amounts to the most ambitious recent search we know of, we considered over 9,238 startups and projects since August 2014 and:

- Created a dedicated website in 5 languages (www.exergeia.com);
- Published 14 online and print op-eds in 5 languages;[18]
- Placed 18 advertisements in a range of specialized media calling for inventors to submit their work and ideas, reaching over 7,800,000 readers in the science space; [19] and
- Conducted site visits to numerous energy clusters and incubators, as well as attending energy conferences and visiting promising labs and startups.

The problem is systemic—and so have to be the solutions

A special focus was on opportunities we could lend support to, so they can scale. The ultimate goal for any superior solution to the big energy puzzle is to achieve massive market penetration, climate impact, and to contribute to human wellbeing by helping to accelerate the energy transition under way. In practice, making progress requires quite a number of different solutions to be put to work from different ends of the problem at the same time—some of the theaters of action are visualized in **Figure 2** below.

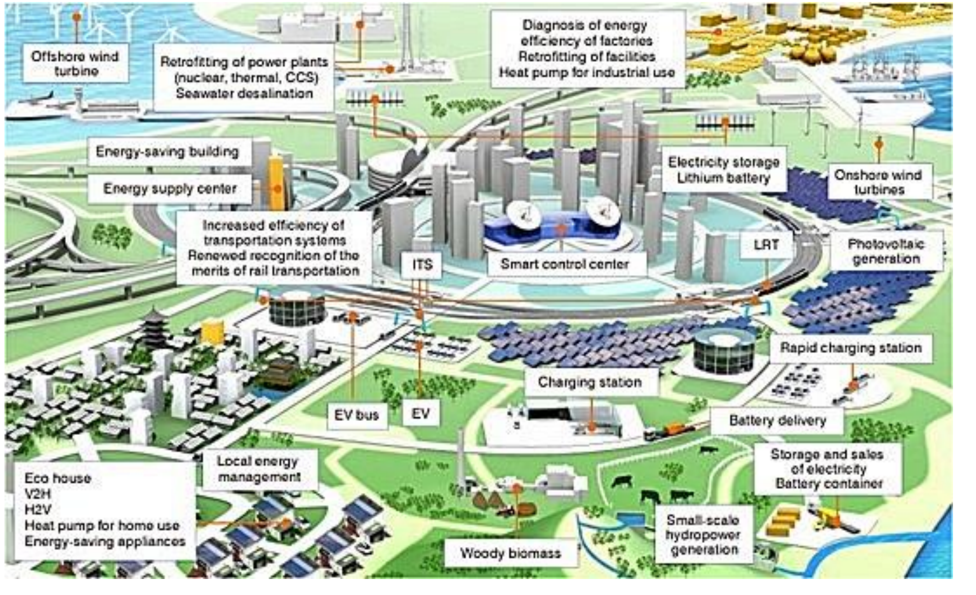


Figure 2: The Renewable Economy Landscape
(Source: Mitsubishi)[20]

To find the next steam engine, we used search filters

As the future powers on, this century's key challenge is affordable, carbon-neutral (or carbon-negative) energy, and security of its supply. If breakthroughs are needed to achieve this goal, what is the next plow in the digital global age—the tool which made human civilization first possible? What is the next steam engine? In assessing potential solutions, we wanted to know:

- The solution's estimated ability to solve a real energy problem;
- Upstream/downstream contribution (energy efficiency, generation, storage, transmission, distribution);
- Ability to scale;
- Economic viability;
- Maturity of solution (invention, proof of practical application, commercial viability); and
- Barriers to market entry.

In designing our approach, we also looked at established search and acceleration initiatives under way, such as the EU's Climate KIC and InnoEnergy, or the US' ARPA-E program (see **Spotlight 1**), and assessed how we could best differentiate our search from, as well as complement these bodies of work.

Spotlight 1: Public Sector Approaches to Invest in Innovation—EIT and ARPA-E

The EU and the US both have dedicated initiatives under way to help surface and support the scientific research needed to take technologies relevant to the energy transition to market, taking different routes to source renewable energy innovations.

Within the framework of its Lisbon Strategy for Growth and Jobs, the EU aims to create a green and innovative economy. To provide a dedicated platform for these efforts, the EU established a flagship institute headquartered in Hungary to integrate innovation, research and growth in 2008, the European Institute of Innovation and Technology (EIT). The goal was to help overcome Europe's perceived innovation gap.[21] EIT runs two main initiatives relevant to the energy field, namely the Knowledge Innovation Communities ("KIC") Climate KIC and KIC InnoEnergy. KIC InnoEnergy focuses on locating new technologies and products to enable sustainable energy for a climate-neutral Europe.[22] Climate KIC's brief focuses more broadly on sustainable cities, adaptive water management and carbon neutral production systems.[23]

To date, Climate KIC has financially supported over 175 startups via two funding platforms, the Climate-KIC Accelerator and the Climate Launchpad.[24] The focus is on very early stage support that is not capital intensive. The accelerator program provides staged support to breakthrough ideas related to a new technology with a substantial climate impact. In the initial "fundamentals" stage, grantees receive up to EUR 20,000 in funding as well as coaching; in the subsequent "validation" stage, applicants meet a minimum of 50 potential clients and can access another EUR 25,000 in funding; in the final "delivery" stage, applicants secure a first customer and receive up to EUR 50,000 in funding. The Launchpad program runs a cleantech business plan competition open to participants from over 20 countries where winners can access EUR 10,000 in funding, as well as becoming eligible for the accelerator program. KIC InnoEnergy similarly funds startups via a variety of windows, including partnering with crowdfunding platforms.[25]

A different approach is taken in the US by ARPA-E, the Advanced Research Projects Agency-Energy. ARPA-E was modeled after the successful DARPA program of the U.S. Department of Defense, which was responsible for bringing us the earliest predecessor to the Internet, global positioning systems (GPS) and many other technological breakthroughs. According to the agency's acting director, ARPA-E's mission is to "catalyze and accelerate energy technologies that will enhance the economic and energy security of the United States."[26] It does this by funding high-risk, high-reward research in technologies that are too early for the private sector and could revolutionize the way we generate, store and use energy.[27] ARPA-E was created in 2007 by the America COMPETES act, but did not officially come into being until 2009 when it was allocated USD 400 million in funding as a part of the American Recovery and Reinvestment Act, better known as the U.S. economic stimulus package.[28] In order to receive funding, applicants are initially invited to submit eight-page "concept papers" that describe the technical concept, followed by a full application if they pass the first cut. Submissions are only reviewed if they are deemed to be compliant, meeting eligibility requirements and conforming to content and form requirements set by the Funding Opportunity Announcement (FOA), and responsive; they also must fall within the technical parameters described in the FOA.[29] Submissions meeting these requirements are then assessed according to evaluation criteria specific to each FOA. ARPA-E states that in its considerations, it may also use Program Policy Factors, which are "broad policy considerations determined by agency needs and priorities."[30] Those who are selected receive assistance in the form of Cooperative Agreements or Technology Investment Agreements with awards ranging from USD 500,000 to USD 20 million.[31] ARPA-E then works closely with its projects for one to three years by establishing and monitoring project milestones and has substantial involvement in the management and direction of every project.

To date, ARPA-E grant recipients have applied for at least 34 patents and no less than five projects have generated spinoff companies or launched Initial Public Offerings (IPOs).[32] During 2011, in the midst of widespread program cuts, the U.S. Congress voted to increase ARPA-E's funding by 50 percent.[33] In fact, ARPA-E has been one of the few programs that both Democrats and Republicans value. This is in stark contrast to the Department of Energy's Loan Guarantee Program, which is notorious for lending USD 527 million to the solar company Solyndra of California, which ended in a controversial bankruptcy.[34] In comparison, ARPA-E has been inexpensive with an annual budget less than that loaned to Solyndra.

The program is not without criticism however. David Victor of the University of California San Diego observes that, "the parts of the innovation chain that are the hardest in energy are the scaling up and demonstration phases, and that's precisely what ARPA-E is not designed to do."[35] In other words, ARPA-E is not designed to help startups master the proverbial valley of death between initial launch and successful achievement of scale and financial viability. ARPA-E's annual budget of USD 300 million, which is spread across dozens of projects, is moreover insufficient for many energy technologies that may require hundreds of millions of dollars to build large-scale demonstrations before private investors are willing to move in.[36] This was precisely supposed to be the role of the above mentioned DOE Loan Guarantee Program which has come under fire after some high profile failures. Although there is much excitement surrounding ARPA-E, only time will tell of its innovation model for the energy ecosystem will yield results that are comparable to those of DARPA.

The solution may well be unconventional

This report explains what we found. One early insight is that it would be unwise to discard unconventional solutions. You will read about technologies that you find intuitive, and others that are literally mind blowing, such as low energy nuclear reactions (see **Spotlight 2**).

We were interested in potential game changers and how they could be brought to market. Just like Chinese leader Deng Xiaoping's famous maxim that "It doesn't matter whether a cat is white or black, as long as it catches mice," we did not mind if solutions were "unconventional," provided they work.[37] We hope the findings will inspire you to revise your ambition level upward as well.

Spotlight 2: A Big Game Changer? Low Energy Nuclear Reactions

What could possibly be the limit when we think about cheap energy, available everywhere without adverse emissions? Can we conceive a world where there is no need for coal, and perhaps not even for power grids? Where homes, communities and offices could generate their own power through a device that has an energy density of up to 8,000,000 times that of today's combustion energy process?

A solution statement that has excited many scientists now for several generations are so-called "Low Energy Nuclear Reactions" (LENR).[38] This is a type of nuclear reaction theorized to occur at near room temperatures.[39] If it can be achieved, it could play an important role in the energy transition by producing energy that is much cleaner, safer and cheaper than any other known source of energy.

How would this work? LENR has been theorized as a phenomenon where unusual amounts of heat are released when certain metals such as nickel or palladium absorb hydrogen or deuterium in the presence of an external stimulus, such as heat or an electric current.[40] Given that LENR would be the Holy Grail of energy generation, it is not surprising that many scientific attempts are ongoing now to replicate and control the LENR effect. One player in seeking to revolutionize this technology is E-Cat, standing for "Energy Catalyzer." E-Cat is a device invented by Italian-American inventor Andrea Rossi: hydrogen gas, powdered nickel and undisclosed proprietary catalysts are combined to produce a large amount of heat through a LENR process inside a specially designed chamber.[41] According to Rossi, the cost of energy produced by the E-Cats will be at least one sixth of the cost of conventional sources. Every six months the E-Cat units would need to have their reaction chambers containing processed nickel and the catalyst replaced by licensed agents. The potential of this device was independently assessed by three European Universities to have about 1,000 times more peak power than gasoline.[42] To get a sense of the order of magnitude, if this technology were to be applied in the automobile industry, with the cost equivalent of one tank of gasoline one could drive several thousand kilometers, without generating any kind of emissions. In 2014, US firm Industrial Heat acquired the rights to Andrea Rossi's E-Cat Technology for USD 11 million.[43] Skeptical scientists have long ridiculed LENR however. Considering it in the category of pseudo-science, they argued that laws of physics as we currently understand them do not permit a LENR device to work. The jury is not yet in though. Let us not forget that immediately before the advent of quantum physics one hundred years ago; leading scientists argued, "All that is left in physics is to figure out the sixth zero behind the decimal."[44] Once quantum physics burst onto the scene, we learned that this assessment was false. Dennis Bushnell, chief scientist at NASA's Langley Research Center argues that LENR has "demonstrated ability to produce excess amounts of energy, cleanly, without hazardous ionizing radiation, without producing nasty waste."[45] According to Bushnell, estimates suggest that one percent of the nickel mined on the planet each year could produce the world's energy requirements at 25 percent of the cost of coal.[46]

Currently, there are however no viable LENR devices on the commercial market, and the bulk of research money is going elsewhere. For example, projects such as ITER ("International Thermonuclear Experimental Reactor" known as the "the way" in Latin) indicate a continued general interest in nuclear fusion: the EU-led international 500 MW nuclear fusion research project is currently building the world's largest experimental tokamak nuclear fusion reactor. Located next to France's Cadarache nuclear research facility, the USD 16 billion project—financed by the seven parties to ITER, the EU, the US, Russia, Japan, China, South Korea and India—seeks to use plasma physics to achieve a full-scale electricity-producing fusion power plant.[47]

2. Fast Forward, Now: Some Market Context

Current growth objectives are too unambitious

Our core Exergeia working assumption was this: the current growth projections for renewable energy in the overall global energy mix are too unambitious. For example, the BP Global Energy Outlook 2015 predicts that among non-fossil fuels, renewables including biofuels but excluding hydro and nuclear power will advance from a market share of 3 percent today to around 8 percent in 2035, overtaking nuclear energy in the 2020s and hydropower in the 2030s. In electricity generation, the percentage of renewables is much higher already: BP predicts that growing renewable energy supply will lift the aggregate non-fossil share from 32 percent in 2013 to 38 percent in power generation by 2035.[48] Due to idiosyncratic factors, some countries already have a high share of renewables in power generation. For example, in New Zealand 70 percent of all electricity comes from renewable sources already, mainly from hydropower and geothermal power.[49]

The lead question follows readily: what technologies do we need to bring to market to raise the share of renewables to 80+ percent in the energy mix, and close to 100 percent in power generation? In addition, which critical blockers stand in the way of a large-scale transition to intermittent sources of renewable energy? We focused on the technologies with the greatest potential to contribute to the overall solution.

The share of renewables is growing, but from a low basis

Renewable energy is energy that is derived from natural processes (e.g. sunlight and wind) that are replenished at a higher rate than they are consumed. Solar, wind, geothermal, hydropower, bioenergy and ocean power are all sources of renewable energy. The share of traditional biomass out of total renewable energy fell from 50 percent in 2000 to 45 percent in 2010, while biofuels (transport fuels produced from biomass feedstock) met a growing share of transportation fuel needs.[50] Hydropower, the largest source of renewables-based electricity, remained stable. Electricity generation from wind grew by 27 percent and solar photovoltaics by 42 percent per year on average during this period.[51] The role of renewable sources in the global power mix, in particular, continues to increase rapidly. On a percentage basis, renewables continue to be the fastest-growing power source. As global renewable electricity generation expands in absolute terms, it is expected to surpass that from natural gas and double that from nuclear power by 2016, becoming the second most important global electricity source, after coal.[52] Globally, renewable generation is estimated to rise to 25 percent of gross power generation in 2018, up from 20 percent in 2011 as deployment spreads out globally.[53]

Bioenergy and hydro are well established

Investment in renewables of USD 6.4 trillion is required over the period 2012-2035.[54] The power sector is estimated to account for 94 percent of the total, including wind (USD 2.1 trillion), hydro (USD 1.5 trillion) and solar photovoltaics (USD 1.3 trillion), with the remainder in biofuels.[55]

Due to its widespread non-commercial use in developing countries, bioenergy is the single largest renewable energy source today, providing 10 percent of world's primary energy supply.[56] It plays a crucial role in many developing countries, where it provides basic energy for cooking and space heating, but often at the price of severe health and environmental impacts. The deployment of advanced biomass cook stoves, clean fuels and additional off-grid biomass electricity supply in developing countries are key measures to improve the current situation and achieve universal access to clean energy facilities by 2030. Global primary energy demand for bioenergy, excluding traditional biomass, is expected to more than double from 526 MTOE in 2010 to nearly 1,200 MTOE by 2035, growing at an average rate of 3.3 percent per year.[57]

Hydro is currently the largest renewable source for power generation in the world, producing 3,431 Terawatt-hours (TWh), meeting 16.3 percent of global electricity needs at competitive prices and representing about 85 percent of global renewable electricity.[58] Hydro dominates the electricity mix in several countries (industrialized, emerging or developing); 159 countries have a fully mature hydro technology. Global hydropower capacity is projected to increase from 1,067 Gigawatt (GW) in 2011 to over 1,680 GW in 2035; incremental hydropower production in OECD countries, where the best resources have already been exploited, is however limited.[59]

Wind and solar: from field mice to 800-pound gorillas?

Solar energy is the conversion of sunlight into usable energy forms. Solar photovoltaics, solar thermal electricity and solar heating and cooling are well-established solar technologies. Today, solar energy produces only a small fraction of the total primary energy supply (TPES), and on the projected path is expected to rise to just over 2 percent in 2035. The potential is much greater though if better solar technologies can come on stream. Solar photovoltaics, often considered the poster child of the renewables industry, decreased from a record USD 91.6 billion in 2011 to USD 79.7 billion in 2012, as continued growth in annual capacity additions was not enough to offset falling photovoltaics prices, but is planned to reach USD 123.7 towards 2022.[60]

Wind energy is developing towards a mainstream, competitive and reliable power technology, producing 2.5 percent of global electricity demand.[61] Globally, progress continues to be strong, with countries that are more active and players increasing annual installed capacity and investments. Technology improvements have continuously reduced energy costs, especially on land; the industry has overcome supply bottlenecks and expanded supply chains. Wind is projected to grow from USD 73.8 billion in 2012, up from USD 71.5 billion the previous year, to USD 124.7 billion in 2022.[62] For both solar and wind technology, the challenge is: how can they graduate from their current status of field mice in the global energy mix and unlock the "800-pound gorilla" potential that is inherent in the sun and wind as sources of energy?

Expect a limited contribution of further renewable energy sources

Investments in biofuels reached USD 95.2 billion in 2012, up from USD 83 billion the previous year, and are projected to grow to USD 177.7 billion by 2022.[63]

Geothermal power comprises mature renewable technology options that can provide base-load power from energy stored in trapped vapor and liquids. In 2012, global geothermal power capacity was 11.4 GW and generated around 72 TWh of electricity.[64] Enhanced geothermal technologies are under development that would allow expanding the use of this technology family beyond countries that have resources suitable for established technologies. As a pioneer, Iceland has a 25 percent share of its total electricity demand provided by geothermal power.[65]

Ocean power, with a minor capacity of 0.54 GW in 2012, encompasses five different types of technologies that exploit the following phenomena, none of which is widely deployed yet: tidal rise and fall (barrages), tidal/ocean currents (kinetic energy), waves, temperature gradients, and salinity gradients.[66]

Infrastructure matters: to achieve an "Energy Union", Europe needs better grid interconnectedness and storage[67]

In spite of Europe's historically leading role in investment in renewable energy, it is important to note that European renewable energy businesses are still small in comparison with fossil fuel companies: in 2014, they had a combined annual turnover of EUR 129 billion and employed just over a million people.[68] EU greenhouse gas emissions fell 18 percent from 1990-2011, benefiting from the demise of polluting industries following from the transformation of Eastern Europe after the dismantlement of the Soviet bloc. Partially driven by policy goals, the renewables industry is set to grow: by 2030, the EU aims to cut greenhouse gas emissions by at least 40 percent, boost renewable energy by at least 27 percent, and improve energy efficiency by at least 27 percent.[69] This is also the EU's vision for a global climate agreement to be negotiated in Paris in December 2015.

The new regulatory idea on the table is the goal of an energy union, or termed more officially, a "Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy."[70] To achieve such an energy union, the EU Commission will introduce new legislation to redesign the electricity market, as well as ensuring more transparency in gas contracts, and developing regional cooperation as an important step towards an integrated market. In practice, this means a stronger regulatory framework, new legislation to ensure the supply for electricity and gas, and increased EU funding for energy efficiency or renewables. Provided public funds are used to finance and provide market access for the most promising inventions, the 'Energy Union' could help to significantly fast track the energy transition.

A common criticism of accelerating the energy transition is that the grid will not be able to handle a very large volume of intermittent sources of power, so grid stabilization is necessary. For example, in discussions one hears routinely from its neighbors that Germany destabilizes the grid—because it is pressing ahead with an ambitious energy transition. Tackling the technical constraint that will otherwise impose a ceiling on the growth rates of renewables will require precisely the fresh solutions we scouted for.

Even otherwise well-integrated economic areas are not necessarily fully integrated grid-wise. For example, in spite of its ambitious plans, the EU is not even close to a single homogeneous energy market: defined as at least 10 percent of installed electricity production capacity being able to "cross borders," 12 EU member states do not yet meet the EU's minimum interconnection target (namely Cyprus, Estonia, Ireland, Italy, Lithuania, Latvia, Malta, Poland, Portugal, Romania, Spain and the UK).[71] 10 percent electricity interconnection by 2020 is the minimum necessary for electricity to flow and be traded among EU states.[72] An appropriately interconnected European energy grid could save consumers up to EUR 40 billion a year.[73] If the EU implements its 137 listed electricity projects—including 35 on electricity interconnection—only two member states would remain under-connected. To get a sense of what an energy transition means at the national level, consider the case of Germany (see **Spotlight 3**).

To take a significant step forward, we need better solutions to both energy storage and to electric power transmission, or the bulk transfer of electrical energy from the point of generation to electrical substations that are located near demand centers. A related question is what the appropriate mix between centralized and decentralized power generation would be in a 100 percent renewable economy. While we found several promising directions in power transmission and distribution to help fast track the energy transition in ways that are commercially viable—room-temperature superconducting technologies, for example—they are not the focus of this report. Instead, we will mainly focus on findings in renewable energy generation and energy storage.

Spotlight 3: The German Energy Transition ("Energiewende")

For the energy transition to succeed, bottom up innovation needs to encounter an enabling market environment that is created by top-down regulation. Germany is a remarkable example of how the demands of a grassroots movement managed to translate into a policy that came to be supported by all major political parties twenty years later.

After the first oil shock in 1973-74, the green movement kicked off and linked up with the anti-nuclear and peace movements. Concerns about environmental protection especially concerning the damage from acid rain, paired with the anti-nuclear movement based on fear of a nuclear catastrophe set free enormous creativity to look for alternative solutions. A growing majority of the population was demanding solutions; this led many scientists and politicians to look for a serious alternative to non-regenerative energy. Moreover, the green movement initially led to the emergence of a new political party, the Green Party. In other words, a grassroots movement led to the creation of an institutional infrastructure and presence in the parliamentary process that would relentlessly position the alternative energy topic. By 1998, this former fringe party would find itself in government.

Once in power, this led to legislation that would guarantee producers of renewable energy a stable price (EEG). Rather than financing investments, a fixed price level was set so that investment made economic sense; the cost was rolled over to all consumers of electricity as a part of the price of electricity. This allowed for the establishment of a market and became the blueprint for other countries. The combination of strict legislation and a price signal made the German renewable energy market a place for solutions to emerge that would be competitive on the global market. German Chancellor Angela Merkel eventually even pressed ahead with a renewable energy transition without nuclear power, initiating a definitive exit from nuclear energy after the Fukushima disaster.

Today, the German Energy Transition is still a work in progress. With imports of 41 billion cubic meters of natural gas from Russia (2013), energy dependence remains massive.[74] Moreover, German consumers currently face among the highest electricity costs in Europe, half of which consist of taxes and fees—seen that the country's energy-hungry industries are largely exempted from carrying the cost of the energy transition.[75]

Notwithstanding, Germany represents the most advanced example of a national energy transition under way. This raises the question why this first happened there. Why not in France, the UK, or in Russia? Other countries did not become first movers because they were both saturated in terms of energy supply and did not face a similarly strong demand from the grassroots level to define an alternative energy future: France with nuclear power, the Netherlands with natural gas, Russia with gas and nuclear power, and the UK with coal, gas, North Sea oil and nuclear power. This is changing—many countries around the world are now working on achieving an energy transition.

As we scout for the next generation of clean energy solutions, it is imperative to be ready to work with governments to put in place the optimal environment for competitive renewable energy to succeed on the market. When bottom-up innovation meets a top-down enabling environment, amazing progress becomes possible.

3. Three Levers of Acceleration

Renewables must succeed on a non-subsidy basis

If the energy transition is to succeed, subsidies can be deployed only to reach critical mass, rather than to operate at scale. To compete, renewable energy will have to become fully price competitive and substitutable with fossil fuels much faster. If renewables can turn out electricity at a few cents a kilowatt-hour, solar panels can capture energy at night, and storage solutions can compete with gasoline in terms of energy density and ability to release energy, then we are talking.

In the past, advances in science have achieved equivalent advances. The next generation of solutions brings current advances in fields such as material sciences, nanotechnology, information technology, or engineering to bear on the problem. We have scouted for breakthroughs in the following five domains, and are reporting back here on interesting solution directions in the first three categories:

- Solar power;
- Wind power;
- Energy storage;
- Energy efficiency (which has to become as simple and ubiquitous as using a smartphone); and
- E-mobility.

Solar photovoltaics is ready for an efficiency revolution

The efficiency improvements in solar photovoltaics over the past 40 years indicate that an efficiency revolution is in the wings (**see Figure 3**).

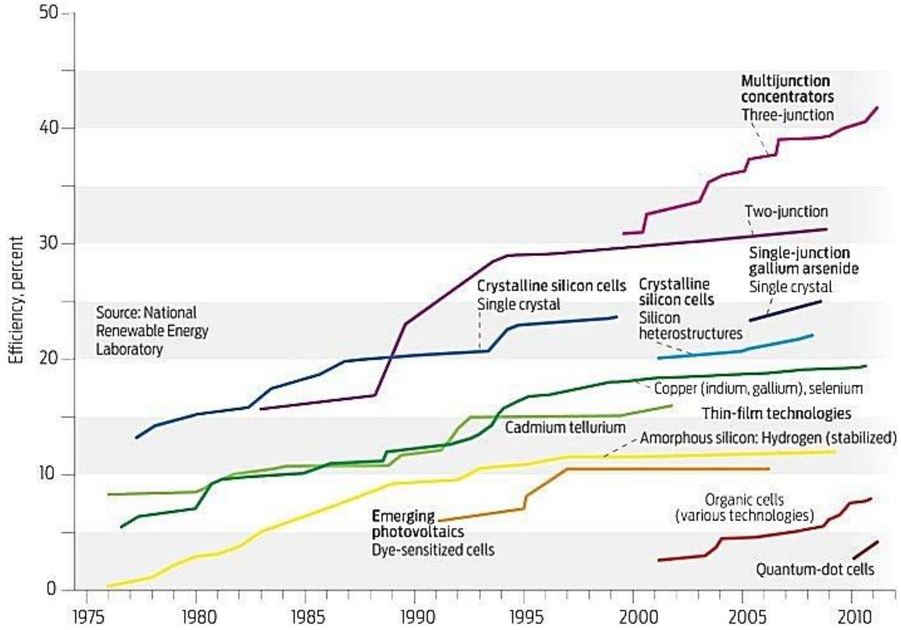


Figure 3: Efficiency Improvements in Solar Photovoltaics, 1975 – 2012 (Source: NREL)[76]

Remember the 'solex' in the Bond movie "The Man with the Golden Gun," released right after the first oil crisis?[77] Daring is essential for our goal of locating inventions that can fast track our energy future.

Multi-junction cells allow for a 46 percent conversion efficiency already today.[78] And the fast rise of the efficiency curve of 'perovskites,' a newer class of materials with a particular crystal structure is exciting: their band gap can be tuned by changing halide content to become very good light absorbers over the whole visible solar spectrum. Reported high carrier mobility and long diffusion lengths mean that photo generated charges can travel longer distances, increasing charge absorption and ultimately producing more electricity. Moreover, using rectifying antennas (or 'rectennas'), one can already convert electromagnetic radiation to electricity, with reported efficiencies of over 90 percent in the microwave range.

In solar photovoltaics, we found two especially promising directions:

- First, physics predicts rectennas can also reach microwave range efficiencies in the infrared and optical ranges, converting sunlight to electricity. An exciting step forward follows then from the energy cost and availability implications of high-efficiency solar energy harvesting, which leverages the full solar radiation spectrum during the day. Possibly one can even conduct long wave radiation energy harvesting at night.
- A second breakthrough opportunity relates to much better trapping sunlight in solar cells. Optical losses consist of light that could have generated an electron-hole pair, but does not, because the light is reflected from the front surface or because it is not absorbed in the solar cell.[79] Optical losses chiefly affect the power from a solar cell by lowering the short circuit current. The way forward is an optical (nano) antenna that keeps the light trapped longer in the cell than by previously used microstructures. For example, Nanotechnology Solar, a startup based in Germany has come up with a solution of using advanced nano-imprint lithography that allows the cost effective production of gradient nanostructures for optical components. First preliminary experiments and simulation results indicate that this solution could increase the relative efficiency of solar cells by over 10 percent and in the future, a silicon solar cell/module with a relative efficiency of over 24 percent could be realized.[80]

A different but also relevant direction consists of providing energy to the 1.3 billion people around the world who are still lacking access to electricity (see **Spotlight 4**).

Spotlight 4: Energy in the Developing World

In the non-OECD countries eager to catch up, industry is growing steadily with an estimated 2.3 percent annual growth rate through 2040.[81] Given industry's ability to provide jobs and create wealth, this is good news. However, industry is also energy intensive. The industrial sector uses more delivered energy than any other end-use sector. It consumes about one-half of the world's total delivered energy.[82] In fact, many industrial applications use 15-85 percent of the supplied energy for heating the materials; most of which supplied by fossil fuels such as coal, gas and fuel oil.[83] For domestic applications and artisanal entrepreneurship, about 3 billion people rely on biomass such as firewood, charcoal, agricultural waste and biomass. While not a problem *per se*, current practice is leading to rapid deforestation. Insufficient cooking technologies also lead to adverse health effects, predominately affecting women and children, and causing more than 3.8 million premature deaths each year.[84]

Next to supply of clean energy and energy efficiency, access is the key theater. Today, an estimated 1.3 billion people around the world have no access to electricity at all; 84 percent of them live in rural areas, and more than 95 percent live either in sub-Saharan African or developing Asia.[85] Estimates indicate that USD 36 billion would need to be invested every year on average until 2030 for everyone to have access to reliable electricity.[86] Delivery and business models need to be adapted though: while individual purchasing power at the Base of the Pyramid (BoP) is low, aggregate expenditure on energy is sizeable; the 3 billion people at the BoP globally currently spend USD 433 billion on energy each year to meet their cooking, lighting, communications and income generation needs.[87]

Given the enormous latent demand for capital backing clean energy in the developing world, our search considered the range of potential solutions that could yield rapid progress—drawing on a range of sources including solar photovoltaics, biomass, hydrocarbon and geothermal. We asked which solutions are practically viable given low purchasing power, rugged environments, as well as widespread shortages of technical skills. In other words, to invest in the vision of a world where everyone has access to energy in a not-too-distant future, solutions have to be incredibly simple, sturdy, and cost effective:[88] a Haitian entrepreneur running a cooking business and a local dairy plant in India have very different setups—but both need adapted solutions to reduce energy costs. To be groundbreaking, a technology needs to be clean, affordable, scalable and able to provide heat for a variety of applications ranging from cooking to industrial processes in the 200-500 Celsius range.

Technological solutions suited to this need have actually existed since the nineteenth century. Augustin Mouchot, a French inventor motivated by his theory that the industrial revolution would eventually run out of coal, developed the first concentrating solar powered engine. His invention was presented to Emperor Napoleon III in 1866.[89] A few decades later, American inventor Frank Shuman took CSP technology a step further when he constructed the world's first solar thermal power station in Maadi, Egypt in 1913. Shuman's plant was able to run a steam engine with enough energy to pump 22,700 liters of water per minute for irrigation.[90] Despite its incredible potential to generate clean energy, interest in the technology was lost due to the advent of World War I and the subsequent discovery of cheap oil as an energy source.

Throughout our search we have come across companies working hard to accelerate the development of this promising technology through frugal innovation with the goal of universal accessibility. It is important to note that CSP does not necessarily compete with Solar PV, but in fact is a complimentary technology. While Solar PV is well suited for distributed electricity generation, CSP is the most efficient clean solution for generating heat.

It is time to graduate to "Big Wind 2.0"[91]

Created by the uneven heating of the Earth's surface by the sun, wind energy is one of the cleanest, most environmentally friendly energy sources.[92] Wind turbines produce mechanical or electrical power from airflow. The potential of wind power is enormous, amounting to nearly 20 times more than what the entire human population needs.[93]

The rise of the modern wind industry using small wind and large onshore and offshore turbines producing electricity by rotating around a horizontal or vertical axis dates back to the 1980s, although windmills, their predecessors, have been around for millennia and wind generators for electricity have been used on farms since the 1930s.[94]

The world's biggest wind turbine, the Vestas V164, is a 8MW geared offshore turbine that came online in January 2014, with 80 meter-long blades and a lightweight nacelle; it is currently being tested at the Danish national wind turbine test center at Osterild.[95] Large 1MW wind turbines can generate enough electricity to supply about 600 U.S homes. Industry experts predict that wind will supply one third of the world's electricity needs by 2050.[96]

Today, there are several interesting frontiers in wind power that could help to further harness its potential (see **Table 1**), relating to:

Horizontal axis wind turbines;

- Vertical axis wind turbines
- Bladeless turbines;
- High altitude winds; and
- Bionic coating as well as coating using nanotechnologies.

Technology	Description	Breakthrough	Environmental Impact	Challenges	Technological Readiness
Horizontal Axis Turbines	The most widespread technology used both on- and offshore	Breakthroughs have led to larger systems and offshore capabilities	High materials footprint. Visual environmental impact	As a mature technology, the challenge is cost reduction	Mature
Vertical Axis Turbines	Wind generators with blades spinning around a vertical axis	Smaller swept area resulting in reduced wake effect. Can harvest wind from any direction		Lower efficiency than horizontal axis turbines	Mature
Bladeless	A bladeless tower can generate energy by vibrations caused by wind[97]	By eliminating the need for blades, materials and maintenance cost are greatly reduced.	Less materials translates into a 40% lower CO_2 footprint. Bird kills are also reduced	The system would need to be much taller to produce the same energy as a conventional system	R&D / Early prototype
High Altitude Wind (HAW)	Wind's kinetic energy increases as the cube function of wind speed which greatly increases with altitude	Due to breakthroughs in lightweight materials and sensors, high altitude kites can fly autonomously	By eliminating concrete and steel structures, HAW can use 90% less material	Autonomous takeoff & landing, regulatory challenges	Several companies have working prototypes
Bionic/Nano Coating	Through biomimicry, researchers are applying designs perfected by nature over millions of years	By imitating feathers for example, turbines could operate in highly variable winds and with greater efficiency	By increasing efficiency, wind resources are maximized	Cost effective production and durability	R&D

Table 1: Performance and Readiness Comparison of Different Wind Technologies

In assessing these opportunities, we found it helpful to ask how they promise progress in the industry associated with one or more of four themes:

- Dealing with the wake effect;
- Repowering;
- Addressing atmospheric turbulence, and
- Harnessing high altitude winds (HAW).

First, the so-called "wake effect" is an aerodynamic turbulent effect that occurs between commercial upwind turbines and downwind turbines, changing natural wind speeds.[98] Upwind turbines create wind wakes that affect the natural wind flow to adjacent downwind turbines. This then causes the downwind turbines to experience diminished energy production and in some cases, increased mechanical loads, leading to overall power losses.

Any wind turbine design that can significantly reduce exposure to the wake effect and run at lower wind speed is relevant to boost economics, power production and land usage efficiency. For example, we found that Swiss company Bogga Wind Power has an advanced design for a vertical axis wind turbine that may be able to overcome the wake effect present in today's large wind farms. As a result, their wind turbines are expected to have a higher power generation efficiency, produce lower noise (0-10 dB compared to 5-60 dB from horizontal axis), increase land efficiency, and be able to harvest turbulent and higher wind speeds.[99]

Second, "repowering" or the process of replacing old turbines with modern wind turbines is becoming a necessity because of both age and performance. For investors in Germany, repowering got a boost with the amendment of the Renewable Energy Law (EEG) on January 1, 2009. Operators of older wind farms came to profit not only from the higher yield of new wind turbines, but also from the so-called repowering bonus (at the rate of 0.5 EUR ct./kWh), an additional modernization incentive.[100] Unfortunately, the German regulators dismissed the "Repowering bonus" introduced in 2009. Also, In 2017, Germany will stop the "Feed-in-tariff", and introduce Project Tendering. This will put additional pressure on wind turbine manufacturers to reduce overall wind power project cost. This new regulation will impact the financing of new wind farms, typically located on low wind speed sites (because high wind speed sites are already developed), and bring additional importance on the repowering of aging wind turbines (already installed on the best wind resources) and the need for maximizing the land usage efficiency (i.e. reduced wake effect).

Third, we found technologies that can harvest winds at higher altitudes interesting because these winds become steadier, more persistent, and have a higher velocity and thus more kinetic energy. For example, for harvesting high altitude winds, Kitenergy, an Italian company has come up with a groundbreaking concept of using airfoils or power kites, similar to those used for kite surfing, linked to the ground by two cables, to reach altitudes of about 600-1000m above the ground. Winds are stronger at such elevations and more constant compared to the elevation where current wind towers operate. The flight of the airfoil is tracked using on-board wireless instrumentation and driven by an automatic control unit, able to differentially pull the lines to influence the wing motion. By converting the traction forces acting on the airfoil, electricity is generated at ground level by rotating mechanisms and electric generators. Electric drives, drums, the on-board sensors and all the hardware needed to control a single kite form a system, the "Kite Steering Unit" (KSU) which forms the core of the Kitenergy technology. A benefit of electricity generation at the ground level is the reduction of weight: a typical 2MW conventional wind turbine weighs 300 tons, whereas an otherwise equivalent Kitenergy system would weigh only 2 tons. The company forecasts that they will be able to produce a 100MW wind farm at a levelized cost of energy (LCOE) significantly less than EUR 50/MWh.[101] This compares favorably to the US Energy Information Administration's (EIA) forecast for the lowest LCOE in 2019 of a fossil fuel electric generation of EUR 51.7/MWh.[102]

Another constraint standing in the way of Big Wind 2.0 is atmospheric turbulence. Atmospheric turbulence impacts wind energy through power performance effects with adverse impacts on turbine loads and noise propagation. To respond, Munich based startup AF-AX has come up with an innovative adaptive rotor blade technique based on bionics that can improve aerodynamics of the blade and help overcome atmospheric turbulence.[103] Coating wind turbines so they can deal much better with turbulence and produce energy at lower wind speeds, as well as suffering from much less downtime is in principle possible, merging design thinking from bionics with advances in materials sciences.

Storage is the critical constraint in the energy transition

Seen that renewable sources produce energy only intermittently, storage becomes a key constraint for the energy transition (the sun does not always shine and the wind does not always blow; but the demand for energy remains). Energy storage thus plays a key role to integrate more renewables into the grid, for continuous and flexible supply of energy and for reducing energy costs by peak shaving.[104] A breakthrough in batteries is moreover a prime enabler of e-mobility.

The problem is: today's batteries are not up to the task. The major challenges batteries of today face consist of cost, life, safety, as well as performance over a wide temperature range (-30 to 52°C). For example, the chemical energy stored in 1 kg of coal is 24MJ/kg. Combusting this coal in a thermal power plant with an efficiency of 40 percent would correspond to a useful energy of 9.6MJ/kg of coal.[105] By contrast, the energy density with the most advanced commercially, available Lithium-Ion technology corresponds to 0.84MJ/kg (Tesla S model, 233Wh/kg). Batteries currently used in hybrid and electric cars average only 150 Wh/kg, compared with gasoline's 12,000Wh.[106] That is far from good enough. Worse, progress in storage compares very unfavorably with, say, advances in semiconducting: rather than progress on a logarithmic scale in computing power, we are looking at progress on a linear scale in storage. That needs to change: the need of the hour is a technology that is capable of effectively maximizing the output, reducing the size and weight of current systems, increasing performance and reducing life cycle costs for batteries—all while improving safety and stability under harsh conditions.

The 2022 goals set by the US Department of Energy with regard to batteries and energy storage provide a useful guideline for identifying such technologies:[107]

- Reduce the production cost of an electric vehicle battery to a quarter of its current cost;
- Halve the size of an electric vehicle battery; and
- Halve the weight of an electric vehicle battery.

Achieving these goals would result in:

- Lowering battery cost from USD 500/kwh to USD 125/kwh; and
- Increasing density from 100 Wh/kg to 250 Wh/kg.

Currently, electric vehicles use a large quantity of Li-ion batteries. These batteries suffer from many drawbacks such as cost, overweight, limited capacity, reliability and risk of fire, which make them less attractive than standard fossil fuel vehicles. New combinations such as Lithium and Sulfur hold the potential to dramatically raise batteries' energy density and lower their cost (see **Figure 4**).

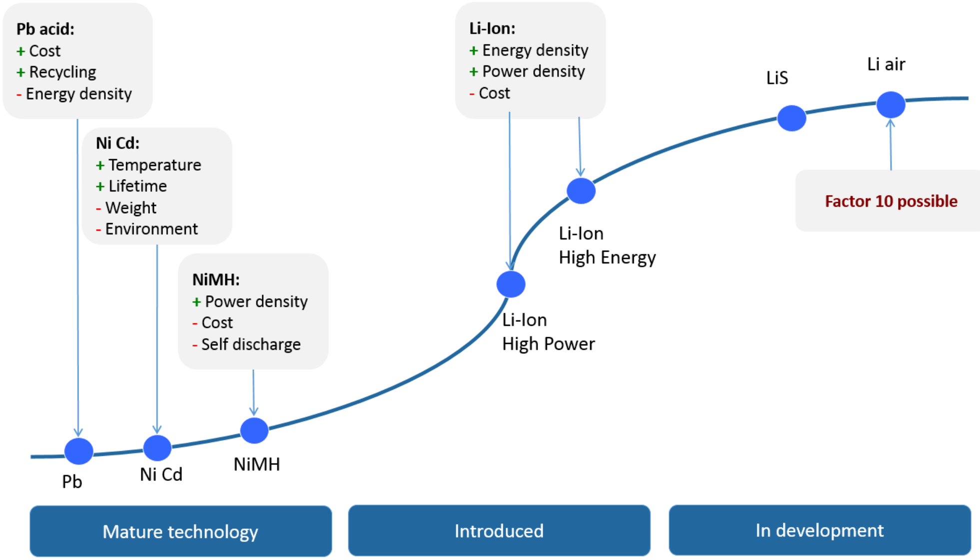


Figure 4: Battery Technology Roadmap
(Source: Gopalakrishnan et al.)[108]

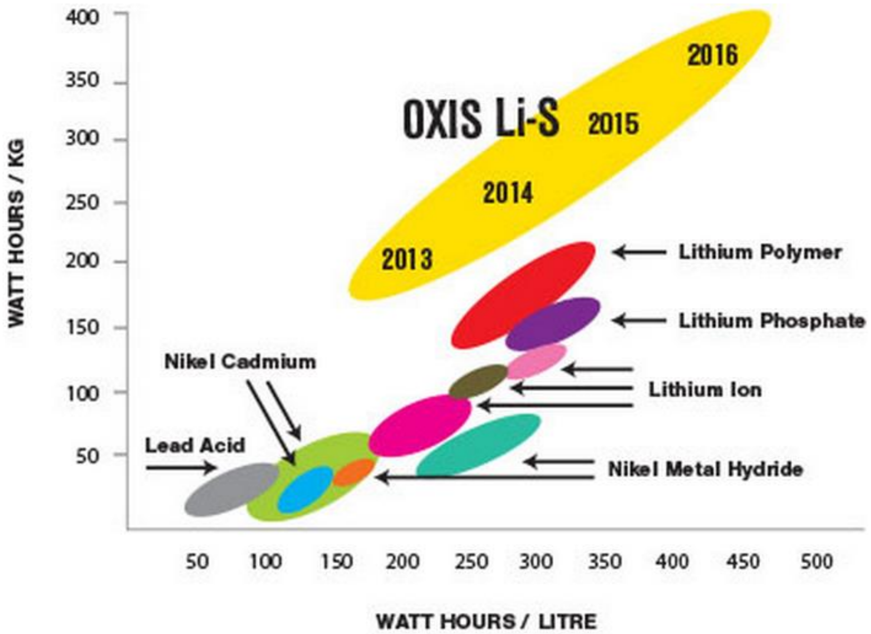


Figure 5: Comparing Different Battery Technologies: The Potential of Lithium Sulphur Batteries (Source: Oxis)[110]

A promising company working with this technology we found is OXIS Energy Ltd. The firm has developed a unique Sulfur based cathode material with high stability and having a theoretical specific energy in excess of 2,700Wh/kg, which is nearly five times higher than that of Lithium-Ion Batteries.

OXIS expects to come out with a prototype in 2016 that will have an energy density of 400Wh/kg with over 2,000 cycles before the capacity reduces to 80 percent of its beginning of life. The battery is projected to cost less than USD 250/kWh (see **Figure 5**).[109]

4. The Yin & Yang of Bottom-Up Innovation and Top-Down Regulation

Market readiness needs to match technological readiness

Cheap, clean, renewable energy fulfills a fundamental need. Fresh ideas are needed to solve the energy conundrum. For example, in power transmission there is work to do: when power stations pass the power that they generate via complex networks comprising transformers, overhead lines and cables to supply the end users, they incur transmission and distribution losses. Transmission losses are in the order of 20 percent; distribution losses reach 50 percent.[111] In our current electricity transmission and distribution paradigm, variable losses alter as a function of the amount of electricity distributed, proportional to the square of the current. Thus, a one percent increase in current means an additional loss of much more than one percent.[112]

We found many fresh ideas to tackle this and other problems. Notwithstanding, any breakthrough technology needs to also succeed on the market. This means the solution has to be both ready technologically *and* find a promising path to market penetration and scale. This is where bottom-up innovation meets top-down regulation and the market structures conditioning market entry; ideally, this is a yin and yang dynamic. But more often, it turns out to be gridlock.

The good news is that a lot is possible that until recently would have sounded like science fiction. For example, what if mobile phones could be charged superfast in 30 seconds, and electric cars in three minutes? This may become reality in 2017: similar to proteins used by body builders to grow bigger faster, StoreDot—a start-up born from the nanotechnology department at Tel Aviv University (Israel)—used biological semiconductors made from naturally occurring organic compounds known as peptides (short chains of amino acids which are the building blocks of proteins) to accomplish this. In 2017, StoreDot plans to release a fast-charging battery capable of replenishing an electric car to full in just three minutes.[113]

One key factor in getting from idea to product is time. Granted, the world is already doing better than with respect to the original pathway of solar photovoltaics: it took more than 100 years from Becquerel's discovery of the photovoltaic effect in 1839 to the first usable silicon solar cell. Today's innovation cycles are fortunately shorter. However, we found that the speed of progress continues to be a major obstacle to a viable energy path forward. Provided it intervenes at the right development stage of a technology, venture capital can speed up this process.

Technological readiness is key for venture capital investment

Any breakthrough innovation starts with the observation of principles that allow a new or more effective way to generate, store, or transmit energy. With additional research, prototyping and piloting, the most promising ideas "graduate" over time and become actual solutions, proven in a real-life operational environment.

In our search process, we classified all projects considered according to their maturity on a scale of levels ranging from one to nine (see **Table**

2). Having reached Technological Readiness Level 4 (TRL) was the minimal condition for any project to be assessed further.

Level	Status
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)

Table 2: Technological Readiness Index (Source: EU Commission)[114]

What is the pathway to market?

Even brilliant ideas rarely succeed on their own. They need pathways to dissemination. The same holds true for new energy technologies. Significant barriers affect all innovation, but they are particularly challenging for the renewable energy sector, resulting in a Research & Development (R&D) intensity as a percentage of value added that is close to zero.[115] Our search confirmed the existence of the proverbial wide "valley of death" where innovative technologies succeed in mobilizing funding to take them from observation of principles (TRL 1) to experimental proof of concept (TRL 3) to only then being unable to receive adequate investment to push them through from development to commercialization (up to TRL 9).

On projects retained for further review, we thus asked how they could win first customers, and what it would take to become a blockbuster success. Key are an enabling market environment, and compatibility with the innovation needs of incumbent players in the respective energy segment, because they understand sales and can block or fast track the pathway to market (see **Figure 6**).

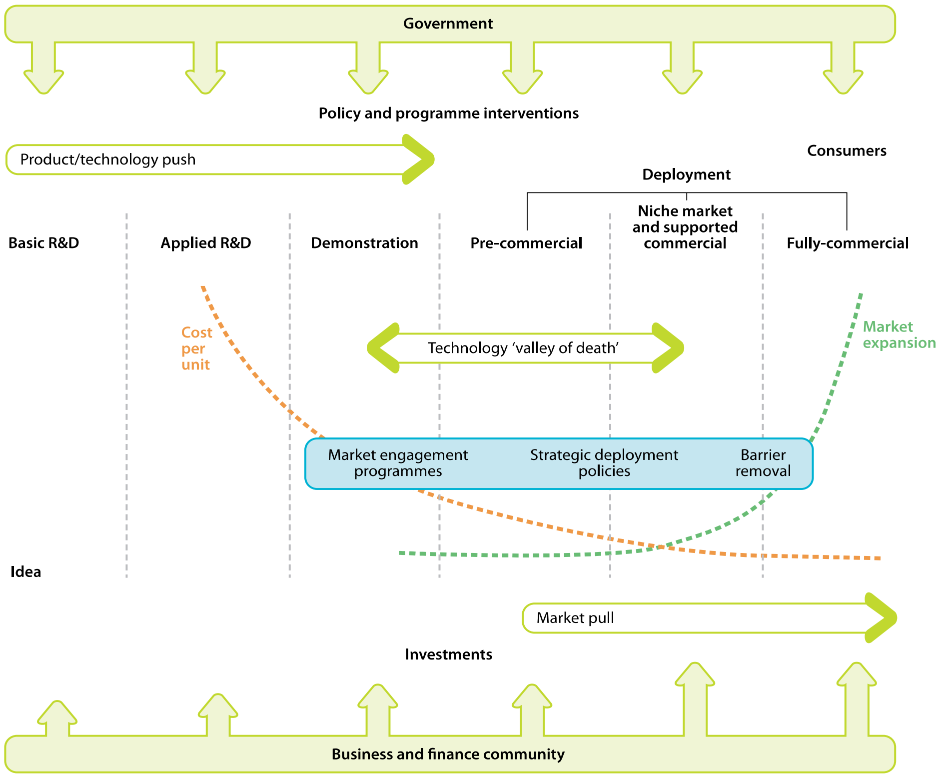


Figure 6: The Startup "Valley of Death"
(Source: M. Grubb)[116]

In particular, how can any promising project overcome the four primary barriers to adoption of clean energy technologies?[117] This is where the yin and yang between a government's top-down work and an entrepreneur's ability to generate innovation becomes relevant. Good strategies are needed to deal with the following four questions:

- First, existing infrastructure encourages evolutionary rather than revolutionary technological innovation. How do we keep radically better new technologies from being blocked by prohibitively high capital costs required for new infrastructure?
- Second, high upfront costs combined with limited access to finance deter investors by creating uncertainty about success prospects. They also raise capital cost and lengthen timescales of development. What is a project's plan to be as asset and capital light as reasonably possible?
- Product differentiation can be difficult or impossible in the energy sector: for example, customers want and need electricity, but seen that electricity is a commodity, most may not care to find out whether it came from a clean and/or renewable source or not. So how can a clean energy technology compete on a price and performance only basis?
- What view does the project have on spillover effects, which may benefit other firms and a society as a whole a lot more than they benefit the innovator (who needs to succeed on the open market where fast followers and substitutes are present)?

Governments can create markets conducive to breakthrough

Venture capitalists are not in the business of formulating public policy. Notwithstanding, innovation activity can be incentivized or dis-incentivized by public policy, adding an important framework condition next to market size and maturity, as well as general ease of doing business.

Governments can fast track renewable energy market development by providing intelligent policies to push technological development with public funding. Moreover, they can accelerate technology adoption in the market by creating conditions that seek to reflect their value added (including environmental externalities), and by removing barriers to entry.

For an investor seeking to bring a groundbreaking product to market, the openness of the market matters. For example, in recent years the UK has done a particularly good job in creating an environment where utilities are adopting low-carbon technologies, and turning them into useful products. This demand driven approach contrasts with continental Europe's primacy of the supply side, funding research that leads to products without opening up the pathway to the market.

As a result, though continental Europe is very well positioned in the clean energy sector, both for R&D and industry, it has not been able to capitalize on its investments as well as it could—whereas others are now piggybacking on its efforts.[118] How is the UK building a pro-cleantech environment? By coordinating its top-down efforts in an effective way to support innovation, from development to market. For example, the UK's Low Carbon Innovation Coordination Group (LCICG) brings together public sector backed organizations who invest in clean energy innovation. By working together, these organizations leverage each other's expertise and reduce wasteful duplication of efforts.[119]

For anyone active in a highly regulated market such as energy, the experience in the UK shows how important it is to have government-backed innovation and R&D policies that support innovative technologies all the way to the point where they are sufficiently proven in the market—and to then provide market-based policy mechanisms when needed.[120]

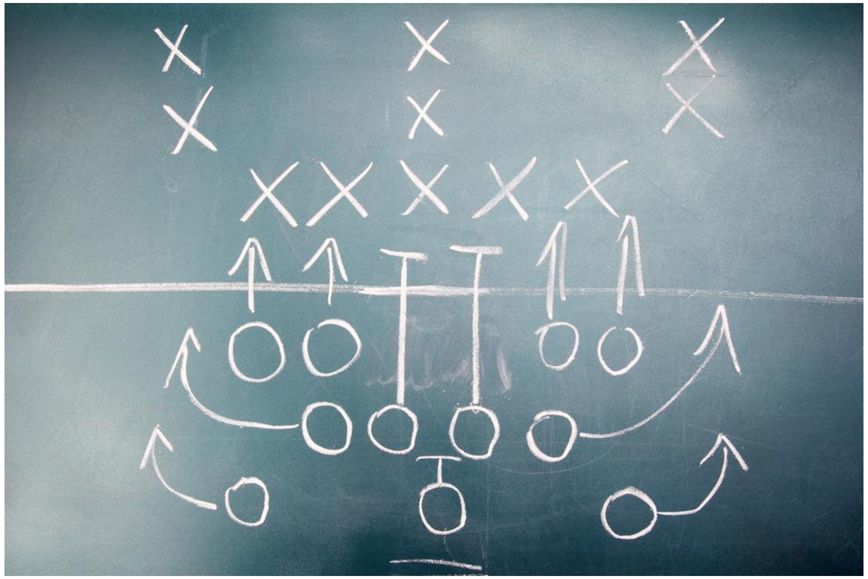
Next to sector-specific enabling conditions, a government's general stance toward startup and incubation activity also matters: many ideas that sound great in the lab will never become a world-leading product. To turn out a critical number of game changers, it is therefore helpful to benefit from startup pipeline buildup. This in turn is contingent not just on general attitudes toward entrepreneurship and risk-taking as is often mentioned. Rather, specific conditions such as access to capital and bankruptcy and tax law, as well as availability of information on players in a country's startup ecosystem condition how many ideas in the lab will eventually become investable opportunities. Italy provides a fascinating case in point (see **Spotlight 5**).

Spotlight 5: The Role of Intelligent Incentives—Italy's New "Innovative Startups" Legislation[121]

Drawing on the report "Restart, Italia!" elaborated by a ministerial task force, new legislation in Italy recognized innovative startups in 2012 as an important driver to achieve sustainable growth, technological development and youth employment, as well as increasing social mobility, and attracting investments and talent from abroad. The plan takes bold action by providing an assortment of strategic incentives to help these companies succeed and grow. Benefits for these innovative startups fall into the following six buckets:[122] First, support in the form of cost saving exemptions related to company registration and corporate legal fees. Second, increased employment flexibility and the ability to hire external service providers, such as lawyers and accountants, through "work for equity" provisions. Third, tax incentives for companies and individuals for the years 2013-2016. These incentives apply both to direct investments and to other companies who invest primarily in startups. Incentives are even greater if the startup involves social goals or focuses on the energy sector. Fourth, introduction of crowdfunding to open capital sources from non-professional investors. Fifth, easy access to a Central Guarantee Fund that facilitates access to credit by offering guarantees on bank loans (incubators are also offered these privileges). Finally, support in international expansion including assistance with regulations, corporate tax, real estate, contracts, payment of expenses related to important international trade fairs and events, and most importantly, matching the startups with potential investors. To be considered an innovative Italian startup and be eligible for these benefits, the startup must fulfill a number of conditions: (1) to have conducted business for less than 48 months; (2) to have its headquarters in Italy; (3) not to exceed a turnover of EUR 5 million by the end of its second year of operations; (4) and to develop, produce or market innovative products or services with high technological value.

(5) Further, the company must meet one of the following three requirements: (a) Expenditure on R&D must be greater than 15 percent of the total value of production; (b) one third of the workforce has or is in the process of earning a PhD or two thirds have master degrees; or (c) the startup owns or licenses at least one patent or is the holder of the rights attached to a computer program. After meeting with many of these Italian startups, it is exciting to see how many talented scientists, engineers, programmers and general innovators have been provided more effective support. Given the aim to back the world’s most brilliant talents to solve the energy puzzle, we would welcome to see other countries follow Italy’s example—there is so much talent throughout Europe that could achieve a lot more, given just a little extra support.

5. Seven Recommendations on Investing in Our Energy Future



To influence a dynamic system, act on the key levers

From our search for groundbreaking solutions follow seven primary recommendations for investors into the energy transition as well as others who are seeking to create an enabling environment so that humanity's race against time will end up being successful.

Recommendation #1:

No storage, no transition—invest considering the target energy density

Solar power is the only alternative energy technology to date that has the scale potential needed to deliver the amounts of energy a growing and Westernizing global population needs. Moreover, in the best of locations, solar radiation delivers as much as 1.1 kW per m^2 (think of the proverbial installation of solar panels in the Sahara).[123]

However, our modern lifestyle also imposes certain energy performance and availability requirements that we cannot just wish away. Nor can we mandate large-scale behavioral and civilizational change. This means that any breakthrough in energy will ultimately be associated with the ability to release and store power at a speed and energy density that is useful.

In our search, we were interested in all devices or physical media that can store energy so as to perform useful processes at a later point in time, including chemical energy, electricity, gravitational energy, temperature differences and latent heat as well as kinetic energy. Economics, performance, and safety were key, as well as whether energy could be stored only short-term or also longer term, such as between opposing seasons for heating (see **Figure 7**).

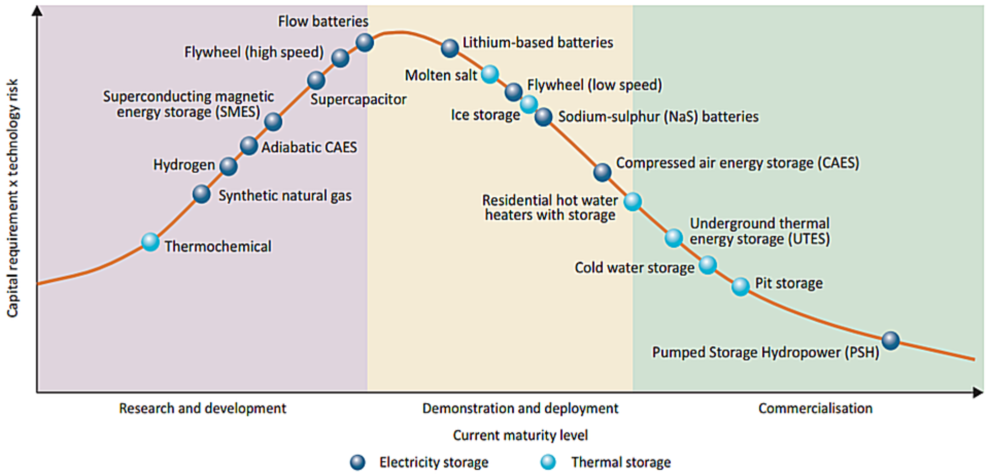


Figure 7: Maturity of Energy Storage Technologies (Source: EIA)[124]

Rather than busying us with the many possible niche applications of alternative energy, we generally considered a renewable energy's potential by comparing it with the energy density and peak power of well-established fossil fuels against which it must compete. In visual terms, consider a Ragone chart, plotting the peak power of various energy sources against their specific energy (see **Figure 8**). The chart compares the performance of various energy-storing devices by plotting energy density (in Wh/kg) against power density (in W/kg) on a logarithmic scale to compare sources with very high power with limited power.

Note that while at this point only a theoretical solution, the Low Energy Nuclear Reactions (LENR) mentioned earlier would provide the kind of performance that would really help. The "E-Cat" would in fact be off the chart: it is theorized to have roughly four orders of magnitude more specific energy and three orders magnitude greater peak power than gasoline. If something like this ever hits the market, its impact will be massive.

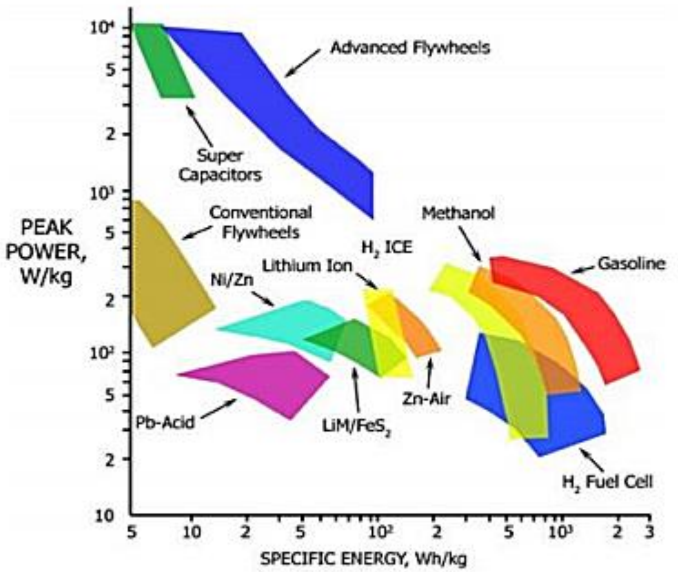


Figure 8: Ragone Plot of Energy Storage: Select Gravimetric Energy and Power Densities of Various Sources

(Source: Cornell University)[125]

Recommendation #2: Invest to take solar to the next level

As is well known, the potential of solar energy is nothing less than amazing. The amount of solar energy reaching the Earth has the potential to cover all our energy needs many times over; the solar energy the earth receives in one hour is enough to cover the world's energy consumption for an entire year.[126]

However, we need to consider additional technologies to engage in solar harvesting: single-junction silicon-crystal photovoltaic cells that excite electrons across a band gap to produce electric power dominate the market. The best commercial silicon module reach efficiencies just above 20 percent.[127]

According to the IRENA Renewable Energy Power Costs Summary of 2014, photovoltaic LCOE prices are in the range of 0.12-0.20 USD/kWh, which is too expensive to be competitive with the fossil fuel LCOE of 0.05-0.1 USD/kWh.[128]

There are several logical responses; all warrant an open eye for potential breakthroughs; and we have scanned for disruptive innovations in all these technologies. Strategies to reduce LCOE prices generally pursue either an increase in efficiency at the expense of higher cost per area, or low cost solutions that can cover a large area, usually sacrificing efficiency. Moreover, there are additional technologies that rely on semiconductors to consider.

First, multi-junction cells which rely on several band gaps to harvest energy from different wavelengths of electromagnetic radiation are much more energy efficient (the current record in the lab stands at 46 percent efficiency).[129] However, they are still too costly to produce, with estimates indicating costs per unit of power produced almost being double that of single-junction cells (let alone fossil fuels).[130] This renders inventions that dramatically reduce cost particularly exciting.

A second logical avenue are thin-film solar cells that rely on band gaps to produce electricity, but do not use expensive silicon based semiconductors. Issues to resolve in thin-film solar are (1) low efficiencies and (2) the toxicity of thin-film materials such as cadmium telluride (CdTe), a stable crystalline compound formed from cadmium and tellurium, or copper indium gallium diselenide ([$Cu(In_xGa_{1-x})Se_2$], abbreviated CIGS).

Finally, given the inherent large potential of solar energy and technology risk, it is also worth exploring completely different approaches to solar harvesting that are now becoming a practical possibility because of current advances in nanotechnology. These include (see **Table 3**):

- Perskovite cells;
- Organic solar cells;
- Quantum dot cells; and
- Plasmonic cells.

Technology	Description	Best Research Efficiency	Cost USD/W	Typical Length of Warranty	Readiness	Environmental Impact
Monocrystalline	Oldest cell technology and most widely used	25%	~0.70	25 years	Mature	High level of embedded energy to produce crystalline silicon
Polycrystalline	Less silicon waste in production process	20.40%	~0.60			
Amorphous Si	Tend to degrade faster than crystalline-based panels Low availability on the market	13.40%	~0.50	10-25 years	Medium	Medium
CdTe		21.50%	~0.70			Toxicity of Cadmium
CIS/CIGS		21.70%	~0.70			Medium
Dye-sensitized	Must reduce cost and increase durability for commercialization	11.90%			R&D	Low impact
Organic		11.10%				
Perovskite		20.10%				
Quantum dot		9.90%				
Multi-junction CPV	Very expensive and used when cost is less of a factor (e.g.: space, CPV)	46%				

Table 3: Performance and Readiness Comparison of Different Solar Cell Technologies

Resulting from our search, we are especially excited about the application of advances in quantum physics to the field of solar energy.

For example, in quantum physics, particles are subject to different constraints than in classical physics because their dual properties include both a particle and a wave. This means that electron tunneling could be used for electricity generation, rather than only the well-established band gap mechanism from solar photovoltaics. This is the core idea behind the so-called "plasmonic effect," a phenomenon where an electromagnetic radiation (e.g., from the sunlight) can induce plasma oscillations in a metal and produce electric current.[131]

For example, applying quantum physics and nanotechnology to come up with a next-generation solar cell, US company SciTech Solar is developing a completely new way of harvesting solar energy without the band gap limitations of conventional solar cells. Their single element solar cell utilizes rectenna technology, which essentially consists of an antenna and a diode combination. The nano scale antenna captures sunlight at a high efficiency and the diode then rectifies the energy into usable direct current.

As the antennae can be tuned to respond to any frequency of solar radiation, the solution can utilize a wide spectrum of the sun's energy. This makes it possible to achieve efficiencies of well over 50 percent, perhaps even 70 percent. Moreover, such cells would be cheap to produce and would not require the use of toxic materials in the production process.[132]

Recommendation #3:

Energy efficiency is not sexy but easy, so take it forward

Service and residential buildings are currently responsible for 39.8 percent of energy consumption in Europe, ahead of transportation and the industrial sector.[133] Energy efficiency can only provide a partial answer to the energy crisis. Notwithstanding, this makes reduction of primary energy demand via greater energy efficiency a natural candidate for investments into fast tracking the energy transition. Consider for example the potential of insulation solutions that offer up to ten times higher insulation performance compared to conventional insulations, are space saving, and reduce energy costs.

The International Energy Agency defines energy efficiency as a way of managing the growth in energy consumption.[134] A device can then be defined as more energy efficient if it delivers (1) more services for the same energy input, or (2) the same services for less energy input.[135]

By using energy more efficiently, we can lower our energy bills, reduce our reliance on external suppliers of oil and gas and help protect the environment. Many relevant initiatives are under way. For example, the EU has set itself a 20 percent energy savings target by 2020 when compared to the projected use of energy in 2000.[136] This is roughly equivalent to turning off 400 power stations.[137]

British Gas research has found that nine out of ten smart meter customers are already taking simple daily steps to manage their home energy use. Nearly two thirds of smart meter customers have identified savings estimated up to GBP 75 per year.[138] By the end of 2020, over 50 million smart meters will be fitted in over 26 million households across Wales, Scotland and England.[139]

The private sector includes a great deal of potential as well. Companies worldwide spend an average 40 percent more energy due to inefficiencies.[140] To reduce demand without negatively affecting the operations of their business, firms need a centralized solution to analyze energy consumption, to detect inefficiencies, and automatically solve them. As the information revolution gives birth to the "Internet of Energy," the solution includes next generation gas and electricity meters that are smart and capable of showing the user via an interactive web portal how much energy they are using, how much that costs, and how to better manage personal or company energy use.

Can energy efficiency solutions be considered groundbreaking? Yes, if they can dramatically expand reach and depth: the next step forward here does not lie in the technology itself, but in designing technologies that dramatically raise a solution's ability to scale. There are several pathways to achieve this, including lowering cost and enhancing convenience. Given the interlinkage of information technology and energy technology, such solutions can become complex very fast.

For example, Spanish company OpenDomo provides state-of-the-art smart meters at roughly half the price of its competitors.[141] Unlike most other smart meter providers, these meters have an integrated gateway that is capable of sending information directly to the OpenDomo cloud or any other server using a standard Ethernet cable or Wi-Fi. This reduces complexity and system setup cost.

Beyond measuring energy, gas and water usage, the smart meter devices are also capable of measuring temperature, humidity or pH acidity, among others. In order to eliminate any type of inefficiency, the device is then also capable of automation and remote control of facilities via a cloud. OpenDomo is currently using machine learning and data mining techniques to develop a high impact software module that can integrate artificial intelligence into the firm's energy management platform.

Recommendation #4:

Invest for a breakthrough to enable e-mobility beyond entertainment

In 2014, the global auto industry expected to have sold 85 million vehicles, up from 82 million in 2013, with sales forecast to break 100 million in 2018.[142] **In comparison, Tesla sold its flagship Model S 20,000 times in 2013.[143]** A 13 percent of global greenhouse gas emissions come from transportation that is currently mainly powered by petroleum-based fuels (gasoline and diesel), which are burned for air, marine, rail and road transportation.[144]

To locate solutions for this sector, we were thus particularly interested in electro mobility (or "e-mobility") solutions that enable the electric propulsion of vehicles and fleets. This comes down to the combined use of electric powertrain technologies, in-vehicle information, and communication technologies as well as dedicated infrastructure for recharging. When most people hear of electric vehicles, they think of one word, batteries. However, batteries are not the only energy source option for electric vehicles. Hydrogen is proving itself a promising clean alternative to fossil fuels that not only competes with, but also complements batteries. Which technological pathway will win is not yet clear, so we considered full electric vehicles as well as plug-in hybrids and hydrogen fuel cell vehicles that convert hydrogen into electricity.

Let us be clear: until the storage problem is solved, e-mobility will remain a trophy exercise for carmakers pleasing regulators, some governments, and lifestyle customers. However, serious progress on the mobility front is urgently needed. We found hydrogen as a fuel very interesting, in spite of the many challenges still to be solved. By weight, hydrogen contains nearly three times the energy of petrol.[145] However, in its gaseous state, hydrogen has a volumetric energy density that is inferior to hydrocarbons.[146]

To compensate for this, the industry standard for FCEV (Fuel Cell Electric Vehicles) such as the Toyota Mirai consists of compressing hydrogen to 700 times atmospheric pressure and then storing it in carbon fiber reinforced cylindrical tanks. The tanks must be cylindrical because this form is strongest in resisting high pressure—but this limits design freedom.[147] There are many other drawbacks to compressed hydrogen gas tanks including high pressure, weight, volume, adaptability and cost. A 2012 report by Strategic Analysis Inc. on behalf of the US Department of Energy found that a 700 bar hydrogen storage system could cost above USD 20/kWh of capacity. Compressing hydrogen is also an energy intensive process, resulting in losses of 5-15 percent of the total energy. The key obstacles to overcome for hydrogen to become a major clean energy sources are storage and CO_2-free production.

In France, we found a company with a potentially groundbreaking solution to both problems: if hydrogen is hard to store, why not produce it on demand? HySilabs has developed a catalyst that can release hydrogen from water on demand, and at atmospheric pressure. This technology is groundbreaking in the sense that it removes the need to store hydrogen entirely. All you need is water and a non-hazardous catalyst mixture. With the same amount of liquid contained in a normal petrol tank, enough energy can be stored to offer the same driving range as fossil fuels, but with the only emission being harmless H_2O. The applications go far beyond vehicles. For example, this technology could be used to store and supply energy to small electronics, power tools, and isolated power generators, and address both the storage and the CO_2-free production problem.

Recommendation #5:

Infrastructure buildup will keep surprising—pick your winners carefully

At the turn of the millennium, experts predicted that wind power would globally reach 30 GW in 2010—in that year, capacity reached 200 GW, and today it stands at 370 GW globally.[148] Similarly, in 2002, it was predicted that solar power would add 1 GW per year by 2010—in 2010, 17 GW of solar capacity were added globally, and in 2014 48 GW.[149] We are in the early days of an incredible capacity build up in the renewables industry. In the near future, people will speak of "Big Solar" and "Big Wind" in similar ways as we do today of "Big Oil" and "Big Pharma". Former US Vice President Al Gore is on his way to becoming the world's most widely known climate billionaire. In short, the alternative energy space is not only important for our future, but also big business for venture capital and later stage investors.

In our search, we found market forces everywhere engaged in building parts of the emerging alternative energy infrastructure. This leads to interesting investment and impact opportunities, often connecting the Internet of Energy to brick and mortar businesses. Notwithstanding, picking winners is difficult at this early stage of market development. For example, the Italian startup Electric Drive Italia (EDI) supplies its customers with a turnkey and tailor made e-mobility integrated system having its core in the ITC platform called B.O.M.T. (Banking-Operation-Maintenance-Telematics).

The B.O.M.T. platform assures banking, operational, maintenance and advanced telematics systems, representing the guarantee of the project business plans that are agreed in advance with the single customers. The system is made of e-cars/buses, charging stations, IT systems for charging station control, car booking management and fleet management. The firm's customers are public and private organizations in the semi-public transportation area. The goal of their service offering is to render e-mobility easy by offering a simple and cheap e-drive experience that solves a critical problem affecting its convenience: fast and safe battery charging. A whole host of ancillary services is conceivable, ranging from fleet management to maintenance and user telematics as well as banking services. Cars could even become part of an energy trading swarm where one can buy electricity from the local utility company at a lower or negative price in the case of an excess supply and then sell it on later. A medium sized Italian city would require at least 20 charging stations: one can only imagine the tsunami of capital investment in infrastructure once e-mobility is fully under way!

Recommendation #6:

Don't go only where everyone is—working on an IT play

One of the most fascinating observations from systematically scouting for breakthrough clean energy solutions is the number of "IT plays" out there. Today's economy still benefits from inventions made more than fifty years ago such as the transistor or nanotechnology; alas it now seems that most of our talents and US West Coast VCs are focused only on information technology applications rather than also giving a hand to the hardware breakthroughs that are badly needed.

Barriers to entry are low for IT—after all, this is about programming some app—and historically valuations for successful IT startups have been such that one may wonder why young talents go into other fields at all. While this was not our investment opportunity focus, here are three examples.

- **Cloud&Heat**[150] is an innovative German startup company founded in 2011. The Cloud&Heat heating system converts the server heat into heating energy. The electricity for operating the servers comes exclusively from renewable sources. By housing their cloud servers in homes and other buildings, they can take advantage of the heat generated by the systems to heat homes. The firm's innovative heating system involves a fireproof safety cabinet that is equipped with servers and installed in the building that is to be heated. With the computing process, the servers generate heat that is fed into a buffer tank. This tank supplies the hot water system and heats the domestic hot water. Additionally, via a centralized air handling system, the waste heat generated is used to heat the building.
- **PlugSurfing**[151] was founded in 2012 and is based in Berlin, one of Europe's most progressive e-mobility cities. PlugSurfing seeks to revolutionize the e-mobility sector. With the PlugSurfing online application clients can find EV charging stations in the entire European continent, also indicating how to get there and showing in real time whether the station is occupied.
- **ICE Gateway GmbH**[152] was founded in 2013 and is also based in Berlin. The ICE LED System targets a reduction of 50-80 percent in operational costs for streetlights through energy efficient LED products, exact timing to turn the lights on and off as well as dimming ability, which follows the German DIN norm for street lighting. Streetlights retrofitted with LED lights can be accessed from a distance and dimmed if traffic or lighting conditions require it.

Recommendation #7:

Don't discount what "out-of-the-box" thinkers can contribute

To achieve any kind of breakthrough, open-mindedness and creativity are key. One needs to be mindful that progress sometimes happens in unexpected ways—and maybe even during holidays. Take an example from another field: Sir Alexander Fleming, a UK successor to the iconic French founding father of microbiology Louis Pasteur. Searching for anti-bacterial agents for ten years, he discovered penicillin in 1928. Departing for a family holiday, he left his lab untidy. One culture of staphylococci became contaminated with a fungus while he was vacationing and destroyed the other colonies surrounding it. Fleming was open-minded enough to recognize the extraordinary event; the rest is history.

A core Exergeia working assumption was that the next Flemings are the ones who can upset the apple cart—so we scouted for them. A fascinating part of the search was the number of people who consider themselves contrarians or may even be active conspiracy theorists arguing that they have the breakthrough solution but could not show it to us (or to anyone else for that matter), either because the world is not ripe, or because they are afraid. Others argue that the likes of Nicola Tesla had already worked out groundbreaking solutions, but that their inventions had been suppressed.

From a scouting perspective, the moment of truth comes when the prototype is or is not presented; moreover, we found that the technological readiness classification mentioned earlier (TRL 1 – TRL 9) is generally a good yardstick to anticipate the steps to master for a working prototype to become a successful product. Given the need to locate out-of-the-box solutions, keeping one's ear to the ground and looking for the unconventional may just hold a missing element for the energy transition to succeed (see **Spotlight 6**).

Spotlight 6: Could Gravity Wheels or Quantum Electrodynamics Solve Our Energy Requirements?

As part of our search outreach, we received numerous inquiries from inventors. One intriguing submission was related to the so-called **Bessler Wheel**.[153] The question is this: is it possible to have a wheel turn continuously, purely from the falling of weights, which have to be lifted again at every revolution?

In 1712, Johann Bessler appeared in the German town of Gera in the province of Reuss and exhibited a "self-moving wheel," which was about two meters in diameter and 10 cm thick. Once in motion, it was reported by contemporaries to be capable of lifting several pounds.

Bessler then moved to another village near Leipzig, where in 1713 he constructed an even larger wheel, 2.75m in diameter and 15cm in width. That wheel could turn at fifty revolutions a minute and raise a weight of forty pounds (18 kg).[154] By 1717, Bessler had literally convinced thousands of people from all tiers of society that he had indeed discovered the secret of a self-sustaining mechanism. The machine underwent numerous tests and passed rigorous inspections. It was deployed to do heavy work for long periods; in an official test, it ran continuously for 54 days. The inventor always closely guarded the secret of the internal design of the machine. Plagued by paranoia and an ill temper, and with no patent laws to protect him at the time, Bessler took his secret to the grave and drifted into obscurity.[155]

The consensus among today's scientists is that Bessler was perpetrating a deliberate fraud, for just how his wheel was powered is not entirely clear. John Collins from England has been working on this topic for almost 20 years now and argues that this year he would reveal the solution behind the Bessler Wheel.[156] We were approached by another inventor who says he has a working Bessler Wheel and are waiting to see the prototype.

Another interesting unconventional idea is the **"Reid Cell:"** an emission free energy conversion technology that uses the energy within space-time as an external source of energy.[157] The technology describes a method to extract energy from the quantum vacuum. The Reid cell is in its basic construction related to a capacitor and has been reported to create a steady direct electric current over an unknown period of time (since 1999). The cell uses a solid polycrystalline silicate that contains nano-structures instead of a liquid electrolyte. Within the nano-structures are clusters and chains of water molecules. The working mechanism of the cell relates to self-adjusted molecular self-oscillation of H_2O molecules that are trapped in the nano material.

In principle, the Reid cell could be viewed as a solar cell; instead of sun light, the environmental heat and coherent quantum fluctuations are used to separate the charges. The term "coherent quantum fluctuations" can then be described as a special oscillation (resonance) between electrons and molecules.[158] In a prototype shown to us, the Reid-Cell was reported to have a power output of 16mW/kg at 25°C and can only be applied to low power applications like clocks, smoke detectors, sensors and camping lights.

6. Conclusion: It's Time to Aim High

The clock is ticking

This report asked how investing in early-stage renewable energy breakthroughs could accelerate the energy transition, given the goal to converge on a global economy powered 80-100 percent by clean energy within our lifetime.

The good news is: our search for groundbreaking clean energy solutions confirmed that alternative energy is an idea for which time has come. If you are skeptical, consider that even the large established players—who had for the most part kept dragging their feet—are waking up to this new reality. Some need to write off nuclear installations (in Germany). Decentralized wind and solar power is hitting customer demand and thus the bottom line. Incumbents need to consider how to incorporate renewables into their business models. They are asking themselves what mix of activity matches the company's current skills and its current geographic presence: in a world where energy provision will become more decentralized, how can one build market share in a business sector that is in formation, and where classical capital-intensive upstream exploration plays less of a role?[159]

Creative destruction is upon us, but there is a lot of work ahead. And the clock is ticking to get it right. Take E.ON, Germany's largest utility. On November 30, 2014, the company announced that it would split itself up into a fossil and a renewables business (which has been colloquially referred to as "E.OFF"). In 2016, the company will be spinning off its fossil fuel and nuclear business in order to focus on its renewables, distribution and customer solutions.[160] After the German government initiated the transition to renewables in 2000, Johannes Teyssen, E.ON's chief executive, argues that, "the traditional business model for utilities has broken apart."[161] The CEO further stated that in his view, technology and not politics is ultimately driving the transition away from traditional sprawling utilities. "In the end technology breaks the value chain in two pieces, and not fundamentally politics or regulation, he says. "The main driver is technology and customers."

Driven by a combination of these factors, Germany is now generating nearly a quarter of its electricity from renewable sources.[162] The German government's goal is to boost this figure to 45 percent by 2035.[163] New technologies enabling clean distributed generation and intelligent demand side management are shifting the focus back to the customers and away from giant centralized utilities. E.ON is the first large European player to adjust its structure, and other energy companies around the world will follow suit. Other incumbents in oil, gas and utilities are wondering when they should move; just like competitors such as Airbnb and Uber came out of nowhere in the hotel business and the taxi business, we can safely assume that there will be a couple of fresh competitors who will suddenly be on everyone's radar in the energy industry.

While incumbents, incumbents need to figure out how to deal with new players who have embraced new renewable technologies and are hungry for a piece of the lucrative energy market, for society the question is whether progress can be achieved fast enough, and investors ask where money can be made. Next to those who are originating the technological progress currently under way, private sector incumbents, governments and investors are all key to solving the energy puzzle. Defensive communication strategies look increasingly insufficient. Given the intermittent nature of much of renewable energy production and prevailing energy consumption patterns in industrial and residential applications, as well as competition from fossil substitutes, alternative energy will however have to be produced much more efficiently in the future. Moreover, energy storage systems in the 80-100 percent renewable economy will need a much larger storage capability, the ability to very rapidly charge and discharge cycling, as well as improved endurance.

The formula consists of capital, ideas and talent—and daring

To invent our way out of these (and other) challenges fast, we need capital, ideas, and talent. In addition, we need to be attentive to enabling technologies that have a ripple effect, that are game changers just like the invention of the wheel or the printing press were in their days. The wheel changed the game in 3,500 BC. When people were already building canals and sailboats or casting metal alloys in the Bronze Age, they still had no carts. 5,500 year later, we take cheap long-distance overland transport for granted. Without the wheel, it would have been impossible to get where we are. Now knowledge travels ever faster, since the invention first of the printing press in the 1430s and the onset of the communication revolution—kicked off when Samuel Morse invented the electric telegraph in 1836.

The Exergeia search made clear that technology is ultimately also a question of imagination and daring. Today's utopia may be standard practice fifty years from now. For illustration, take the Luna Ring concept developed by Japanese scientists: a belt of solar cells around the 11,000 km lunar equator generates electric power—which it transmits to the Earth from the near side of the Moon, which always faces the Earth. To achieve this, the Luna Ring uses microwaves and high-powered laser beams for energy transmission. The Luna Ring could generate enough electricity to power the entire Earth. 20km-diameter antennas are envisioned to transmit power to the receiving rectennas and a high-energy-density laser to be beamed to the receiving facilities. Transmitted anywhere on the Earth, electricity could then be fed to the grid, stored or used to produce hydrogen. Though fascinating, the Luna Ring is not an investable proposition today. The Japanese scientists working on this project hope to start building the Luna Ring in 2035: after machines and equipment from the Earth are assembled in space and landed on the lunar surface for installation, robot-controlled solar production plants would then move automatically while producing solar cells from lunar resources, and installing them.

Perhaps for our energy imagination, not even space may be the limit. But more practically, whatever is rolled out needs to work and be cheap—otherwise large-scale adoption will remain a fantasy. For example, if a recent discovery makes it to production, organic batteries could become key to getting to the storage solutions we need. The price signal is good: MIT scientists have created an organic flow battery that costs only USD 27 per kWh compared to metal batteries at USD 700 per kWh. This is nearly a 97 percent saving.

To win the race against time, we need to cut through the Gordian knot

As one invests into our energy future, it is essential to keep things simple and practical whenever possible. For example, we do not know when low energy nuclear reactions will turn into products, but a premier research institution should probably have this technology on the radar.

In the meantime, many new technologies are viable today; they need thoughtful and ambitious venture capital to graduate from their existence in the lab.

The reader might expect an all-encompassing conclusion here. Having considered over 9,238 startups and projects allows us to go deeper into a number of directions; but this would be beyond the scope of this report. Rather than offering a grand narrative, the way forward depends on everyone's starting point, inventors, investors, governments, the energy industry, and civil society.

But let's be clear: to win the race against time, we need to cut through the Gordian knot of energy innovation. This requires intelligent action at the micro as well as macro levels. Discussing multibillion dollar figures and theoretical CO_2 emissions reduction targets is alone insufficient to get micro-level incentives right.

Success can only be achieved collectively, and be rendered more likely if every actor intervenes where they have leverage. This means both putting up the resources and backing the talent who can invent and deliver:

- Next to the efforts under way at the level of the international community (cue: "climate deal"), governments around the world need more ARPA-E type facilities to strengthen renewable energy innovation, combined with programs to remove obstacles from technologies' pathways to market and facilitating innovative financing;
- Private investors need to fully grasp the magnitude of the industrial transformation that is building up; realizing just how complex the energy industry is, our search nevertheless gave us insights into possible portfolios;
- Inventors are getting more and more support; we have however not yet seen the winning formula how public sector professionals can best support the scientists that are most deserving, while paying attention to both their track record as well as preserving the flexibility to act fast and back true genius when it manifests itself;
- It is natural for the established energy industry to be worried about its bottom line. But the new paradigm change is approaching. Incumbents are well advised to develop business strategies to take economic advantage of the renewable energy revolution that is around the corner, rather than going down fighting it;
- Finally, civil society and philanthropy have an important role to play in connecting the generations and citizens in a world where centrifugal forces could take over if we can neither provide energy to the energy poor at the Base of the Pyramid, nor prevent a new Migration Period once climate refugees start to cross borders on a massive scale. In due course, climate refugees and geostrategic shifts will become a problem especially for scarcely populated resource-rich countries and regions such as Russia's Siberia or Argentina that look vulnerable to climate-driven migration.

Just like our best scientists dare every day, we will also need to explore new avenues to accelerate innovation and investment in the renewable energy space. For those who get it right, many fresh opportunities to make both money and a positive contribution are around the corner.

Looking ahead

Next to having identified a promising pipeline of groundbreaking clean energy opportunities, the search process' key conclusion is straightforward: to sort this out, we need everyone. To solve the energy problem at the scale required, we will need all the talent we can get.

Without being naïve about people's capabilities and motivations, we will need to find new ways of working together: scientists, investors, and business developers. Even adepts of conspiracy theories assuming that all the solutions needed already exist but have been suppressed may have a contribution to make.

In the age of the citizen and the investor, it is up to all of us to find, nurture and back the next generation of clean energy solutions. We do not know how fast we will progress. However, as master conductor Herbert von Karajan reminds us, we can safely assume that it would be a mistake to aim too low. There is too much at stake. It's time to aim high.

Hopefully this report brought both relevant information and inspiration to you as you make your personal contribution to the energy transition, and has given you the evidence needed to revise your goals upward.

7. Acknowledgements, Author Information, Partner, Disclaimer

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Dr. Martin created the first global philanthropic services and impact investing department for a bank in Europe with teams in Asia, the Americas and Europe, the world's leading convening of ultra-high net worth individuals (UBS Philanthropy Forum), the brand Impact Economy, and Corporate Impact Venturing.

Always keen on anticipating what is next, he has led and participated in numerous projects and innovations in the field of responsible business and authored more than one hundred articles and position papers that have helped define the trajectory of market-based solutions and the impact revolution in finance, business and philanthropy. In 2013, Dr. Martin was invited to write the Primer on impact investing "Status of the Social Impact Investing Market" for the G8 policy makers' conference, which considered the potential and development options for this new branch of the financial industry. Dr. Martin holds an MA in anthropology from Indiana University, a MPA from Harvard University, and a Ph.D. in economic anthropology from the University of Hamburg. He also created the first university course on social entrepreneurship in Europe and serves or has served as a Visiting Professor and Lecturer in Social Investment and Entrepreneurship at the Universities of St. Gallen and Geneva, as well as at Ashoka U.

Impact Economy

Impact Economy is a global impact investing and strategy firm headquartered in Switzerland providing strategy advisory, investment services and corresponding research to companies and professional investors. Whether creating value from business innovation and investments in the USD 5 trillion Base of the Pyramid economy, the USD multibillion "Lifestyles of Health and Sustainability" consumer segment, accelerating green growth around the world, or the mobilization of private capital for innovative public-private partnerships, Impact Economy provides the holistic view and execution capabilities for clients to benefit from new opportunities to create both economic value added and social impact.

The firm's work has been featured in media including Il Sole 24 Ore, Energética XXI, Buzz Feed, The Financial Express, Australian Power Energy News, Cleantech Republic, CleanTechIQ, Energía Renovables, Ecotextile News, Nanowerk, Impact Investor, Singapore Institute of Directors, Stanford Social Innovation Review, Dowser, Dhaka Tribune, Business of Fashion, Daily Sun, Apparel Magazine, Ecotextile, Die Zeit, Mötesplats Social Innovation, VITA, Hürriyet Daily News, International Business Daily, La Nación, The Guardian, Myanmar Business Today, Global Corporate Venturing, Alliance Magazine, Real Leaders, Colombia Reports, Le Temps, Huffington Post, Investment News, Business Insider, Addis Standard, and Next Billion.

The Exergeia Project

The Exergeia Project aims to push the boundaries of usable energy solutions. The focus is to support potentially groundbreaking inventions and innovations in all fields of alternative energy, including unconventional approaches. Fields include energy efficiency, generation, storage, transmission, and distribution.

A core assumption is: it is time to accelerate innovation cycles in energy. This can only happen if breakthroughs in science reach full-scale impact much faster. Consider solar photovoltaics, where it took more than one hundred years from the discovery of the photovoltaic effect to the first usable silicon solar cell. In spite of remarkable advances in fields such as materials sciences, information technology, engineering, and other natural sciences, the current innovation cycle is too slow to achieve a 100 percent renewable energy economy in our lifetime.

Inventors/engineers are bound to playing a key role in coming up with the answers. If you are working on a potentially groundbreaking solution relevant to alternative energy, and want to ally yourself with a committed, competent group that has deep financial and industrial expertise and a track record of game-changing solution design, please contact us. We value originality, sound scientific foundations, and practical viability. All information submitted is handled confidentially and with integrity.

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