ENERGY FOR THE FUTURE

PROVIDING LOW-COST, ACCESSIBLE ENERGY SOLUTIONS

A PRELIMINARY RESEARCH STUDY

MARCH 2018

Contents

HOW TO USE THE REPORT

This paper is organized according to XPRIZE's ImpactMap development process: Insight, Foresight, Action:

- Insight: hi-fidelity research is conducted, aimed at establishing a baseline, that is, a description of the current state of affairs in a given field (or fields). Establishing this baseline is crucial to identifying gaps, which potential XPRIZEs could solve.
- Foresight: forecasting techniques are employed to determine the baseline scenario (extrapolating the current state into the future), and a preferred future, which will require a series of XPRIZEs in order to be achieved.
- Action: ideation techniques are used in order to identify potential breakthroughs, which could later become XPRIZEs.

BACKGROUND

In 2014, 1.06 billion people still lived without access to electricity - about 15% of the global population - and about 3.04 billion still relied on solid fuels and kerosene for cooking and heating:

- The electricity access deficit is overwhelmingly concentrated in Sub-Saharan Africa (62.5% of Sub-Saharan Africa population) and South Asia (20%), followed by East Asia and the Pacific (3.5%), and Latin America (3%) and the Middle East and North Africa (3%).
- In Sub-Saharan Africa, 609 million people (6 out of 10) do not have access to electricity, and in South Asia, 343 million people do not have access to electricity.
- At the country level, India alone has a little less than one-third of the global deficit for electricity (270 million for electricity), followed by Nigeria and Ethiopia. Additionally, the 20 highest access-deficit countries for electricity account for 80 percent of the global deficit.

Between 2000 and 2014, there were advances in electrification, with the global electricity deficit declining from 1.3 billion to 1.06 billion, and the global electrification rate rising from 77.7% to 85.5%. Progress with rural electrification is evident, with the global rural electrification rate increasing from 63% in 2000 to 73% in 2014. Urban areas around the world are already close to universal access with 97% electrification.

Although rates for urban access have risen relatively little in the past 25 years, this level remains a major achievement when viewed against the rapid urbanization that has brought an additional 1.6 billion people into the world's cities during this period.

How much improvement will be needed to get the world back on track? Progress has fallen consistently short of the population growth rate since 2010, meaning that efforts in the remaining years will need to be stepped up to 0.9% for electricity. This implies that the number of rural households for which access needs to be created will stabilize and not be inflated by population growth. ***Although urban connections may be perceived as lower cost and therefore easier to implement than rural connections, the challenges presented by urban slums require regulatory and financial incentives to ensure that universal access is attained.*** A further challenge is presented by the recent spread of the “rapid growth of households” from developed countries to developing countries.

Despite the current progress, formidable obstacles to a cleaner energy future remain. The first is technological: Batteries capable of storing energy for use when the sun is not shining and the wind isn’t blowing are still quite expensive, though their costs are falling. The second is financial: Despite increased private investment in renewables, the United States and other industrialized countries have not lived up to their pledge at the Copenhagen conference in 2009 to provide $100billion a year to underwrite climate projects in poorer countries. The third challenge is political: It’s clear that imposing a price on fossil fuels will encourage investment in cleaner fuels. A carbon tax has cut emissions in British Columbia, but carbon taxes remain a nonstarter in the United States. Overall, the falling cost of renewables is a positive thing. The prospect of keeping energy affordable while saving the planet should inspire global stakeholders to bolder action.

INSIGHT

TREND ANALYSIS

METHODOLOGICAL NOTE

Trend analysis is a method of analysis that allows us to identify the key drivers that will shape the future, how this future will look, and the key areas one needs to change or impact in order to shape a different, more desired future (from a subjective point of view). Another way to describe trend analysis in the context of XPRIZE's studies is environmental scanning - the possession and utilization of information about occasions, patterns, trends, and relationships within an organization's external environment.

SOCIAL/DEMOGRAPHIC TRENDS

World economic growth is projected at 3.1% per annum, close to its average for the past twenty-five years, with higher growth rates in developing countries and the transition economies, and lower rates in the OECD area. World population is expected to increase substantially, albeit at a gradually slower pace, reaching 8 billion in 2020 and 9 billion in 2050. Consequently, total energy use is rising by 2% per annum and energy intensity is decreasing by 1.1% per annum.

The impact of ageing populations and rising incomes - One of the key demographic evolutions of the coming decades, common to all OECD countries as well as some major developing countries, is ageing. But its impact on energy consumption is likely to be ambivalent. Population numbers will gradually level off, but household numbers are expected to grow quickly due to the reduction in household sizes

The emerging information society and urbanization trends – Energy demand will also be affected by globalization and the ongoing transition from the post-industrial to the information society. Most notably, such deep socio-economic changes are expected to lead ultimately to changes in the organization of work and leisure, in mobility patterns, and in urbanization trends. As a result of globalization and the current and future international division of labor, some industrial and service activities will continue to shift from OECD countries, and also from newly industrialized countries, to low-wage-cost developing countries. In some developing countries, rapidly growing industrial clusters will generate large urban centers. This in turn will lead to higher-than-expected increases in energy consumption and environmental problems.

TECHNOLOGICAL

The electrification of energy demand will increase overall energy efficiency and reliability. While the electrification of trains began a century ago, cars and trucks are now increasingly battery-powered. Electric heating is also driving efficiency increases as heat pumps begin replacing other forms of heating, including gas, oil and direct electric heating on a broader scale. This means that along with an increasing demand for electric-based energy, there will be a growing demand for a variety of energy storage solutions.

New materials in energy such as graphene in solar, hybrid solar cells and wide range bandgap semiconductors in power converters will increase the reliability, performance and efficiency of next generation solar panels and electric grids. These could be great solutions for access to power in remote places.

Digitalization will lead to more, faster and better data, increased computing power and better connectivity of all elements in the power system. This will optimize the design, planning and operations of assets in wind, solar, transmission, distribution and the use of electricity in society. Costs for maintenance of wind turbines and wind farms will be lower and demand response invitations, where customers can voluntarily reduce demand at peak moments, will be better-tuned to individual and changing consumer wishes.

Renewable energy technologies are deployable in a decentralized and modular manner – This makes them a particularly suitable energy source for small grids or off-grid solutions, which in turn bear great potential in many rural regions where connection to the grid is either too expensive or disadvantageous for other reasons. A renewable energy policy network and off-grid renewable solutions are increasingly acknowledged as the cheapest and most sustainable options for rural areas in much of the developing world.

Mini-grids are emerging as a key player for cost-effective and reliable electrification of rural areas. It is projected that one-third of total investments toward achieving universal access by 2030 will be targeted at mini-grids, with the vast majority (over 90%) coming from renewable energy generation. Hybridization of mini-grids is increasingly popular, especially in countries that have been powering exiting mini-grids with diesel. Moreover, improvements in storage systems will increase the use of renewables and decrease the share of diesel, which would mainly supply evening peaks. Mini-grids can also contribute to the socioeconomic development of a given region. Besides providing basic energy services (lighting and phone charging), they can fuel productive activities such as pumping, milling, and processing.

A variety of developments in solar will drive down costs of solar photovoltaic (PV) by 40% in the next ten years. The PV learning curve indicates that the module price will decrease by over 20% for every doubling of capacity. By 2025, solar PV will be the cheapest form of electricity in many regions of the world.

Electricity storage will be optimized for three electricity discharge durations: wholesale, system support and "behind the meter." Technologies will include: chemical batteries for storing solar energy for consumers, technologies with high power ratings for system support at systems scale and smart software in batteries to enable optimal use of batteries.

Bi-directional communications in demand response management will address changing customer circumstances and thus help overcome the major disadvantages of the two most common forms of demand response today. In one form, utilities directly control the program, disregarding the local circumstances and changing customer wishes, which makes it feel rather intrusive. In the other form, demand is adjusted automatically based on consumers reacting to price incentives, making this form of demand response unreliable and controllable from the systems perspective. With the abundance of mobile devices (especially in developing countries), this could be a force multiplier in understanding and managing energy needs.

Smart energy producing buildings–A vision of a smart energy-producing house is one in which solar is the main source of energy. Adding devices that have some flexibility in their energy behavior, like battery electricity storage, heat pumps, air conditioning, and charging of electrical vehicles enables further optimization of energy use with smart, self-learning thermostats. Smart meters will make it possible to measure this flexibility and monetize it. While developments in solar and storage may suggest that buildings go 'off-grid', the opposite is more likely to occur. Buildings have the potential to become energy hubs, an invaluable asset for the much-needed flexibility in power grids.

ECONOMIC/FINANCIAL

Relative stability in energy demand patterns - Three uses are considered in energy demand: electricity, mobility, and stationary use (mostly heating). In the OECD countries, electricity and mobility have been remarkably stable in the past, growing broadly in line with GDP in spite of the oil price shocks of 1973 and 1979. Stationary use, on the other hand, has been affected by oil shocks through sharp energy efficiency increases (mostly due to price signals and partly to policies), rising demand for low-energy service activities, and the relocation of some industrial activities to developing countries. These trends are largely expected to continue in the coming decades, but with some important variations. **In developing countries, energy use is likely to rise markedly**, due to higher living standards, population growth, rapid urbanization and the gradual substitution of noncommercial fuels by commercial fuels. The outlook is less certain in transition economies, where past observations on energy intensity cannot be used to predict the future. OECD countries might experience some saturation in stationary use–heating in particular, but the extent and timing are difficult to predict. In short, non-OECD countries will play a much more important role than they do at present, both in terms of demand and supply, and in terms of CO2 emissions.

Demand for electricity will grow twice as fast as that for transport–China and India will account for 71% of new capacity. By 2050, electricity will account for a quarter of all energy demand, compared with 18% now. How will that additional power be generated? More than three-quarters of new capacity (77%) will come from wind and solar, 13% from natural gas, and the rest from everything else. The share of nuclear and hydro is also expected to grow, albeit modestly.

Less developed countries invest more in renewable energy than rich countries for the first time–A total of about $275 billion was spent on renewable power and fuels globally in what was a record year for investment in the sector, but more than $150 billion of that total, which doesn't include large hydropower schemes and heating and cooling technologies, took place in less developed countries like China, India and Brazil.

The huge potential for electricity access using mini-grids is hindered by numerous challenges - **including inadequate policies and regulations, lack of proven business models for commercial roll-out (notably for pico-solar systems), and lack of access to long-term finance.** But many countries are currently developing mini-grid policies to address these problems. India released a draft national policy for mini and micro grids which, if adopted, will create the proper framework and environment for developing 500MW capacity over the coming decade. Kenya's Energy Regulatory Commission recently licensed Powerhive East Africa.

ENVIRONMENTAL

The challenge of climate change - Climate change increases land and sea temperatures and alters precipitation quantity and patterns, resulting in the increase of global sea levels, risks of coastal erosion and an expected increase in the severity of weather-related natural disasters. Changing water levels, temperatures and flow will in turn affect food supply, health, industry, and transport and ecosystem integrity. Climate change will lead to significant economic and social impacts with some regions and sectors likely to bear greater adverse effects. Certain sections of society (the elderly, disabled, low-income households) are also expected to suffer more.

A couple major climate trends are relevant to the energy sector: Increasing air and water temperatures and decreasing water availability in some regions and seasons. Increasing temperatures will likely **increase electricity demand** for cooling and decrease fuel oil and natural gas demand for heating. Some of these effects, such as higher temperatures of ambient water used for cooling, are projected to occur in all regions. Other effects may vary more by region, and the vulnerabilities faced by various stakeholders may differ significantly depending on their specific exposure to the condition or event. However, regional variation does not imply regional isolation as energy systems have become increasingly interconnected. Compounding factors may create additional challenges. For example, combinations of persistent drought, extreme heat events, and wildfire may create short-term peaks in demand and diminish system flexibility and supply, which could limit the ability to respond to that demand.

WHAT'S IN, WHAT'S OUT
METHODOLOGICAL NOTE

Determining what the Future of Energy study entails also means determining what it does not. Therefore, it is important to set boundaries and determine the scope, as it helps focus activities and allows for significant creativity within the defined zone of focus.

AREAS OF FOCUS

Core:

- Markets (demand – focus on consumers)
- Markets (supply: energy generation like solar, wind, and geothermal)
- Energy security

- Technology (mainly around efficiency and storage)
- Regulation

Periphery:

- Markets (business models, e.g. household vs community models)
- Geopolitics and political economy
- Transportation
- Fossil fuel developments
- Energy-related information technology
- Environment (protection)

WHO'S DOING WHAT? (BENCHMARK ANALYSIS)

METHODOLOGICAL NOTE

Benchmarking is a way of discovering the highest level of performance being achieved – whether in a particular company, by a competitor, or by an entirely different industry. This information can then be used to identify gaps in an organization's processes in order to achieve a competitive advantage. However, unlike business-driven benchmark analysis, in the context of XPRIZE prize development, benchmark analysis is aimed at answering the following question: Who (innovators, academics, corporates) is developing solutions to a similar problem? What solutions are they developing? And who is providing funding in this area?

ANALYSIS

Cutting-edge technology, hardware and, especially, software, is unlocking geological potential in places and ways hardly imaginable even a few years ago. Energy companies now rank among the most important and sophisticated technology companies in the world. Information technology companies are pioneers on every front of the energy revolution by:

- Driving innovations in exploration;
- Cutting energy consumption in buildings through software-driven construction and energy management;
- Allowing utilities to more smartly source and manage their energy output;
- Empowering individuals to understand how to reduce their energy use. This underscores the "Power of One"—how each and every one of us can become players in the energy game;
- Enabling the design and testing of energy systems, from solar arrays and wind turbines to nuclear plants.

Among the least appreciated technologies are those that empower companies and individuals to understand, manage, and thus significantly reduce their energy consumption.

Energy technology is also bringing its transformative power to other parts of the world, principally by decoupling energy from its traditional sources. Renewable energy sources like wind and solar exist across the globe. The incredible diaspora of shale gas and oil resources, and the reserves unlocked by deep water exploration, expand the energy map even further. This "localization" of energy could be a major force in lifting Africa out of poverty by bringing reliable energy supplies to remote areas. It will help enable the continued boom in urbanization, since energy consumption and high energy costs are one of the hindrances to economic development. By being locally embedded, energy technologies will help keep communities globally connected—rather than dependent.

New technologies have not only empowered dozens of countries, but they also have made corporations and individuals participants in the energy game. The future will be powered by multiple clean energy technologies; the key is to find the ones that will ignite a revolution and scale to meet the world's energy needs.

Meanwhile, smart meters, the Internet, and advanced software are all allowing individuals to fine-tune their energy consumption. For both companies and individuals, technology has unleashed the potential creation of a virtuous energy cycle; by understanding and managing energy use, individuals save money, companies increase profits, and both groups lessen environmental impact.

City governments are increasingly collaborating with the private sector to address common challenges related to climate change and sustainable development. The Intergovernmental Panel on Climate Change (IPCC) has indicated that achieving a 1.5°C- or 2°C–compatible future is a very challenging task, yet almost all the technologies needed to build this future are commercially available today. Many countries are acting to reduce emissions through renewable energy (RE) and energy efficiency (EE) programs, and when policies are well-designed, both local and global communities benefit.

The six case studies presented below, describe the social, economic, and environmental benefits that RE and EE programs bring to localities where they are implemented. They highlight innovative initiatives implemented in a diverse set of cities and regions:

- **New Delhi's** municipal government has partnered with Infrastructure Leasing and Financial Services Environment (IL&FS Environment) to build a waste-to-energy plant that will save approximately 8.2 million tons of greenhouse gas emissions over its 25-year lifespan, while reducing landfill area, air, and water pollution. The project helps transition former waste pickers to new jobs, directly hiring 70 people at the new plant, and has created a community center that provides support and job training to approximately 200 local women.

- **Nanjing, China** worked with the electric vehicle industry to add 4,300 electric vehicles to its streets between 2014 and 2015. This transition has helped the city reduce emissions by 246,000 tons of carbon dioxide equivalent (CO_2e) in 2014, while saving over US $71 million in lower energy bills.
- **In the industrial Valle Del Cauca corridor of Colombia**, The Women's Cleaner Production Network developed action plans to reduce industrial pollution and address climate change in small and medium-sized enterprises. The initiative has created a host of benefits, including a 110 percent increase in enterprise production efficiency and a new residential solar installation program. In Lagos, and in many other Nigerian cities, private companies are piloting new approaches to make solar energy more accessible and affordable. A partnership between a solar start-up and local telecommunications provider has brought solar power to 50,000 homes, clinics, schools, and businesses, benefiting more than 250,000 people and creating 450 new jobs.
- **Uganda's capital city, Kampala**, has partnered with businesses to scale up an array of clean cooking technology initiatives, installing 64 improved eco-stoves in 15 public schools, constructing bio digesters in 10 public schools, and funding companies that train women and youth to produce low-carbon briquettes from organic waste.
- **Mexico City's** Sustainable Buildings Certification Program–developed and implemented in partnership with the local construction and building industry–

covers 8,220 square meters of floor area across 65 buildings and has reduced 116,789 tons of carbon dioxide (CO_2) emissions, saved 133 million kilowatt-hours (kWh) of electricity and 1,735,356 cubic meters of potable water, and created 68 new jobs between 2009 and 2017.

These initiatives have great potential to motivate countries and non-state actors to build new channels for collaboration, raise their ambitions, and scale up their efforts. The 1 Gigaton Coalition will continue to promote RE and EE efforts, evaluate their emissions impacts, and show how they contribute to achieving both international climate objectives and sustainable development goals.

TYPE	EXAMPLE ORGANIZATIONS	PROGRAMS/ PRODUCTS/ INNOVATIONS
Global Organizations/ NGOs/ Academia	• Alliance to Save Energy • American Council for an Energy-Efficient Economy • APNPP • Baku Initiative • COGEN Europe • Clean Energy Ministerial • Council of European Energy Regulators • Energy and Minerals Business Council • Energy Charter Treaty • Energy Regulators Regional Association • Energy Technology Data Exchange • Energy Watch Group • Eurelectric • Gas Exporting Countries Forum • The Global Covenant of Mayors for Climate & Energy • INOGATE • Interamerican Association for Environmental Defense • International Association of Oil & Gas Producers • International Energy Agency Energy in Buildings and Communities Program • International Energy Forum • International Gas Union • International Partnership for Energy Efficiency Cooperation • Joint Organizations Data Initiative • OPEC	**Combined Heat and Power Partnership -** The CHP Partnership is a voluntary program seeking to reduce the environmental impact of power generation by promoting the use of environmentally beneficial combined heat and power (CHP). **The Global Covenant of Mayors for Climate & Energy** - an international alliance of cities and local governments with a shared long-term vision of promoting and supporting voluntary action to combat climate change and move to a low emission, resilient society. **The World Bank Group -** implementing electrification projects in the rural areas in Mali, in conjunction with the Malian Agency for the Development of Household Energy and Rural Electrification (AMADER). As part of the Global Partnership of Output-Based Aid (GPOBA), the World Bank has also provided financing for projects to install new electricity meters in the commune of Sébékoro, in the Kayes region, to the west of Bamako. These meters are more affordable than those generally available on the market. The supply of electricity to the commune was also extended to run between 6 pm and midnight.

TYPE	EXAMPLE ORGANIZATIONS	PROGRAMS/ PRODUCTS/ INNOVATIONS
	• OREDA • Petrocaribe • RECS International • South American Energy Council • World Coal Association • World Energy Council • World LPG Association World Petroleum Council	
Governments/ Academia	• Advanced Research Projects Agency - Energy (ARPA-E) • U.S. Geological Survey • The MIT Energy Initiative • Office of ENERGY EFFICIENCY & RENEWABLE ENERGY • California Energy Commission • InnovFin Energy Demo Projects (EDP) facility - funded under Horizon 2020, the EU research and innovation programme • Government of China	**EnergyStar -** a joint program of EPA and the U.S. Department of Energy that helps American businesses and consumers save money and protect the environment by investing in energy efficient products and practice. **The Federal Energy Management Program's (FEMP) Energy Incentive Program** helps federal agencies take advantage of these incentives by providing information about the funding-program opportunities available in each state. **The Energy Innovations Small Grant (EISG) Program** provides up to $150,000 for hardware projects and $75,000 for modeling projects to small businesses, non-profits, individuals and academic institutions to conduct research that establishes the feasibility of new, innovative energy concepts. **The Government of China** - The scale of investments being made in new energy technologies is unprecedented. Beijing is investing $1.7 trillion in "strategic sectors," a major portion of it targeted to clean energy technology.
Private Sector	• Google	Google has built a $915 million portfolio of clean energy investments.
	• Apple	Hydrogen-based laptop battery that could last for months

TYPE	EXAMPLE ORGANIZATIONS	PROGRAMS/ PRODUCTS/ INNOVATIONS
	• BuffaloGrid	BuffaloGrid hubs aim to help connect the next billion people who currently have no access to power by bringing mobile power to people who are off the grid. They're making a big push against the next digital divide. Through its hub - a large power pack attached to a solar panel - people can plug in their phones and recharge them.
	• SEaB Energy	SEaB energy turns a neighborhood or business into its own power plant with closed-loop systems known as the Flexibuster (for food waste) and the Muckbuster (for agricultural waste). The systems, which fit into a shipping container, generate electricity and heat that are sent to a micro grid to be shared between neighbors.
	• Origami Energy	A real-time marketplace to distribute energy: through an online marketplace where a distributed network of energy generating, energy using and energy storing assets are connected to the electricity grid and monitored through an online marketplace, which means the supply and demand of electricity is matched more evenly in real time.
	• Bulb	Bulb supplies 100% green energy that's cheaper than fossil fuels. With 150,000 members and growing, those who have signed up are saving 285,000 tons of CO_2 - or the equivalent of removing 200,000 cars from the road.
	• H2GO Power	A company that develops hydrogen energy storage.
	• Kite Power Systems	One of the world's first commercial kite-driven power stations
	• Upside Energy	A company that helps people make smart choices about their energy use by using AI to orchestrate the energy stored in their devices.
	• Powerhive	Develops and operates solar mini grids of a total capacity of 1MW to power 100 villages in Kenya.

TYPE	EXAMPLE ORGANIZATIONS	PROGRAMS/ PRODUCTS/ INNOVATIONS
	• Pollinate Energy	an Australian energy start-up who provides solar lanterns to urban India. The company has distributed 11,437 systems to 52,775 people in India to date.
	• Uncharted Play	Uncharted Play aims to improve the enormous issue of energy supply in the developing world. The SOCCKET ball's energy solution provides off-grid power that is 100 percent clean and renewable, but they don't use solar, wind or any other mainstream method of energy production. The SOCCKET is a soccer ball that stores and converts kinetic energy throughout the day while the ball is in motion. Similarly, the PULSE skipping rope produces energy simply by being used. A thirty-minute soccer game or skipping session can power an LED light for more than three hours. The SOCCKET balls and PULSE jump ropes are already operational in developing countries in Africa and Central America – providing energy solutions that are not only innovative and renewable but also fun, engaging and healthy.

As mentioned, Mini-Grids powered by renewable energy or hybrids are increasingly recognized as having important potential to provide least-cost electricity supply to unserved settlements which are not viable for main grid connection, but densely enough packed to give Mini-Grids an advantage over a series of household solar systems. While such delivery is possible technically and innovation is moving globally, the roll out to date in developing countries has been slow. The following table present Examples of emerging delivery models for mini-grids

Examples of emerging delivery models for mini-grids

COMPANY	OUTREACH	CURRENT TARGET	COUNTRIES	ENERGY SOURCE	SIZE RANGE	FOCUS/INNOVATION
E.ON	7 systems, 420 customers	1m people in 10 years	Tanzania	Solar, bio-diesel	6–12kW	Standardisation for scale; Establish track record for finance Cellphone payment
GHAM POWER	3 micro-grids	>100 micro-grids in 10 years	Nepal	Solar	1–10kW	PPA with N-cell (telecoms) for reduced risk revenue stream Rent-to-own agreements
HUSK POWER	15,000 house-holds, several 100 businesses	75,000 house-holds, 10,000 businesses, 125 agro units	India Tanzania	Biomass, Solar	15–250kW (biomass); 20kW (solar)	Accept >5 year payback Targeting 8–10 year loans Rural empowerment 3-year expansion plan Inclusive business model
INENSUS	Supports mini-grid development in Africa with related management systems and consultancy		Senegal	Solar, Wind	5–10kW	Low-cost smartcard meter Sale of "electricity blocks" "MicroPowerEconomy" delivery system—flexible tariffs & micro-credit
M-KOPA	340,000 homes (Mar 16)	+500 homes/ day	Kenya, Tanzania, Uganda,	Solar	5–20W	PAYG business model Small SHS, LEDs & mobile phone charging services
POWERGEN (RENEWABLE ENERGY)	20+ mini-grids	50 mini-grids in 2016	Kenya & Tanzania, Zambia	Solar	1–6kW	Mini-grids compatible with central grid standards
POWERHIVE	4 sites, 1500 people (~300 connections)	100 villages	Kenya, Philippines (Africa/Asia expansion)	Solar	~20kW	Integrated tech system; Mobile money networks for pre-payment Dedicated software—predict revenue streams;
RUAHA POWER	1 pilot project (JV with Husk Power)	100 projects	Tanzania	Solar, biomass	300kW	Business model without subsidies Build Own Operate model Pre-payment meters
SPARKMETER	3 Earthspark mini-grids in Haiti	No fixed target	Asia, Africa, Latin America	Service for all types of mini-grids	0–500W	Metering with mobile payment system Cloud-based software "Gateway" usage dbase

GAP ANALYSIS

METHODOLOGICAL NOTE

Gap analysis involves the comparison of actual performance with potential or desired performance. Simply put, gap analysis addresses three questions:

- Where are we? (the present state); and
- Where do we want to go? (the target state)
- What must be addressed to get from today to the target?

The first question is answered through the previous research components, that is, the trend and benchmark analysis. These two components are basically a description of the present state and the elements that will shape the future. The second question is answered through the description of the desired end-state (as was described in the hypothesis section). So, if we know where we are (current state), what the desired state is, and who is working on solving related-challenges, we can also identify what areas are being neglected (and for what reason). These areas (and reasons) are the gaps.

The gaps described below give rise to the problem of finding an optimal time path, new technologies, modes of international co-operation, and innovative policy incentives to meet the grand challenge in a cost-effective way.

These are the early days of the high-tech energy era. Our knowledge of the potential and consequences of new technologies is still in its infancy. The full cast of players (i.e., states, technology companies, energy producers) is only now emerging onto the stage. How all of these forces interact and play out in the coming decades could well determine not just where we get our energy from and how much it costs, but also the shape of domestic and global development. The breakneck pace of the energy technology revolution likely masked inherent risks and gaps–especially in terms of the environment and public reaction.

GAP DESCRIPTION

Capital costs - The most obvious and widely publicized barrier to renewable energy is cost–specifically capital costs, or the upfront expense of building and installing solar and wind farms. Like most renewables, solar and wind are exceedingly cheap to operate. Their "fuel" is free, and maintenance is minimal, so the bulk of the expense comes from building the technology.[1] Higher construction costs might make financial institutions more likely to perceive renewables as risky, lending money at higher rates and making it harder for utilities or developers to justify the investment. For natural gas and other fossil fuel power plants, the cost of fuel may be passed onto the consumer, lowering the risk associated with the initial investment (though increasing the risk of erratic electric bills). However, if costs over the lifespan of energy projects are taken into account, wind and utility-scale solar can be the least expensive energy generating sources.[2] Even more encouragingly, renewable energy capital costs have fallen dramatically since the early 2000s and will likely continue to do so in the future.[3]

Market entry - For most of the last century US electricity was dominated by certain major players; including coal, nuclear, and, most recently, natural gas. Utilities across the country have invested heavily in these technologies, which are very mature and

---

[1] For example, The average cost in 2017 to install solar systems ranged from a little over $2,000 per kilowatt (kilowatts are a measure of power capacity) for large-scale systems to almost $3,700 for residential systems. A new natural gas plant might have costs around $1,000/kW. Wind comes in around $1,200 to $1,700/kw.

[2] As of 2017, the cost (before tax credits that would further drop the costs) of wind power was $30-60 per megawatt-hour (a measure of energy), and large-scale solar cost $43-53/MWh. For comparison: energy from the most efficient type of natural gas plants cost $42-78/MWh; coal power cost at least $60/MWh.

[3] For example: between 2006 and 2016, the average value of photovoltaic modules themselves plummeted from $3.50/watt $0.72/watt—an 80 percent decrease in only 10 years.

well understood, and which hold enormous market power. This situation—the well-established nature of existing technologies–presents a formidable barrier for renewable energy. Solar, wind, and other renewable resources need to compete with wealthier industries that benefit from existing infrastructure, expertise, and policy. It's a difficult market to enter.

New energy technology startups face even larger barriers. They compete with major market players like coal and gas, and with proven, low-cost solar and wind technologies. To prove their worth, they must demonstrate scale: most investors want large quantities of energy, ideally at times when wind and solar aren't available. That's difficult to accomplish, and a major reason why new technologies suffer high rates of failure. Increased government investment in clean energy; in the form of subsidies, loan assistance, and research and development would help mightily.

Unequal playing field - You don't tend to see multi-billion-dollar industries without also seeing outsized political influence--and the fossil fuel industry is no exception. Oil Change International estimates that the United States spends $37.5 billion on subsidies for fossil fuels every year. Through direct subsidies, tax breaks, and other incentives and loopholes, US taxpayers help fund the industry's research and development, mining, drilling, and electricity generation. While subsidies have likely increased domestic production, they've also diverted capital from more productive activities (such as energy efficiency) and constrained the growth of renewable energy. The renewables sector enjoys fewer subsidies and, generally speaking, receives much less preferential political treatment.

Reliability misconceptions - Renewable energy opponents love to highlight the variability of the sun and wind as a way of bolstering support for coal, gas, and nuclear plants, which can more easily operate on demand or provide "baseload" (continuous) power. The argument is also used to undermine large investments in renewable energy, presenting a rhetorical barrier to higher rates of wind and solar adoption. However, reality is much more favorable for clean energy. Solar and wind are highly predictable, and when spread across a large enough geographic area and paired with complementary generation sources, they become highly reliable. Modern grid technologies like advanced batteries, real-time pricing, and smart appliances can also help solar and wind be essential elements of a well-performing grid. Many utilities, though, still don't consider the full value of wind, solar, and other renewable sources. Energy planners often consider narrow cost parameters, and miss the big-picture, long-term opportunities that renewables offer. Increased awareness and a willingness to move beyond the reliability myth, is sorely needed.

Data availability and information sharing remain a perennial challenge-- one that is preventing countries and supporting organizations from systematically evaluating their work's impact, although renewable energy and energy efficiency projects and policies are growing in developing countries. The 1 Gigaton Coalition has developed a database of about 600 internationally supported projects implemented in developing countries between 2005 and 2016.

Energy poverty circumstances and consequences - the largest challenge, which may even dwarf other challenges discussed below, will be the eradication of energy poverty, especially electricity poverty, in the least developed countries and regions. There are several causes of energy poverty, the most obvious of which is living in a community having no, or very limited, access to electricity. Energy poverty can also exist in geographical regions that have inadequate electricity supplies, especially urban areas in less developed countries. In these circumstances, the inability to afford electricity and associated end-use equipment are among the many consequences of poverty that cause suffering to hundreds of millions of people including malnutrition and preventable disease.

A de-coupling of energy utilization from economic growth is required for a transition to one that is sustainable- Although energy consumption needs to grow at rates high enough to support economic development, rapid expansion of fossil fuel use will have deleterious effects on the environment. Therefore, in emerging countries, a major energy policy objective should be the "decoupling" of economic growth from fossil fuel energy consumption growth. Along with efforts to promote energy conservation and efficiency, clean energy supplies such as nuclear and renewables will be needed; gas is a cleaner – burning fossil fuel than coal and will help achieve greenhouse gas (GHG) targets but is not sufficient to decarbonize the electricity sector. However, there is uncertainty whether the electricity sector will attract enough investment to meet growing demand, especially in unstable countries. Business models as well as regulatory regimes tested and practiced in OECD countries will not necessarily be applicable to emerging economies due to the difference in not only developmental stages but also social, political and cultural backgrounds.

GRAND CHALLENGES

METHODOLOGICAL NOTE

Grand Challenges (GCs) are lists of difficult but important problems articulated by the research team to encourage the discovery of (mainly) technological innovation (i.e., breakthroughs) that could potentially solve the main issues. In other words, a GC is one or more specific critical barrier(s) that, if removed, would help solve an important problem with a high likelihood of global impact through widespread implementation.

Articulating important challenges that have the potential to deliver real impact and allocating significant resources to address these GCs later in the process, allows XPRIZE to bring the best minds to the table by engaging crowds who might not otherwise be engaged in global research.

KEY CHALLENGES

- Lack of reliability for some forms of renewables
- Cheaper battery solutions
- Technology misconceptions (does it really work? Isn't it too expensive?)
- Aesthetic challenges (some don't like the look of energy panels on homes)
- Commercialization of breakthroughs
- High capital or startup costs
- Efficient transmission of renewable energy
- Few/declining subsidies

FRAMING A GRAND CHALLENGE

- **Widely applicable problem… -** Over 1.2 billion people (about 20% of the global population) around the world lack access to electricity, which prevents many from living healthy productive lives. In addition, 3.04 billion people still rely on solid fuels and kerosene for cooking and heating. This electricity access deficit is overwhelmingly concentrated in Sub-Saharan Africa (62.5% of the population) and South Asia (20% of the population). The underlying challenges to providing renewable energy in many less developed countries are energy generation, energy storage, and achieving energy efficiency. It is imperative to pull the bottom billion out of darkness and poverty and provide them with the dignity and quality of life every person on the planet deserves.

- **for which scientifically sound solutions are imaginable…**like converting heat to focused beams of light, solar paint, next generation batteries, and predicting renewable energy,
- **but not quite at hand… -** Some of these innovations are still decades away
- **with deep societal importance –** With over 1 billion people living without proper electricity, the world needs to develop sustainable innovations to end energy poverty and allow people to live happy, healthy, and productive lives.

FORESIGHT

METHODOLOGICAL NOTE

Scenarios inform present-day decision-making by exploring different possible futures. In contrast to forecasting, scenarios examine what is most uncertain and surprising as a mechanism to generate insight and provoke action regarding future-focused risks and opportunities. Scenarios can stretch our thinking about divergent plausible futures. Importantly, the value of scenarios analysis is to examine all of the possible futures identified—rather than focusing on the more desirable ones—with the understanding that any scenario may occur. Thus, scenarios are a tool to uncover blind spots and broaden perspectives about alternative future environments in which today's decisions might play out. The implications drawn from the scenarios are designed to trigger discussion, rather than serving as prescriptive outcomes.

The Global Economic Slowdown scenario describes a future with sustained low economic growth or economic contraction and/or global conflict. Worldwide, economic impacts result from stock market declines, high unemployment, international debt, global conflict, and/or consumer unease and anxiety. In a slow economy, the desire for reduced greenhouse gas emissions may remain, but a slower turnover of appliances, cars, and other energy-consuming technologies can slow the adoption of more efficient technologies. A focus on consumer behavior will drive design and marketing of new innovative products and services. Less purchasing power may drive consumers to delay purchases of perceived luxury items and lean more toward adoption of cost-saving products and services. A slow economy also can stall or reverse demand growth for electricity in all sectors, leaving electric utilities with limited capital for investment. Policies that are viewed as potentially increasing costs of electricity or other commodities, such as renewable portfolio standards (RPS) and carbon legislation, are unlikely when the political focus is on improving the economy. For innovation, the emphasis is likely to shift to getting more from existing assets by extending plant life and decreasing operation and maintenance costs. As the economic slowdown spreads internationally, countries may turn inward to focus on improving their own economies, while reducing investment in global institutions, including those that promote economic growth such as trade and investment agreements. Also affected: the ability of developed countries to aid developing countries in promoting access to electricity and reducing emissions. Technological collaboration may be limited. However, developing countries' motivation to expand electricity access will persist even in a poor economy, and it is likely that they will continue to invest in electricity infrastructure and innovations.

What to Watch:

- Worldwide GDP and direction of productivity (e.g., low economic productivity).
- Monetary or fiscal policies that try to address productivity (e.g., slowdown of the economy).
- Economic disparities.
- Access to electricity in developing countries.
- Domestic and international policies related to renewables and greenhouse gases.

R&D Needs:

- Life extensions of existing generation and R&D assets.
- Operation and maintenance cost decreases.
- Cost reductions for new-build, low-carbon technologies.
- Low-cost distributed generation for developing economies.

The Hydrocarbon Fuels Dominate scenario describes a future in which hydrocarbon fuels are low cost and supply is abundant. Significant innovation in hydrocarbon extraction technologies and little change in policies that limit hydrocarbon use lead to sustained low cost and abundant supply. Global economic growth persists. The North American shale gas boom continues, keeping domestic natural gas prices low and expanding international markets for liquefied natural gas (LNG). Natural gas production increases internationally in conventional and shale gas basins. While low natural gas prices may decrease U.S. coal production, China, India, and other economies continue to rely on abundant, low-cost coal. Crude oil prices remain low. Low electricity prices lead to increased electricity use, a rise in manufacturing, and a higher "hurdle" to justify behind-the-meter distributed generation installations, resulting in continued load growth for grid-supplied electricity. Continued low costs of hydrocarbon fuels could drive an increase in participation in activities in a broader local area, creating a market for increased and convenient transportation, either individual or shared. Technology innovation likely focuses on extracting fuels efficiently, at low cost, to keep operating costs low and sustain revenues. Natural gas is promoted as a "bridge fuel" to a low-carbon economy, but with some concern about greater dependence on natural gas without further reducing carbon. Therefore, focus is also on technologies to reduce environmental impacts such as methane leaks, more efficient fossil plants, and opportunities to use abundant fossil fuels in cleaner ways, such as carbon capture, utilization and storage (CCUS). Increases in electricity load, as well as increases in natural gas use, likely require investment in grid and pipeline infrastructure to expand capacity.

What to Watch:

- Innovations in fossil fuel extraction and productivity.

- Futures pricing for natural gas, oil, and coal.
- Globalization of gas and LNG markets.
- Corporate strategies of hydrocarbon fuel companies.
- International environmental commitments, goals, and regulations.

R&D Needs:

- Carbon capture, utilization, and storage technologies.
- Efficient gas turbines and fossil plant designs.

The Localization of Energy Systems scenario describes a future in which energy systems are focused at the local customer and community level. Electricity generation is increasingly focused at the local level through community systems and microgrids, and consumers become more engaged with their energy use through smart appliances, connected devices, and innovations in both technology and product and service offerings. Policies and market regulations are enacted that facilitate and encourage localized energy systems and self-generation (e.g., feed-in tariffs or net metering). In rural areas of developing countries with no prior access to the grid, the opportunity arises for a "clean sheet of paper" to develop a grid of local energy systems. Technology development and adoption will see an increase in "globalization" where global products are adapted for the uniqueness of local culture, more often in developing economies. These local solutions could potentially be exported to other geographic regions creating disruptions in established markets, particularly in developed regions. While some consumers may be motivated to make environmentally conscious and socially responsible investments, others may seek increased reliability and dependability of electricity services, or to be isolated from security issues or attacks on the larger grid. Others may desire basic services at the lowest cost possible. Investment in photovoltaic systems, electric cars, micro turbines, micro grids, and other technologies are driven by falling prices, technological innovation, and consumer values such as clean energy, reliability, choice, and control. A divergent economic status of customers could result in a growing disparity between those able to invest in self-generation and those who cannot. The obligation of utilities will be to serve those who cannot self-generate. Increased use of distributed electricity generation leads to flat growth or reduced demand for grid-supplied electricity. Utility innovation is at the intersection of technology developers and third-party suppliers as they become partners and integrators, though a move is foreseeable toward disaggregation of control of local energy systems from traditional utilities. New business models and differentiated product and service offerings allow consumers to choose individual electricity plans that meet their specific desires, including basic services, renewable energy, superior reliability, or others. With rapid technology innovation in consumer products and electricity technologies, more reactive products and services are needed to satisfy customers' needs. An increase in wireless communication, protocols, and standards will enable innovation adoption.

What to Watch:

- Deployment of micro grids and adoption of behind-the-meter and community energy systems.
- Development and adoption of consumer electronics.
- Technology breakthroughs and cost reductions in distributed generation, energy storage, electric vehicles, etc.
- Grid resiliency/reliability concerns and/or events.
- Shareholder resolutions on sustainability.
- Regulatory structure (e.g., feed-in-tariffs, net energy metering) and pricing regimes (e.g., time-of-use, capacity payments).
- Innovative third-party business models and disintermediation.

- Globalization – countries taking products and services to other regions.
- Globalization – countries developing products and services to address the uniqueness of local culture, resources, and economies.

R&D Needs:

- Information technology communication protocols and standards.
- Grid operation and planning tools for distribution systems.

The Significant Reduction in Environmental Footprint scenario describes a future in which actions significantly reduce water use, waste discharges, and emissions, including criteria pollutants, and greenhouse gases. Expansive new policies and political pressures push to significantly decarbonize the electricity sector and the economy. Policies also focus on environmental concerns, such as air pollutants, clean water, and water availability. A strong economic environment allows for increased environmental stringency. Achieving reductions in the global environmental footprint requires switching from fossil fuels to clean energy sources (such as decarbonized electricity, hydrogen produced from clean electricity, or sustainable biofuels). This in turn results in a net increased demand for electricity. Meanwhile, greater regulation of the extraction and transportation of coal, natural gas, and petroleum may increase hydrocarbon fuel prices. Innovation focuses on bringing down the costs and expanding the capabilities and adoption of technologies that reduce the electricity sector's environmental footprint, and on electrifying other energy sectors. Technologies include renewables, advanced nuclear, CCUS, and energy storage systems; electrification technologies such as electric vehicles, heat pumps, and hydrogen electrolysis; as well as energy efficiency and energy management systems. Consumer behavior like urbanization and the sharing economy may also reduce personal environmental footprints, by reducing the size of living space per person and by reducing ownership of individual modes of transportation. This could drive a reduction in energy use beyond energy efficiencies resulting from cost effective innovations in electric-enabled industries. The ultimate adoption of certain technologies will depend strongly on public opinion, the technology's acceptance, and availability. While some technologies evaluated in this scenario may not be operating by 2030, understanding the need for their availability can accelerate R&D.

What to Watch:

- International and domestic environmental commitments, goals, and regulations.
- Shareholder resolutions on sustainability.
- Coal dust and methane emission regulations.
- Carbon prices.
- Technology breakthroughs and cost reductions in next generation technologies.

R&D Needs:

- Advanced generation technologies – renewables, CCUS, next-generation nuclear, energy storage.
- Electrification technologies – electric vehicles, heat pumps, hydrogen electrolysis.
- Energy management technologies – demand response, energy efficiency, management systems.
- Information technology communication protocols and standards.

PREFERRED FUTURE

The preferred future is typically captured as a vision. A vision is an image of the future. It creates an attractive mental picture of an outcome that people can strive for. Most people think of the future in ideas rather than images. Attractive ideas are progress, security, enjoyment; unattractive ones include overpopulation, pollution, sickness, and death. None of these are visions, however, because they are not images. What does it look like? How does it feel? What does it taste like, sound like? The vision is something tangible and concrete - something that excites people and enables them to take action in support of reaching the preferred future state.

A future of plenty or a future of scarcity is certainly not a given. It's possible to address system failures to leverage, shift, or even reverse trends—even global mega trends—by enabling and incentivizing bold actions. But to truly think boldly, we cannot start with today. It's imperative to start with a preferred future state. The following scenarios are examples of preferred futures.

"By 2040, all those living in energy poverty will have access to affordable, efficient, renewable and sustainable electricity in order to live a healthy and productive life."

ACTION

METHODOLOGICAL NOTE

Solving grand challenges is complex. XPRIZE only launches the most impactful prizes, those that when launched in conjunction with others will achieve a moonshot and radically transform a given domain. XPRIZE begins this process by developing a Futures ImpactMap that maps the full landscape of what is currently happening, what needs to change, and which breakthroughs would not happen unless the crowd was incentivized to develop radical innovations. Once we know which breakthroughs will not be achieved by traditional actors alone, XPRIZE sources brilliant Visioneers in the crowd to vet and evaluate which breakthroughs should become the next XPRIZE.

BREAKTHROUGH EXAMPLES

A major feature of energy consumption in the coming decades might well be the shift from raw fuels to cleaner, more flexible fuels, and electricity-based energy, combined with a move towards more differentiated energy services. New consumer behavior patterns, boosted by (among other things) regulatory changes, could be a driver behind this trend, triggering or reinforcing substantial efficiency improvements in end-use technologies, in transport as well as household goods, industrial use, and residential and commercial buildings. In many of these areas, new technologies are already available: hybrid petrol-electric engines, direct injection engines, and fuel cells for cars; supercapacitors used in household goods; more efficient electric motors, materials processing technologies and manufacturing processes; high-tech windows, super-insulation, more efficient lighting, advanced heating and cooling systems in buildings. But their development is generally hampered by excessive costs or by the absence of adequate infrastructure. With a fifty-year horizon, however, they could represent a substantial market share in energy end-uses.

Converting heat to focused beams of light - a team of MIT scientists has built a non-traditional solar energy device that uses inventive engineering and advances in materials science to capture far more of the sun's energy. The trick is to first turn sunlight into heat and then convert it back into light, but now focused within the spectrum that solar cells can use. While various researchers have been working for years on so-called solar thermophotovoltaics, the MIT device is the first one to absorb more energy than its photovoltaic cell alone, demonstrating that the approach could dramatically increase efficiency. The key step in creating the device was the development of something called an absorber-emitter. The researchers are also exploring ways to take advantage of another strength of solar thermophotovoltaics. Because heat is easier to store than electricity, it should be possible to divert excess amounts generated by the device to a thermal storage system, which could then be used to produce electricity even when the sun isn't shining. If the researchers can incorporate a storage device and ratchet up efficiency levels, the system could one day deliver clean, cheap—and continuous—solar power.

Solar Paint - A group of researchers at RMIT University in Australia have created a new technology they call "solar paint." That may sound like a new kind of solar panel, but it's actually a completely different technology, and one that should prove to be far less costly. Solar paint consists of two components: a moisture absorbing catalyst and light absorbing titanium oxide. The titanium oxide particles absorb light from the sun and convert it into electric energy. Since the titanium oxide is in close contact with the moisture absorbing catalyst, this captured solar energy can be directly transferred into the catalyst, where it is used to split water and produce hydrogen. This developed catalyst has the ability to absorb more moisture from humid air, which results in its ability to continuously split water using the energy provided by the sun.

Next-generation battery - Harvard researchers have developed a cheap, non-toxic battery that lasts more than 10 years, which they say could be a game changer for renewable energy storage. This new type of battery stores energy in organic molecules dissolved in neutral pH water. This makes the battery non-toxic and cheaper. It's suitable for home storage and lasts for more than a decade.

Predicting renewable energy - The production of energy from renewable sources is growing rapidly. With the advancement of technology development harnessing energy from wind, sun, hydro, amongst others, it is becoming more popular and economically accessible. Negative effects on the environment from energy sources such as natural gas, oil and coal have further accelerated this shift. The biggest challenge with renewables is that energy production is intermittent. The production depends on weather conditions, such as the wind blowing or sun shining. Unlike conventional power, this means such sources cannot necessarily meet surges in demand. There has been a lot of research studying accuracy and prediction capabilities, by harnessing advanced AI technology:

- A paper by Gul M Khan from University of Engineering and Technology in Peshawar describes neural network approaches in creating power generation predictions of wind-based power plants. The results show the predictions from a single hour up to a year with mean absolute percentage error as low as 1.049% for a single day hourly prediction.
- In 2015, IBM was able to show an improvement of 30% for solar forecasting while working with the U.S. Department of Energy SunShot Initiative. The self-learning weather model and renewable forecasting technology integrated large data-sets of historical data and real-time measurement from local weather stations, sensor networks, satellites, and sky image cameras. The platform is

exploring how to address forecasting challenges in wind and hydro-power plants.

- Nils Treiber and his colleagues from the University of Oldenburg discuss how machine learning can be used to predict wind power. Their study focuses on predictions for individual turbines and then how entire wind parks can predict production from a matter of seconds to hours. They compare their results to a persistence model and show an increase in accuracy of over 24%.

Solar Leaf - Developed by professors at MIT, the Solar Leaf is made out of a thin silicon solar cell which is dropped into water in order to separate hydrogen and oxygen molecules, turning them into electricity by connecting them to fuel cells. The reason for the name 'Solar Leaf' is that the process imitates the photosynthetic process of a real leaf by converting water and sunlight into energy. Essentially, one solar leaf placed in around one liter of water can produce up to 100 watts of energy, 24 hours a day. In terms of efficiency, they aren't actually as efficient as traditional and emerging solar technologies; however, they are considerably cheaper. This feature makes them a suitable lighting solution for developing nations, which poses a promising addition to the ever-growing renewable energy revolution.

CONCLUSION

Transformational change is the process of creating a new era. It begins with one or more bold leaders who see that the old era is no longer suitable for the present, much less the future. These bold visionaries articulate a preferred future for the new era and enroll others in the campaign to bring that future about. These leaders and those that follow face enormous obstacles from the doubts and resistance of the majority to the challenge of leaving behind old ways of doing things even before the new ones are ready. Nevertheless, they are compelled to engage in this work because it must be done sooner or later, and it's best to start today before the terms of change can be dictated.

APPENDIX A: DEFINITIONS

1. **Breakthrough:** To overcome "Grand Challenges" and achieve a "Preferred Future," it's essential to identify potential breakthroughs that can create massive, global impact. Breakthroughs are evaluated based on 4 criteria: impact potential, level of audacity, market readiness level, and desired timeline for impact.
2. **Domain:** XPRIZE operates within 7 domains: shelter and infrastructure; energy and resources; planet and environment; health and wellness; learning and human potential; space and new frontiers; and civil society. Emerging exponential technologies and other innovations in policy and financing have the potential to address grand challenges in these areas, but require new action by key stakeholders and innovators from around the globe.
3. **Futures ImpactMap:** Is an analytical tool for understanding persistent problems and barriers that make up grand challenges in various domains as well as the actions that key stakeholders can take to overcome them and achieve a preferred future state. XPRIZE uses Futures ImpactMaps to help identify potential XPRIZE competitions and other actions that can accelerate a bridge to abundance for all across domains.
4. **Grand Challenge Area:** Is a topic area like "Nourishing the Next Billion," which comprises a combination of complex and overlapping social, technological, economic, environmental, and policy issues. Only the most effective actions will address these issues and accelerate progress toward a more positive future.
5. **Grand Challenge Statement:** A problem statement, which defines the issue to be solved.
6. **Preferred Future:** Is typically captured as a vision—an image of the future. It creates an attractive mental picture of an outcome that people can strive for.

7. **Scenario:** Scenarios inform present-day decision making by exploring different possible futures. In contrast to forecasting, scenarios examine what is most uncertain and surprising as a mechanism to generate insight and provoke action regarding future-focused risks and opportunities.
8. **XPRIZE:** The XPRIZE Foundation is the global leader in designing and implementing innovative competition models to solve the world's grandest challenges. XPRIZE utilizes a unique combination of gamification, crowdsourcing, incentive prize theory, prize philanthropy, and exponential technologies as a formula to make 10x (vs.10%) impact in the grand challenge domains facing our world. The XPRIZE philosophy is that—under the right circumstances—igniting rapid experimentation from a variety of diverse lenses is the most efficient and effective method to driving exponential impact and solutions to grand challenges.
9. **XPRIZE (competition):** An XPRIZE is an incentivized prize competition designed to create 10x impact on the world. The exponential trend of computing power has led us to this period in time, where technology that was just 30 years ago only available to industries like NASA is now on the smartphones in our pockets. XPRIZE competitions leverage this exponential technology with the power of the crowd to spur innovation in areas where there is market failure, empowering individuals across the globe to become the world's next changemakers. The competitions are engineered for success: they are required to meet a series of 10 criteria through a rigorous evaluation at our Visioneers Summit in order to be deemed ready for launch. Each XPRIZE competition results in audacious breakthroughs that have scalable impact, leading us closer to the XPRIZE Foundation's vision of a future in which humanity as a whole benefit by having access to what was once scarce, and is now made abundant.

REFERENCES

(2012, February). Financing renewable energy in developing countries. Drivers and barriers for private finance in sub-Saharan Africa. UNEP. Geneva. From http://www.unepfi.org/fileadmin/documents/Financing_Renewable_Energy_in_subSaharan_Africa.pdf

(2014, August 15). Integrated sustainable rural development: Renewable energy electrification and rural productivity zones. United Nation Development Programme. From http://www.undp.org/content/undp/en/home/librarypage/environment-energy/mdg-carbon/integrated-sustainable-rural-development--renewable-energy-elect.html

(2016, April 4). A renewable energy boom. The New York Times. From https://www.nytimes.com/2016/04/04/opinion/a-renewable-energy-boom.html

(2017). BP energy outlook 2017 edition. BP. From https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf

(2017, Feb 3). A perspective on the future of energy: scenarios, trends, and global points of view. Electric Power Research Institute. California. From http://integratedenergynetwork.com/wp-content/uploads/2017/02/3002009918-Scenarios-Trends-and-Global-Points-of-View_FINAL.pdf

(2017, February 13). Making renewable energy more accessible in Sub-Saharan Africa. The World Bank. From http://www.worldbank.org/en/news/feature/2017/02/13/making-renewable-energy-more-accessible-in-sub-saharan-africa

(2017, July). Future energy scenarios. National Grid. From http://fes.nationalgrid.com/

(2017, July 13). At what cost? Can the world thrive on 100% renewable energy? A transition away from fossil fuels is necessary, but it will not be painless. The Economist. From https://www.economist.com/news/finance-and-economics/21725011-transition-away-fossil-fuels-necessary-it-will-not-be-painless-can

(2017, August). Staff report to the secretary on electricity markets and reliability. U.S. Department of Energy. From https://energy.gov/downloads/download-staff-report-secretary-electricity-markets-and-reliability

(2017, December). Global energy perspective: Reference case 2018. McKinsey Energy Insights. From http://www.apren.pt/contents/publicationsothers/global-energy-perspective-reference-case-2018-vp.pdf

(2017, December). Renewable energy. California Energy Commission. From http://www.energy.ca.gov/renewables/tracking_progress/

Birkhoff, R. (2016, September 1). Breaking down barriers to renewable energy development in the Caribbean. Renewable Energy World. From http://www.renewableenergyworld.com/articles/2016/09/breaking-down-barriers-to-renewable-energy-development-in-the-caribbean.html

Delmon, J. (2016, June 9). How can developing countries find the right renewable energy solutions?. World Economic Forum. From https://www.weforum.org/agenda/2016/06/how-can-developing-countries-find-the-right-renewable-energy-solutions

Gifford, G. (2016, June 4). 5 energy innovations revolutionizing the developing world. Renewable Energy Focus. From http://www.renewableenergyfocus.com/blog/2016/4/6/5-energy-innovations-revolutionizing-the-developing-world/1191.aspx

Hsu, A., Rosengarten, C., Weinfurter, A. & Xie, Y. et. al. (2017). Renewable energy and energy efficiency in developing countries: Contributions to reducing global emissions. The 1 Gigaton Coalition. From http://wedocs.unep.org/bitstream/handle/20.500.11822/22149/1_Gigaton_Third%20Report_EN.pdf?sesequen=1

Johnston, I. (2016, May 31). Developing world invests more in renewable energy than rich countries for first time, new study says. Independent. From http://www.independent.co.uk/environment/climate-change/renewable-energy-investment-developed-world-developing-world-ren21-report-a7058436.html

Lahidji, R., Michalski, W., Stevens, B., Bourdaire, J., Grubler, A. & Imboden, D. M. et. al. (1999). Energy: The next fifty years. OECD. From https://www.oecd.org/futures/17738498.pdf

Londoño, E. (2017, August 12). Chile's energy transformation is powered by wind, sun and volcanoes. The New York Times. From https://www.nytimes.com/2017/08/12/world/americas/chile-green-energy-geothermal.html

Manzini, F. (2010, November 30). Clean energy sources and technologies. UNAM. From https://www.griffith.edu.au/__data/assets/pdf_file/0004/268357/Clean-Energy-Sources-and-Technologies.pdf

Marshall, J. (2013, February 16). Solar energy solutions for the developing world. Tiny lamps and clever financing may finally bring solar to the developing world. Ensia. From https://ensia.com/features/solar-energy-solutions-for-the-developing-world/

Mathews, J. A. (2016, May 16). Developing countries and the renewable energy revolution. OECD. From http://www.oecd.org/dev/developing-countries-and-the-renewable-energy-revolution.htm

McCrone, A. et. al. Global trends in renewable energy investments 2017. Frankfurt School-UNEP Centre. Frankfurt. From http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2017.pdf

McKibben, B. (2017, June 26). The race to solar-power Africa. American startups are competing to bring electricity to communities that remain off the grid. The New Yorker. From https://www.newyorker.com/magazine/2017/06/26/the-race-to-solar-power-africa

(2013, September). World energy scenarios composing energy futures to 2050. World Energy Council. From https://www.worldenergy.org/wp-content/uploads/2013/09/World-Energy-Scenarios_Composing-energy-futures-to-2050_Executive-summary.pdf

Numminen, S. & Lund, P. D. (2016, September 30). Frugal energy innovations for developing countries – a framework. Wiley Online Library. From http://onlinelibrary.wiley.com/doi/10.1002/gch2.1012/full

O'Sullivan, M., Overland, I. & Sandalow, D. (2017, June). The geopolitics of renewable energy. Center on Global Energy Policy, Columbia University, SIPA & The Geopolitics of Energy Project, Belfer Center for Science and International Affairs, Harvard Kennedy School. From https://sites.hks.harvard.edu/hepg/Papers/2017/Geopolitics%20Renewables%20-%20final%20report%206.26.17.pdf

Reed, S. (2017, October 17). A small firm in Germany has big ambitions in green energy. The New York Times. From https://www.nytimes.com/2017/10/17/business/energy-environment/germany-renewable-energy-solar-wind.html

Riley, T. (2016, August 24). Investing in off-grid renewables in the developing world: what you need to know. The Guardian.

From https://www.theguardian.com/sustainable-business/2016/aug/24/renewables-developing-countries-clean-energy-off-grid-investment-climate-change-mobile-money

Sawin, J. L., Seyboth, K. & Sverrisson, F. et. al. (2017). Renewable 2017, global status report. REN21. From http://www.ren21.net/gsr-2017/

Shahan, Z. (2014, November 21). 40 companies & organizations bringing solar power to the developing world. Renewable Energy World. From http://www.renewableenergyworld.com/ugc/articles/2014/11/40-companies–organizations-bringing-solar-power-to-the-developing-world.html

Stram, B. N. (2016, May). Key challenges to expanding renewable energy. Elsevier. From https://www.sciencedirect.com/science/article/pii/S0301421516302646?via%3Dihub

Stromberg, J. (2013, May 2). Five innovative technologies that bring energy to the developing world. Smithsonian. From https://www.smithsonianmag.com/science-nature/five-innovative-technologies-that-bring-energy-to-the-developing-world-49271677/

U.S. Energy Information Administration. (2017, January 5). Annual energy outlook 2017 with projections to 2050. EIA. From https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

World Bank. (2017, May 1). State of electricity access report 2017. World Bank. From https://openknowledge.worldbank.org/handle/10986/26646AR