AMERICA 3.0
THE RESILIENT SOCIETY

A SMART THIRD INDUSTRIAL REVOLUTION INFRASTRUCTURE AND THE RECOVERY OF THE AMERICAN ECONOMY

A Report Prepared for Senator Charles Schumer, U.S. Senate

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TABLE OF CONTENTS

AMERICA 3.0
THE RESILIENT SOCIETY
PART 1: THE VISION

TIR CONSULTING GROUP

*See Appendix for a description of TIR Consulting Group, LLC's scope of work

TABLE OF CONTENTS

HIGHLIGHTS

THE AMERICA 3.0 INFRASTRUCTURE TRANSFORMATION (2020 – 2040)

- A $16 TRILLION DOLLAR INVESTMENT TO SCALE, DEPLOY, AND MANAGE A SMART DIGITAL ZERO-EMISSION THIRD INDUSTRIAL REVOLUTION INFRASTRUCTURE FOR A 21ST CENTURY ECONOMY
- THE CREATION OF AN AVERAGE 15 TO 22 MILLION NET NEW JOBS OVER THE PERIOD 2022 to 2042
- EVERY DOLLAR INVESTED IN THE AMERICA 3.0 INFRASTRUCTURE IS PROJECTED TO RETURN $2.9 DOLLARS IN GDP BETWEEN 2022 AND 2042
- AN INCREASE IN THE ANNUAL GROWTH RATE OF GDP FROM A BUSINESS AS USUAL 1.9% GDP TO 2.3% GDP, AND A $2.5 TRILLION LARGER GDP IN 2042, (MOVING FROM $29.2 TO $31.7 TRILLION IN THAT YEAR)
- 377 BILLION TO LAY DOWN 22,000 MILES OF UNDERGROUND CABLE AND INSTALL 65 TERMINALS TO BUILD OUT AND MANAGE A STATE-OF-THE-ART HIGH VOLTAGE DIRECT CURRENT CONTINENTAL ELECTRICITY INTERNET ACROSS THE COUNTRY
- 2.3 TRILLION TO INSTALL AND MAINTAIN 74,000,000 RESIDENTIAL MICROGRIDS, 90,000 COMMERCIAL/INDUSTRIAL MICROGRIDS, AND 12,000 UTILITY-SCALE MICROGRIDS IN COMMUNITIES ACROSS AMERICA FOR THE GENERATION AND SHARING OF RENEWABLE ELECTRICITY
- $97 BILLION DOLLARS TO INSTALL FIBER-BASED BROADBAND IN ALL 121 MILLION HOMES ACROSS THE UNITED STATES
- $1.4 TRILLION TO BUILDOUT AND MAINTAIN A NATIONWIDE EV CHARGING INFRASTRUCTURE TO POWER THE MILLIONS OF ELECTRIC VEHICLES COMING INTO THE MARKET BETWEEN 2020-2040
- $4.4 TRILLION TO RETROFIT THE NATION'S COMMERCIAL AND INDUSTRIAL BUILDINGS
- $4.3 TRILLION TO INSTALL SOLAR PV ON OR AROUND COMMERCIAL BUILDINGS
- $1.8 TRILLION TO RETROFIT RESIDENTIAL BUILDINGS
- $1.61 TRILLION TO INSTALL PV ON OR AROUND RESIDENTIAL BUILDINGS
- A ROUGHLY DOUBLING IN AGGREGATE EFFICIENCY – THE RATIO OF POTENTIAL WORK (AMOUNT OF REAL GDP) COMPARED TO USEFUL ENERGY – ACROSS THE AMERICAN ECONOMY
- THE AVOIDANCE OF $3.2 TRILLION IN AIR POLLUTION AND HEALTHCARE COSTS AND $6.2 TRILLION IN CUMULATIVE CLIMATE-RELATED DISASTER COSTS
- PRIORITIZATION OF THE AMERICA 3.0 INFRASTRUCTURE IN THE NATION'S DESIGNATED 8,700 OPPORTUNITY ZONES – THE POOREST AND HIGHEST-RISK DISADVANTAGED COMMUNITIES
- THE SHIFT IN THE BUSINESS MODEL FROM OWNERSHIP TO ACCESS, MARKETS TO NETWORKS, SELLERS AND BUYERS TO PROVIDERS AND USERS, PRODUCTIVITY TO REGENERATIVITY, GDP TO QUALITY OF LIFE INDICATORS, AND NEGATIVE EXTERNALITIES TO CIRCULARITY ACROSS THE VALUE CHAINS

1 AMERICA 3.0

The coronavirus pandemic is spreading into communities across America. Tens of thousands of local businesses have been forced to shut down. Millions of American workers have been laid off and, at the same time, the United States and the world are facing increasingly severe climate change disasters, including floods, droughts, wildfires, and hurricanes, taking America into the sixth extinction of life on Earth. Where do we go from here?

The United States has faced two economic collapses and accompanying social upheavals in its history. Each time, they were followed by a grand new economic vision and a compelling social contract that led to a vast recovery across America.

The American Civil War from 1861-1865 devastated the economy as citizens took up arms against each other, leaving the country in shambles. After the war, the American people came together in a massive economic recovery, giving rise to the First Industrial Revolution… America 1.0. The Federal government financed the first telegraph experiment, followed by the installation of a continental telegraph communication system across the country. The Pacific Railroad Acts authorized the issuance of government bonds and land grants to railroad companies, hastening the buildout of a transcontinental rail infrastructure. The federal government's Homestead Acts ceded over 270 million acres of federal public lands—10 percent of the total US land area—for free to 1.6 million homesteaders.[1] The Federal Government's Morrill Land-Grant Acts established land-grant public colleges and universities across the country, providing the education and skills necessary to transform American agriculture and industry. The economic recovery was accompanied by the ushering in of a new social contract - the Progressive Era - taking the country into the twentieth century and a new period of prosperity.

The Great Depression of the 1930s led to a second collapse of the American economy and social disarray. Once again, the American people rallied together to build a fledgling Second Industrial Revolution - America 2.0. The Federal government established the Public Works Administration (PWA) to promote the new infrastructure transition for the country. The Work Projects Administration (WPA) hired millions of unemployed people to carry out public works projects, including the construction of buildings and roads. The Roosevelt administration also introduced a mammoth electricity-generation project—the Tennessee Valley Authority—that built giant dams to produce cheap subsidized hydroelectricity for rural communities that had not yet become electrified. The Federal Housing Administration (FHA)— created in 1934—helped millions of Americans afford home ownership. The Federal Government's GI Bill offered free higher education for nearly 8 million veterans. The government assistance facilitated a high-quality workforce to both complete the build-out of the Second Industrial Revolution infrastructure and manage the new business opportunities and employment that plugged into it. The Federal Government's National Interstate and Defense Highways Act of 1956 connected the country with a seamless interconnected road system, spawning the

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[1] Lee Ann Potter and Wynell Schamel, "The Homestead Act of 1862," *Social Education* 61, no. 6 (October 1997): 359–64.

development of suburban America. The economic recovery was accompanied by a new social contract, The New Deal. The America 2.0 social contract enjoyed widespread popular support for more than 40 years.

Once again, the United States needs to take hold of a new economic vision for the country's future. We are on the cusp of a Third Industrial Revolution - The Resilient Society. How do we begin to tackle something of this magnitude?

Every major economic infrastructure transformation in world history has required three elements, each of which interacts with the others to enable the system to operate as a whole: a new communication medium; a new power source; and a new transportation mechanism to “manage”, “power”, and “move” society. Infrastructure paradigms also create new kinds of human habitats and are accompanied by new economic systems and new forms of governance to manage them. Although it’s long been assumed that economic systems and forms of governance establish infrastructure, it is, rather, new infrastructure paradigms that largely determine the kinds of economic systems that plug into them and the forms of governance that oversee them.

Infrastructures, at the deepest level, represent an extension of what every organism needs to stay alive. Every organism needs a means to communicate, a continuous supply of energy to stay alive, a means of motility and mobility to engage its environment, and a semi-permeable membrane – a skin or shell – to mediate its internal life with the outside world. Infrastructures perform the same function. They allow ever-larger collectivities of human beings to engage in more complex, integrated, and inclusive economic, social, and political life as an extended social organism.

Communication technology is the brain that oversees, coordinates, and manages the economic organism. Energy is the blood that circulates through the body politic, providing the nourishment to convert nature’s endowment into goods and services to keep the economy and society alive and growing. Mobility and logistics are extensions of our limbs, allowing communities to interact physically across temporal and spatial domains facilitating the movement of goods, services, and people. Buildings are the skin—the semipermeable membranes that allow our species to survive the elements, store the energies and other resources we need to maintain our physical well-being, provide secure and safe places to produce and consume the goods and services we require to enhance our existence, and serve as a congregating place to raise our families and conduct social life. Infrastructure is akin to an immense technological organism that brings large numbers of people together as an extended figurative family collectively engaging in more complex economic, social, and political relationships.

In the nineteenth century, steam-powered printing and the telegraph, abundant coal, and locomotives on national rail systems meshed in a common infrastructure to manage, power, and move society, giving birth to the First Industrial Revolution and the rise of urban habitats, capitalist economies, and national markets overseen by nation-state governance. In the twentieth century, centralized electricity, the telephone, radio and television, cheap oil, and internal combustion vehicles on national road systems converged to create an infrastructure for the Second Industrial Revolution and the rise of suburban habitats, globalization, and global governing institutions.

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In a 2018 report, the Intergovernmental Panel on Climate Change (IPCC) concluded that to avoid further environmental degradation brought on by climate change we would have to cut the emission of global warming gases 45 percent from 2010 levels. This will require a transition of our global economy, our society, and our way of life.

While the global climate crisis has become a lightning rod in the political sphere, there is a parallel movement within the business community that will shake the very foundation of the global economy in coming years. Key sectors of the economy – ICT; power and electricity; transportation and logistics; and real estate – are beginning to decouple from fossil fuels in favor of ever cheaper solar and wind energies and the accompanying clean technologies, green business practices, and processes of circularity and resilience that are the central features of an ecological society.

New studies across industries are sounding the alarm that upwards of trillions of dollars in stranded fossil fuel assets could create a carbon bubble likely to burst, causing the collapse of the fossil fuel civilization.[2] The levelized costs of utility-scale solar and wind installations have plummeted and are now below the cost of nuclear power, oil, coal, and natural gas, leaving the old conventional energies and accompanying technologies behind.[3] "Stranded assets" are all the fossil fuels that remain in the ground because of falling demand as well as the abandonment of pipelines, ocean platforms, storage facilities, energy generation plants, backup power plants, petrochemical processing facilities, gasoline stations, auto service centers, and the myriad industries tightly coupled to the fossil fuel culture. The United States, currently the leading oil-producing nation, will be caught in the crosshairs between the plummeting price of solar and wind and the fallout from peak oil demand and accumulating stranded assets in the oil industry. The marketplace is speaking, and governments everywhere will need to quickly adapt if they are to survive and prosper.

We are on the cusp of a Third Industrial Revolution. The digitized broadband Communication Internet is converging with a digitized Continental Electricity Internet, powered by solar and wind electricity, and a digitized Mobility and Logistics Internet made up of autonomous electric and fuel-cell vehicles, powered from the electricity internet. These three internets are continuously being fed data from sensors embedded across society that are monitoring activity of all kinds in real time, from ecosystems, agricultural fields, warehouses, road systems, factory production lines, retail stores, and especially from

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[2] Jason Channell et al., Energy Darwinism II: Why a Low Carbon Future Doesn't Have to Cost the Earth, report (Citi, 2015),

[3] *Lazard's Levelized Cost of Energy Analysis—Version 12.0*, 2018, https:// www.lazard.com/media/450784/lazards-levelized-cost-of-energy -version-120-vfinal.pdf (accessed March 12, 2019); Naureen S. Malik, "Wind and Solar Costs Keep Falling, Squeezing Nuke, Coal Plants," Bloomberg *Quint*, November 8, 2018, https://www.bloombergquint.com /technology/wind-and-solar-costs-keep-falling-squeezing-nuke-coal -plants (accessed March 12, 2019).

the residential, commercial, and institutional building stock, allowing humanity to more efficiently manage, power, and move day-to-day economic activity and social life from where they work and live. This is the Internet of Things (IoT). In the coming era, buildings will be retrofitted for energy efficiency and climate resilience and embedded with IoT infrastructure. They will also be equipped with edge data centers, giving the public direct control over how their data is collected, used, and shared. Smart buildings will also serve as green micro power-generating plants, energy storage sites, and transport and logistics hubs for electric and fuel cell vehicles in a more distributed zero-emission society. Buildings in the Third Industrial Revolution will no longer be passive, walled-off private spaces but, rather, potentially actively engaged nodal entities sharing their renewable energies, energy efficiencies, energy storage, electric mobility, and a wide range of other economic and social activity with one another at the discretion of their occupants. Self-reliant, smart buildings are an essential component of the emerging Resilient Society.

2 THE CONTINENTAL ELECTRICITY INTERNET

The construction of a Continental Electricity Internet across America will serve as the backbone of The Resilient Society infrastructure transformation. The electricity grid is moving from a fossil fuel–based centralized system to a highly distributed electricity system made up of a digitized high-voltage direct current (HVDC) power grid embedded underground. The HVDC power grid brings large utility-scale solar and wind generated electricity from sparsely-settled regions favored with vast solar and wind generating capacity to regional alternating current (AC) transmission lines serving dense urban and suburban centers of the country. These local electricity transmission lines, in turn, connect with millions of small-scale neighborhood solar and wind generating sites – microgrids – all feeding green electricity in and off each other in a seamless smart digitized Continental Electricity Internet. In the new system, every business, neighborhood, and homeowner becomes a potential producer of electricity on their microgrid, sharing their surplus with others on a smart Electricity Internet using the same digital-driven analytics and algorithms we use to share information, news, knowledge and entertainment on the communication internet.

The smart US power grid, providing seamless digital interconnectivity to enable the sharing of electricity from renewable energy sources across the US and beyond, is analogous to the buildout of the Interstate Highway System, which provided a seamless interconnectivity for mobility across North America, Europe, and the world in the twentieth century. When Dwight Eisenhower became president of the United States in 1953, he had in mind a ‘grand plan’ for an Interstate Highway System connecting all of the American economy and society to provide the streamlined mobility infrastructure for the post-WWII economic boom. Like the Interstate Highway System, the continental Electricity Internet in the US will digitally connect businesses, homeowners, civil society, and government services across the US landmass, dramatically increase the aggregate efficiency of all fifty state economies, reduce each state’s carbon footprint to near-zero, and usher in a more sustainable and resilient high-performance American economy.

There is another parallel between the Third Industrial Revolution's renewable Electricity Internet and the Interstate Highway System. In the 1950s, the existential threat was a potential nuclear attack. President Eisenhower argued that the Interstate Highway System would speed mass-evacuations from the cities in the event of a catastrophic nuclear war. Today, the threat is cyber war and climate disasters.

On the upside, a smart US power grid will manage an ever more diverse and complex energy infrastructure made up of literally millions of energy producers and consumers generating and sharing renewable electricity in communities across the continent. Yet, the very complexity of the current system makes it increasingly vulnerable to cyberattacks and climate disasters. The key to cybersecurity and climate adaptation rests in deepening resiliency and that, in turn, requires an expansion of distributed power in every community. The installation of microgrids will be the US' frontline insurance. Were a cyberattack or climate disaster to happen anywhere in America, crippling parts of the continental power grid, homeowners, businesses, and entire communities will be able to quickly go off-grid, reaggregate, and share electricity neighborhood to neighborhood on micro-grids, which would allow society to continue functioning.

In addition to overseeing the build out of the smart Continental Electricity Internet, the federal government and the 50 states will also have to jointly take responsibility for establishing the new codes, regulations, standards, and the incentives and penalties that will need to be enacted to speed the transition into an integrated green zero-emission Third Industrial Revolution infrastructure across America. One of the principal impediments in the buildout of the smart TIR infrastructure are the outmoded codes, regulations, standards, and incentives still in place to oversee a Second Industrial Revolution infrastructure. These regulations block the speedy scale-up of a continental digital infrastructure. Clearing away these antiquated regulations will be essential to accelerate the transition into a green economy.

3 THE BIRTH OF A NEW ECONOMIC SYSTEM

Connecting everything and everyone via the America 3.0 infrastructure offers substantial economic benefits. In this expanded digital economy, individuals, families, and enterprises will be able to connect in their homes and workplaces to the IoT and access Big Data flowing across the World Wide Web that affects their supply chains, production and services, and every aspect of their social lives. They can then mine that Big Data with their own analytics and create their own algorithms and apps to increase their aggregate efficiency and performance, reduce their carbon footprint, and lower the marginal cost of producing, distributing, and consuming goods and services and recycling waste, making their businesses and homes greener and more self-resilient in a post carbon economy (marginal cost is the cost of producing an additional unit of a good or service, after fixed costs have been absorbed).

The marginal cost of some goods and services in this green digital economy will even approach zero. In economic theory, we are taught that the optimum market is one in which businesses sell at marginal cost. Businesses are encouraged to introduce new technologies and other efficiencies that can reduce the marginal cost of producing and distributing their goods and services, enabling them to sell at a cheaper price, win over market share, and bring back sufficient profit to their investors.

Markets are transactional and start/stop mechanisms. Sellers and buyers come together at a moment in time and fix on a transaction price, the good is delivered or the service rendered, and the two parties walk away. The downtime between transactions is lost time against fixed overhead and other expenses, where the seller is in limbo. Aside from lost production costs, there is the time and expense in bringing the seller and buyer together again—including advertising costs, marketing, the cost of storing goods, downtime across the logistics and supply chain, and other overhead expenses that have to be paid out. This phenomenon of shrinking marginal cost and shrinking profits playing out against the slow transaction of one-off sales of goods and services between sellers and buyers makes traditional markets all but useless in a digitally enhanced high-speed infrastructure. In the Third Industrial Revolution, the discontinuous transaction of goods and services in markets gives way to a continuous flow of goods and services in networks.

In the new America 3.0 economic system now emerging, ownership gives way to access, and sellers and buyers in markets are replaced, in part, by providers and users in networks. In provider/user networks, industries and sectors are replaced by “specialized competencies” that come together on platforms to manage the uninterrupted flow of goods and services in smart networks, returning sufficient profit, even at low margins, by the 24/7 continuous traffic across the system.

Many key sectors of the economy are already partially transitioning into provider-user networks and platform services. For example, the transformation of the electricity sector from fossil fuels and nuclear power to solar, wind, and other green energies has forced a concomitant shift in the electricity sector business model from a centralized to a distributed format. The new solar and wind generated electricity is increasingly being harvested by millions of small players, with surplus green electricity sent back to the grid to be shared with others across regions and continents. Given this new reality, power and electricity companies will be harvesting less electricity. In the new energy practice, the electricity companies will mine Big Data on electricity consumption across each client’s value chains and use analytics to create algorithms and applications to help their clients increase their aggregate energy efficiency, reduce their electricity use, carbon footprint, and marginal cost along their supply chains and production and distribution processes in an ever-tighter circular business operation. Their thousands of clients – businesses, homeowners, etc. – in return, will share a portion of the financial savings accrued from their aggregate efficiency gains back with the electricity companies via performance contracts. Power companies will profit more from managing energy use more efficiently and selling less rather than more electricity.

The mobility and logistics sector is also in the early stages of partially transitioning its business model from buyer-seller markets to provider-user networks in the wake of the transition from gasoline-powered vehicles to electric and fuel-cell vehicles powered by green energies; the shift to shared vehicle services; and the introduction of self-driving vehicles. Each of these shifts is revolutionary and, standing alone, would be enough to disrupt the transportation sector. Together, feeding off of each other, they portend a complete upheaval of mobility and logistics.

The long-term partial transition, which will include ownership of vehicles as well as access to mobility in driverless transport on smart road systems, will alter the business model for the transportation industry. Automobile companies are already repositioning themselves as aggregators of the global Mobility and Logistics Internet, managing mobility services on automated road systems.

4 THE RISE OF THE SHARING ECONOMY

Margins for some goods and services shrink so low “toward zero” in the America 3.0 economy that profits are no longer viable, even in capitalist networks, because the goods and services produced and distributed are nearly free. This is already occurring and giving rise to a new phenomenon—the Sharing Economy. At any given time of the day, hundreds of millions of people are producing and sharing their own music, YouTube videos, social media, news blogs, and research. Some are taking massive open online courses, taught by professors at the best universities, and often receiving college credit, for free. All one needs is a smartphone, a service provider, and an electrical outlet to power up.

More and more people are also generating their own solar and wind electricity for use off-grid and/or for sale back to the grid, again at near-zero marginal cost. Increasing numbers of millennials are sharing homes, rides, clothes, tools, sporting equipment, and an array of other goods and services.[4] Some of the sharing networks like Uber are capitalist provider/user networks where the marginal cost of connecting riders and drivers is nearly zero, but the providers command a price for temporary access to the service. Other sharing networks are nonprofits or cooperatives where members freely share knowledge, goods, and services with one another. Millions of individuals are constructing the knowledge of the world and sharing it on Wikipedia, a nonprofit website that is the fifth-most-trafficked website, all for free.[5]

The sharing of a range of virtual and physical goods is the cornerstone of a circular economy, allowing us to use far less of the resources of the Earth and pass on what we no longer use to others and, by doing so, dramatically reducing carbon emissions. The Sharing Economy is a core feature of The Resilient Society.

The Sharing Economy is now in its infancy and is going to evolve in many directions. But this much is assured: The Sharing Economy is a new economic phenomenon made possible by the digital infrastructure of communication, energy, and mobility that is changing economic life. To this extent, the Sharing Economy is the first new economic system to enter onto the world stage since capitalism in the

[4] Millennials and the Sharing Economy: European Perspectives Page 2
[5] “Wikipedia.org Traffic Statistics,” Alexa, https://www.alexa.com/siteinfo/wikipedia.org (accessed February 6, 2019).

eighteenth century and socialism in the nineteenth century.

Already, a younger generation of digital natives—under the age of forty—are ensconced in this new hybrid economic system. Part of the day, they are sharing all sorts of goods and services for nearly free in open-source commons, much of which is not measured in the GDP or standard economic accounting. The rest of the day, they are increasingly intertwined in capitalist provider/user networks, paying for access to goods and services. This hybrid economic system is the playing field on which The Resilient Society will emerge in the years ahead.

5 GLOCALIZATION AND THE PIVOT FROM GEOPOLITICS TO BIOSPHERE POLITICS

The Third Industrial Revolution is being accompanied by a shift from globalization to "glocalization" as individuals, businesses, and communities connect with each other around the world in digitally-integrated platforms and at very low fixed cost and near-zero marginal cost, allowing them to oftentimes bypass nation-state oversight and global companies that mediated commerce and trade in the twentieth century. Glocalization makes possible an historic shift from offshoring to onshoring and the uptake of regional manufacturing clusters to buttress an increasingly resilient economy and society and an immeasurable expansion of social entrepreneurship with the proliferation of smart high-tech small and medium-sized enterprises and cooperatives operating laterally in glocal networks.

In short, America 3.0 brings with it the prospect of a game-changing democratization of commerce and trade on a planetary scale. Many global companies will survive the transition and flourish, but their new role will be more along the lines of aggregating supply chains and work schedules, aligning tasks, and providing technical expertise and training for local small and medium-sized enterprises (SMEs) who will do much of the economic deployment.

It's important to emphasize that the evolution of the Smart Third Industrial Revolution infrastructure is driving the change in the economic paradigm and the shift to glocalization and onshoring. The introduction of billions and soon trillions of sensors in an evolving Internet of Things infrastructure is quickly spreading across every neighborhood and community and throughout the world and is already generating massive amounts of data. This is forcing a seismic shift in the collection and storage of data and the management of analytics and algorithms away from traditional giant vertically integrated global companies to glocally-situated and distributed high-tech SMEs embedded in cooperatives and spread laterally around the planet.

The ICT industry is projecting that the sheer volume of IoT data will soon vastly outstrip the data storage capacity of centralized data centers as well as their capacity to utilize the data in real time. Already, small "edge data centers" are appearing alongside IoT infrastructure, collecting data on-site and sharing it across multiple platforms in real time.[6]

ICT industry leaders are also coming to understand that cloud computing – sending locally generated data along to remote giant data centers – is too slow to react in real time to locally unfolding events.[7] This is called the "latency factor." If, for example, an autonomous vehicle was about to crash, the response time in sending up-to-the-moment data to the cloud and receiving back instructions on the ground would be too slow to react and avoid a collision. Given this reality, a new term has entered the ICT lexicon. It is called "fog computing." Over the course of the next several decades, millions of ever cheaper edge data centers embedded in homes, offices, local businesses, neighborhoods, communities, and in the environment will lateralize and glocalize the collection and storage of data on-site and allow populations to use analytics and algorithm governance in real time in glocally connected networks, increasingly bypassing the vertically integrated and centralized ICT networks that characterized the first generation of digital enterprises.

This lateralization and glocalization in the way we access information and communications mirrors the way we are beginning to access energy. Millions of homeowners, local businesses, neighborhood associations and farmers, have formed electricity cooperatives and are producing their own solar and wind generated electricity on-site for their use, and selling surpluses back to the emerging Smart Electricity Internet for distribution to others near and far.

6 A GIANT LEAP IN AGGREGATE EFFICIENCY

The transition to a fully digital economy and the Third Industrial Revolution results in a leap in aggregate efficiency far beyond the gains achieved by the Second Industrial Revolution in the twentieth century. Aggregate efficiency is the ratio of useful to potential physical work that can be extracted from energy and materials. Increasing aggregate efficiency means using less of the Earth's material resources and energies by achieving more useful work with less entropy waste in every economic conversion. During the period from 1900 to 1980 in the United States, aggregate energy efficiency steadily rose, along with the development of the nation's infrastructure, from 2.48 percent to 12.3 percent. Aggregate energy efficiency began to level off in the late 1990s at around 13 percent and then peaked at 14 percent in 2010 with the completion of the Second Industrial Revolution infrastructure. Germany reached 18.5% aggregate efficiency shortly thereafter, and Japan led the world, reaching a peak of 20% aggregate efficiency around the same time. Despite a sizable increase in aggregate efficiency, which gave the United States and other highly industrialized nations unparalleled prosperity, more than 80% of the Earth's material resources and energies used during the Second Industrial Revolution were wasted

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[6] Sharma, Pradip Kumar, Mu-Yen Chen, and Jong Hyuk Park. "A Software Defined Fog Node Based Distributed Blockchain Cloud Architecture for IoT." *IEEE Access* 6 (September 29, 2017): 115–24. https://doi.org/10.1109/access.2017.2757955, 115

[7] Puthal, Deepak, Obaidal, Mohammad, and Priyadarsi Nanda et al. "Secure and Sustainable Load Balancing of Edge Data Centers in Fog Computing." *Institute of Electrical and Electronic Engineers Communications Magazine* 56, no. 5 (May 2018): 60. https://doi.org/10.1109/MCOM.2018.1700795.

across the global economy.[8]

Even if we were to upgrade the carbon-based Second Industrial Revolution infrastructure, it would be unlikely to have any measurable effect on aggregate efficiency. Fossil fuel energies have matured. And the technologies designed and engineered to run on these energies, like the internal combustion engine and centralized electricity grids, have exhausted their aggregate efficiencies, with little potential left to exploit.

With the shift to an Internet of Things platform and a Third Industrial Revolution, it is conceivable to increase aggregate energy efficiency to as high as 60 percent over the next twenty years, amounting to a qualitative leap in generativity, while transitioning into a nearly 100 percent post carbon renewable energy society and a highly resilient circular economy.[9]

7 EXPONENTIAL CURVES AND AN ACCELERATED TRANSITION

While the dramatic aggregate energy efficiency gains brought on by the transition into a smart America 3.0 infrastructure might seem far off in the future considering the sheer magnitude of the task, in reality the shift to the new economic paradigm will likely occur quickly and be fully operational in twenty years – a single generation – because of the nature of exponential curves. Exponential curves are the sine qua non of every great infrastructure revolution in history. Remarkably, little to any attention is paid to exponential curves in the business community, governments, and academia despite the fact that they represent the profound economic disruptions in history. Here's how they work.

Exponential curves record the doubling process of any given phenomena. For example, given a choice between receiving a dollar and having it double every day for thirty-one days or, instead, being promised a million dollars on day one, common sense dictates that virtually everyone would choose the latter option. However, if one were to receive a dollar and have it doubled every day for thirty-one days, it would add up to about one billion dollars. Although seemingly incomprehensible, this is the nature of exponential growth.

The concept itself received very little attention in the public mind until Gordon Moore, cofounder of Intel, the world's largest semiconductor chip maker, noted a curious phenomenon, which he described in a now-famous paper published in 1965. Moore observed that the number of components in an integrated circuit had been doubling every year since its invention in 1958: "The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase." [10] Moore slightly modified his

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[8] Robert U. Ayres and Benjamin Warr, *The Economic Growth Engine: How Energy and Work Drive Material Prosperity* (Northampton, MA: Edward Elgar Publishing, 2009), 334-37.
[9] John A. "Skip" Laitner, "Linking Energy Efficiency to Economic Productivity: Recommendations for Improving the Robustness of the U.S. Economy," WIRE's Energy and Environment, 4 (May/June 2015): 235.
[10] Gordon E. Moore, "Cramming More Components onto Integrated Circuits," Electronics 38(8) (April 19, 1965): 115.

earlier projection in 1975 saying that the doubling is occurring every two years. That doubling process has continued unabated to date.

Where 60 years ago a typical IBM 7090 computer system cost $2.9 million, today 3.8 billion people are equipped with relatively cheap smartphones with thousands of times more computing capacity than the most powerful mainframe computers of the 1960s. Amazingly, an inexpensive smart phone has more computing power than what sent our astronauts to the moon.[11]

All of the critical components of a smart America 3.0 infrastructure – computing, solar and wind power, batteries, Internet of Things/smart sensors, LED lighting, electric vehicles - are experiencing plunging exponential cost curves which, in turn, are accelerating market penetration around the world. Increasing market penetration is further accelerating plunging cost curves, leading to even faster market penetration in a continuous feedback loop, creating a virtuous cycle.

For example, in 1977 the fixed cost per watt of silicon photovoltaic cells used in solar panels was $76; today, that cost has dropped to below 50 cents.[12] Currently, power and utility companies are quietly buying long-term power generation contracts for solar for as little as 2.42 cents a kilowatt-hour.[13] A 2019 study released by the International Renewable Energy Agency (IRENA) reports that onshore wind is being generated at as low as 3 to 4 cents per kilowatt-hour, with no end in sight in terms of the exponentially falling cost of generating the new green energies.[14]

According to a November 2018 study by Lazard—one of the world's largest independent investment banks—the levelized cost of energy (LCOE) of large solar installations has plummeted to 36 dollars/megawatt hour, while wind has fallen to 29 dollars/megawatt hour, making them "cheaper than the most efficient gas plants, coal plants, and nuclear reactors." The numbers tell the story. Global solar capacity increased from 41,542 MW in 2010 to 586,434 MW in 2019. Revenues from Wind Power in the United States grew from 636 Million in 2004 to 15,401,000,000 in 2020, a 24x increase.[15]

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[11] Michio Kaku, Physics of the Future: How Science Will Shape Human Destiny and Our Daily Lives by the Year 2100 (New York: Doubleday Publishing, 2012), 23; "2019 Annual Global Mobile Market Report" Newzoo, September 17th, 2019. https://newzoo.com/products/reports/global-mobile-market-report/ (accessed May 28th, 2020), 4.

[12] Peter Diamandis, "Solar Energy Revolution: A Massive Opportunity," *Forbes*, September 2, 2014, https://www.forbes.com/sites/peter diamandis/2014/09/02/solar-energy-revolution-a-massive-opportunity /#7f88662d6c90 (accessed March 12, 2019); Solarponics, *The Complete Homeowners' Guide to Going Solar*, 2016, https://solarponics.com/wp -content/uploads/2017/02/chgtgs.pdf (accessed March 24, 2019), 1.

[13] LeAnne Graves, "Record Low Bids Submitted for Abu Dhabi's 350MW Solar Plant in Sweihan," *The National*, September 19, 2016, https://www .thenational.ae/business/record-low-bids-submitted-for-abu-dhabi-s -350mw-solar-plant-in-sweihan-1.213135 (accessed March 3, 2019).

[14] IRENA, *Renewable Power Generation Costs in 2018*, International Renewable Energy Agency (Abu Dhabi, 2019): 18; *Lazard's Levelized Cost of Energy Analysis—Version 12.0*, 2018, https:// www.lazard.com/media/450784/lazards-levelized-cost-of-energy -version-120-vfinal.pdf (accessed March 12, 2019).

[15] *Lazard's Levelized Cost of Energy Analysis—Version 12.0*, 2018, https:// www.lazard.com/media/450784/lazards-levelized-cost-of-energy -version-120-vfinal.pdf (accessed March 12, 2019); Naureen S. Malik, "Wind and Solar Costs Keep Falling, Squeezing Nuke, Coal Plants," Bloomberg *Quint*,

Battery costs have plummeted from $1,200 per KWH in 2009 to less than $200 per KWH in 2019, with a projection of costs declining to less than $100 per KWH by 2030. According to the Rocky Mountain Institute, the precipitous decline in battery costs has led to accelerating market penetration, which is leading to ever increasing reductions in costs, etc.[16]

The cost of an IOT sensor has fallen from $1.30 in 2004 to a projected $0.38 cents in 2020. The falling exponential cost curve is projected to increase worldwide market penetration, which in 2017 was a mere $110 billion but is expected to rise to $1.567 trillion in 2025.[17]

The cost of LED lighting has decreased from $150 per kilolumen in 2008 to $10 in 2015, and the cost is continuing to dive on an exponential curve. In just a two-year period from 2012 to 2014, "total installations of common home LED bulbs increased six-fold from 13 million to 78 million—particularly rapid growth considering there were fewer than 400,000 installations as recently as 2009."[18]

Bloomberg New Energy Finance projects that worldwide sales of electric vehicles will leap from a paltry 1.1 million in 2017 to an impressive 30 million by 2030, as their price tag dips below the cost of manufacturing internal combustion vehicles in the mid-2020s. By 2028, BNEF predicts that electric vehicle sales will account for 20 percent of all global vehicle sales.[19] According to a study conducted by Fitch Ratings, one of the three major US credit rating agencies, global electric vehicles could number as many as 1.3 billion by 2040.[20]

For skeptics who suggest that scaling the America 3.0 infrastructure and deploying the smart zero-emission economy will take much longer than twenty years, a look back at the speed at which an America 2.0 infrastructure spread across the country in the twenty-five-year period, from 1902 to 1927, might be informative.

In 1902, there were 4.9 million miles of telephone wires stretching across the United States. By 1927,

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November 8, 2018, https://www.bloombergquint.com /technology/wind-and-solar-costs-keep-falling-squeezing-nuke-coal -plants (accessed March 12, 2019).

[16] Charlie Bloch et al. "Breakthrough Batteries Powering the Era of Clean Electrification," *Rocky Mountain Institute*, 2019. https://rmi.org/wp-content/uploads/2019/10/rmi_breakthrough_batteries.pdf, (accessed May 18th, 2020), 10.

[17] Bank of America and Merril Lynch, "Average Costs of Industrial Internet of Things (IOT) Sensors from 2004 to 2020," Future Reality: Virtual, Augmented, and Mixed Reality (VR, AR, &MR) Primer September 2016 (accessed May 20th, 2018), 80.

[18] Joe Room, "5 Charts That Illustrate The Remarkable LED Lighting Revolution," *ThinkProgress*, August 2nd, 2016, https://archive.thinkprogress.org/5-charts-that-illustrate-the-remarkable-led-lighting-revolution-83ecb6c1f472/ (accessed May 20th, 2020).

[19] Bloomberg New Energy Finance, "Electric Vehicle Outlook 2020," May 1st, 2020, (accessed May 19th, 2020), https://about.bnef.com/electric-vehicle-outlook/, 7.

[20] *Batteries Update: Oil Demand Could Peak by 2030*, Fitch Ratings, 2018, http://cdn.roxhill media.com/production/email/attachment/660001_670000/Fitch_Oil%20 Demand%20Could%20Peak%20by%202030.pdf (accessed May 1, 2020), 2.

there were 63.8 million miles of telephone wires connecting the country. The number of telephones increased from 2.3 million units in 1902 to 18.5 million units in 1927. The telephone sector, valued at $400 million USD in 1900 climbed to $1.7 billion in 1922. The number of employees in the telephone Industry increased from 262,629 in 1917 to 375,272 in 1927. [21]

Privately owned central electric light and power stations, valued at $403 million USD in 1900, shot up to $1.2 billion USD in 1922. The total number of electricians increased from 50,210 in 1900 to 277,514 in 1930. [22]

In 1902, there were 23,000 automobiles registered in the United States. By 1922, there were 10,704,000 on the road. In 1902, motor vehicles were valued at $3.3 million USD. By 1922, the total number of motor vehicles was valued at $4.5 billion USD. [23]

The first filling station in the United States was established in St. Louis, Missouri in 1905. By 1929, there were 121,500 filling stations across the country, which accounted for nearly $1.8 billion in total sales.[24]

Given America's past history of plummeting exponential cost curves and accompanying rising market penetration in the initial twenty-year build out of a Second Industrial Revolution infrastructure, it's fair to suggest that the America 3.0 infrastructure, which is experiencing similar plunging exponential cost curves accompanied by increasing market penetration, can likely come online in the span of a single generation.

8 THOUSANDS OF NEW BUSINESSES AND MILLIONS OF GREEN JOBS

The build-out of The Resilient Society smart infrastructure will involve every competency: the ICT sector, including telecommunication, cable companies, internet companies, and the electronics industry; power and electric utilities; transportation and logistics; the construction and real estate industries; the manufacturing sector; retail trade; the food, agriculture, and life sciences sectors; and the travel and tourism industry. The laying out of the new smart sustainable infrastructure, in turn, makes possible the new kinds of mass employment that characterize the turnover to a green economy.

The transition from a Second Industrial Revolution to a Third Industrial Revolution will be formidable. To make this happen, we will need to train millions of people and put them to work, or back to work. We

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[21] The United States Census Bureau, Statistical Abstract of the United States: 1930, 1930, https://www.census.gov/library/publications/1930/compendia/statab/52ed.html (accessed May 26th, 2020), 359.

[22] The United States Census Bureau, *Statistical Abstract of the United States: 1930*, 1930, https://www.census.gov/library/publications/1930/compendia/statab/52ed.html (accessed May 26th, 2020), 291.

[23] The United States Department of Transportation, "State Motor Vehicle Registrations, By Years, 1900-1995, March 29th, 2018, https://www.fhwa.dot.gov/ohim/summary95/mv200.pdf, 1.

[24] David A. Fryxell, "History of Gas Stations," Family Tree Magazine, May/June 2013, https://www.familytreemagazine.com/premium/history-of-gas-stations/ (accessed May 27th, 2020).

will have to decommission and disassemble the entire stranded fossil fuel and nuclear energy infrastructure—the pipelines, power plants, storage facilities, etc. Robots and AI won't do that. It will necessitate a far more agile semiskilled, skilled, and professional workforce. The communication network will have to be upgraded, with the inclusion of universal broadband. Human beings will have to lay the cable and make the connections. The energy infrastructure will need to be transformed to accommodate solar, wind, and other renewable energies. Robots and AI will not install solar panels and assemble wind turbines. The dumb centralized electricity grid will have to be reconfigured into a smart and distributed digital Electricity Internet to accommodate the flow of renewable electricity produced by countless green micro power plants. Again, this is complex work that can only be done by semiskilled and skilled professionals. The antiquated twentieth-century electricity transmission grid will need to be replaced by a twenty-first-century high-voltage direct-current power grid. This will marshal the employment of a huge workforce over a twenty-year transformation. The transportation and logistics sector will have to be digitized and transformed into a GPS guided autonomous Mobility Internet made up of smart electric and fuel-cell vehicles powered by renewable energy and running on intelligent road, rail, and water systems. Here, too, low-tech and high-tech skilled employees will be put to the task. The introduction of electric and fuel-cell transportation will require millions of charging stations and thousands of hydrogen fueling stations. Smart roads, rail, and inland water systems equipped with ubiquitous sensors, feeding real-time information on traffic flows and the movement of freight, will also have to be installed. Again, more jobs. Buildings will need to be retrofitted to increase their energy efficiency. Skilled laborers will have to install insulation and new windows and doors, and gas and oil heating will need to be replaced with electrical heating powered by green energy. Energy storage technologies will have to be built into every layer of the infrastructure to secure intermittent renewable energy. This is going to provide ample employment.

The change in the makeup of the labor force in the transition to an America 3.0 economy is already showing up in the rise in employment across the industries that make up the new green domain. The Resilient Society infrastructure will require employment from 320 unique occupations spread out across three major sectors: clean energy production, energy efficiency, and environmental management, and enlist a green workforce of millions of workers.[25]

The twenty-year buildout of the smart glocal infrastructure will require a massive workforce comprised of semi-skilled, skilled, and professional workers. The business at hand will be to provide both retraining for the existing workforce and the appropriate skill development for students coming into the labor market to ease the transition into the new job categories and business opportunities that come with a massive build-out of a Third Industrial Revolution infrastructure. Although a herculean effort will be required to transition the workforce, the human race has shown itself capable of similar efforts in the past—particularly in the rapid shift from an agricultural to an industrial way of life in the late nineteenth century and early twentieth century.

[25] Brookings Institution, *Advancing Inclusion Through Clean Energy Jobs.* April 2019, https://www.brookings.edu/wp-content/uploads/2019/04/2019.04_metro_Clean-Energy-Jobs_Report_Muro-Tomer-Shivaran-Kane.pdf#page=14.

The shift in the makeup of the labor force in the transition to a Third Industrial Revolution economy is already showing up in the rise in employment across the four industries that make up the nervous system of the new green economy. The statistics are impressive. According to the 2017 US Energy and Employment Report compiled by the US Department of Energy, close to 1 million Americans work in the energy efficiency, solar, wind, and electric vehicles sector, which is nearly five times the employment in the fossil fuel electric industry.[26] If part-time workers in the construction industry engaged in retrofitting buildings are included, the number climbs to 3 million Americans "working in part or in whole for the energy efficiency, solar, and wind sectors."[27] These employment numbers are going to grow exponentially as the nation turns its attention to a zero-emission 3.0 Industrial Revolution economy over the next two decades.

Preparing a nationwide workforce for the various competencies that will be needed to transform the entire infrastructure of the country into a smart green paradigm will require massive training and/or retraining, on the scale of what the United States did at the beginning of World War II, when the country's male workforce was suddenly deployed to the war effort and women were called forth to manage American industries on the home front. This seemingly impossible task was accomplished in less than eighteen months across every industry. Of late, there has been growing discussion around a similar mobilization and training of high school and college graduates in the form of apprenticeships in communities and industries queued to the build-out and scale-up of the green infrastructure.

According to a Brookings Institution study, there are currently 14.5 million infrastructure workers across the fifty states.[28] Brookings notes that "the transition to the clean energy economy will primarily involve 320 unique occupations spread across three major industrial sectors: clean energy production, energy efficiency, and environmental management." Most of these jobs will require some level of both vocational and professional training in design, engineering, and mechanical knowledge. Interestingly, hourly wages in the new green jobs exceed the national average by 8 to 19 percent; equally important, workers at the lower end of the income ladder can make $5 to $10 more per hour than in comparable jobs in the old economy.[29] The problem is that much of the existing infrastructure workforce is nearing retirement, posing the question of how to prepare a new generation with the skills necessary to transition America into a postcarbon green era. State, municipal, and county governments are just now beginning to establish infrastructure academies whose purpose is both to retrain the existing workforce and to prepare a younger generation for the new infrastructure jobs that accompany the shift into a Third Industrial Revolution economy. For example, in 2018, Washington, DC, mayor Muriel Bowser established the DC Infrastructure Academy, a joint initiative between the city and public-private

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[26] US Department of Energy, 2017 U.S. Energy and Employment Report, https://www.energy.gov/downloads/2017-us -energy-and-employment-report (accessed March 24, 2019).
[27] Ettenson, "U.S. Clean Energy Jobs Surpass Fossil Fuel Employment."
[28] Brookings Institution, Advancing Inclusion Through Clean Energy Jobs, April 2019, https://www.brookings.edu/wp-content/uploads/2019/04 /2019.04_metro_Clean-Energy-Jobs_Report_Muro-Tomer-Shivaran -Kane.pdf#page=14[29] Ibid.
[29] Ibid.

partners, including Washington Gas, DC Water, and Pepco, the electric utility, to train workers living in the city's most disadvantaged neighborhoods for the new green employment opportunities.[30]

There is growing interest in establishing green academic apprenticeships in the 50 states—a Green Corps, a Conservation Corps, a Climate Corps, an Infrastructure Corps—that will provide "a living wage" and technical and professional certification and / or clinical learning credits toward academic degrees upon completion of service, allowing a younger generation of Americans to advance careers in the emerging green economy. These academic apprenticeships should be universally available, but they should also prioritize student engagement in the most disadvantaged communities. There is ample precedent for these initiatives in the United States. The Peace Corps, VISTA, and AmeriCorps have proved invaluable in encouraging public service and providing opportunities for young people to learn new skills, which have helped them find career paths and employment. Universities, trade schools, unions, and local governments across the US will play an important role in partnering with the various service corps in preparing the new green workforce of the twenty-first century.

Granting paid apprenticeships, technical and professional certification, and clinical learning credits toward academic degrees to millions of young people will provide the coming generation with the talent and skills to engage in trade, technical, and professional employment in a climate change economy increasingly focused on new resilient business models and accompanying careers. These proposed clinical learning agencies at the state, county, and local level will also be among the first responders in climate events and disaster relief and recovery missions that will increasingly be a constant reality rather than a rare anomaly.

9 THE RESILIENT SOCIETY: A NEW SOCIAL CONTRACT

During the First and Second Industrial Revolutions, the ruling paradigm favored short-term efficiency gains and quick profits over long-term resilience and steady and reliable returns on investments. The result is that we now live in a highly fragile and vulnerable society prone to massive disruptions that often come without warning in the form of increasingly severe climate disasters, pandemics, and cyberterrorist incursions, crippling whole parts of society, destroying the natural environment, damaging the economy, and undermining the health and well-being of millions of American citizens.

Then too, our continental electricity grid, made up of a patchwork of local electric utilities and a largely archaic servo-mechanical electricity grid, is becoming the target of malware attacks and cyberterrorist probes whose mission is to shut down parts of the national grid, throwing regions and communities across the country into pandemonium.

A future punctuated by increasing climate disasters, cybercrime, and cyberterrorism can quickly cripple

[30] "Mayor Bowser Opens the DC Infrastructure Academy," press release, March 12, 2018, https://dc.gov/release/mayor-bowser-opens-dc -infrastructure-academy.

and even take down large parts of the global electricity network, disrupting supply chains and putting communities and even the entire society in jeopardy. In turn, global pandemics can shut down air traffic shipping virtually overnight. When the logistics system is compromised, the basic necessities of life – food, water, and medicine – can't be delivered and entire populations are at risk. This lesson has come home in the wake of the COVID-19 pandemic, which has paralyzed the US and world economy, shutting off the supply of vital medical equipment, medicines, and food supplies, leaving local economies helpless and unable to secure the basic necessities to maintain their health and well-being.

That said, it is essential that resilience be built into the American logistics and supply chains by relying on more onshoring and regional manufacturing centers. In addition, it will be especially important as we move to autonomous electric passenger vehicles and fuel cell freight trucking on smart road systems, that backup power be available across the entire road system of the United States to ensure supply chains and logistics. This will require that fueling stations at travel centers along interstate highways are equipped with dedicated on-site or nearby solar and wind installations to generate electricity for electric charging stations and hydrogen fuel cell pumps that can keep electric vehicles and long-haul hydrogen powered freight trucks on the road. In addition, warehouses and distribution centers will need similar solar and wind power generated on-site or nearby to provide electricity for lighting, heating, air conditioning, and mechanical and robotic services to ensure that basic necessities can be properly logged in, stored, and sent on their way. Similarly, all industries using data centers will need to be made more resilient by situating solar and wind generating installations on-site or nearby to manage the flow of data were the conventional power grid to experience a short-term or long-term blackout.

America 3.0 prioritizes resilience built into every facet of the nation's infrastructure. For instance, consider what would happen were a catastrophic wildfire, flood, or hurricane to shut down parts of the national and regional power grid and cell towers, leaving millions of American families and businesses with the loss of power for their computers and cell phones. Were this to happen, homes, local businesses, neighborhoods, and localities could quickly transfer off the central power grid and on to literally millions of solar and wind-generating microgrids lodged in or around homes, offices, factories, and neighborhoods and reaggregate in distributed networks to keep the electricity flowing and computers and cell phones powered up, ensuring uninterrupted connectivity to the outside world.

Similarly, retrofitting building stock to harden homes, offices, and factories to be more resilient to withstand climate disasters is fast becoming a necessity for survival. A vast number of existing US buildings will have to undergo a complete retrofit to seal interiors, minimize energy loss, optimize efficiency, and buttress structures to be resilient to climate- related disruptions. Gas and oil heating, which is a big source of global warming emissions in buildings, will need to be replaced by electrical heating across the residential, commercial, industrial, and institutional building stock. The return on a building's retrofit investment in energy efficiency and energy savings takes place over relatively few years, after which the owner or renter enjoys a reliable stream of savings on energy costs for decades.

While the generation of solar and wind electricity will power a Resilient Society, because these energies are intermittent, the storage of green electricity will be an essential feature of the America 3.0 infrastructure transition. Tens of millions of electric vehicles can store green electricity and, when necessary, upload it back onto the Continental Electricity Internet to address peak and base load electricity requirements while profiting the owners of the vehicles.

It will also be important to add a second layer of storage resilience with the large-scale introduction and deployment of green hydrogen storage. A percentage of solar and wind generated electricity will need to be utilized to electrolyze water and create green hydrogen that can be used to 1) store green electricity; 2) repurpose gas pipelines away from natural gas and to green hydrogen for heating across the buildings infrastructure; 3) provide fuel for road, rail, inland water, marine, and air transport 4) supply hydrogen feedstock for industrial processes, and 5) generate requisite heat for use in hard-to-abate industries like steel and cement. The Hydrogen Economy provides a versatile storage medium to ensure a highly resilient post-carbon economy.

The America 3.0 infrastructure extends into other domains that are vital to securing resilience. The COVID-19 pandemic has accentuated the importance of the IoT and telemedicine in bringing health professionals together with quarantined patients to help diagnose and care for those struck by the virus.

The COVID-19 pandemic has also awakened the American public to how dependent we've become on foods grown in other countries and shipped on supply lines to America. These global food supply chains can be stymied overnight in the midst of pandemics and climate disasters exposing America's collective vulnerability to global food chains. A growing segment of the American farm community and consumers are waking up to this new reality and beginning to focus attention on providing locally-sourced food to nearby communities to ensure more resilient supply lines.

American farms are also increasingly dependent on the fluctuating and unpredictable price of fossil fuel on world markets, which often makes or breaks a farmer's margins and viability in any given season. Not surprising, there is a movement toward organic and ecological practices on a growing number of American farms with the aim of establishing an agricultural system that is more climate resilient and also less reliant on conventional petrochemical practices that exacerbate global warming emissions.

Farmers are also joining together in the creation of electricity cooperatives and beginning to install solar, wind, and biogas energy technologies.[31] Some of the green electricity is being used on the farm to operate machinery, and the rest is being sold back to the Electricity Internet, creating a second source of income.

Reshoring of food and the shift to locally-sourced food converging with the transition to ecological agricultural practices and the establishment of solar and wind cooperatives is laying the groundwork for

[31] Karlee Weinmann, "Thanks to Co-op, Small Iowa Town Goes Big on Solar," Institute for Local Self-Reliance, February 3, 2017, https://ilsr.org /thanks-to-co-op-small-iowa-town-goes-big-on-solar.

more resilient farming practices.

A more resilient approach to agriculture is being accompanied by the shift from mechanical to digital operations on farms, changing the way that food is grown, harvested, stored, and shipped. Farmers are beginning to utilize the emerging IoT by placing sensors across their agricultural fields to monitor weather conditions, changes in soil moisture, the spread of pollen, and other factors that affect yields. Automated response mechanisms are also being installed to ensure proper growing conditions.

The phase-in of the Internet of Things infrastructure across American farmland promises huge gains in aggregate efficiency and productivity for American farmers, food processors, wholesalers, and distributors while reducing carbon footprint. As the IoT infrastructure is phased in with the implantation of sensors across supply chains to track every moment of the ag journey from the planting of crops to the final destination at retail stores, farmers, processors, wholesalers, and distributors in the United States will be able to mine the Big Data flowing across their value chains and, in doing so, increase their aggregate efficiency and reduce their marginal cost and ecological footprint in the managing and powering of farms and in the processing and transporting of food, taking the food industry out of the chemical era and into an ecological era mediated by new smart digital interconnectivity.

The Internet of Things is also being embedded in water reservoirs – a critical part of the Earth's hydrosphere – and in the pipelines that bring freshwater to consumers and remove wastewater, sending it back to treatment plants for re-purification. The sensors continually monitor pressure on the pipes, the wear and tear of the equipment, potential leakages, and the change in water clarity and chemistry in real time, and use the data and analytics to predict, intervene, and even remotely fix trouble spots along the line. Smart meters and ubiquitous sensor monitoring also provide key just-in-time data on water flow, including the volume and time of usage, to more effectively manage the resource and increase aggregate efficiency all along the water system, from provisioning and ensuring clean water distribution to recycling and purifying wastewater that can then be reused time and again by consumers, thus saving water in a virtuous circular system. The embedding of the Internet of Things throughout our water systems becomes particularly important when we consider the fact that "6 billion gallons of treated water are wasted every day because of leaking pipes", according to the American Society of Engineers[32].

The IoT nervous system of the America 3.0 infrastructure is also becoming an indispensable technology for monitoring climate change impacts. For example, sensors are being embedded across the Earth's biosphere, monitoring flood and drought conditions and wind currents to both measure the impact of climate change and to alert authorities on potentially dangerous hot spots that can flare up and unleash raging floods or wildfires, giving first responders advance notice to intervene with appropriate mitigation.

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[32] American Society of Civil Engineers, *The 2017 Infrastructure Report Card: A Comprehensive Assessment of America's Infrastructure*, https:// www.infrastructurereportcard.org/wp-content/uploads/2017/01/2017 - Infrastructure-Report-Card.pdf, 36-37.

Other IoT sensors are being placed along ecosystem corridors, tracking wildlife and providing critical data on endangered species, including the thinning of herds and flocks. The data is mined with analytics to assess avenues of intervention for protecting wildlife and maintaining biodiversity in various bioregions around the world.

IoT has also become essential in monitoring air pollution to provide up-to-the-moment readings on the air quality of the atmosphere, which is particularly important for at risk populations suffering from asthma and other pollution-related illnesses.

Sensors are even being inserted just below the Earth's crust to monitor the conditions of the soil – the lithosphere – around the world to inform scientists of the "nutrient health" in what is called the "Critical Zone", which all of life on Earth depends on for survival.

In a sense, the IoT is analogous to a planetary nervous system that is monitoring the health of the critical organs of the Earth – the hydrosphere, the biosphere, the atmosphere, and the lithosphere – and what we are discovering, in real time, is that changes to any one of the Earth's spheres spills over and affects every other sphere and, not surprising, every species, including our own. This profound realization is likely to fundamentally change humanity's worldview, teaching us that every phenomena on Earth, be it biological, chemical or physical, is intimately connected to every other, and whatever happens anywhere along the earth's complex gradients and nervous system intimately affects everything else, including the wellbeing of our own species.

10 AN INCLUSIVE TRANSITION

We traditionally think of infrastructure as overarching centralized platforms, financed at considerable expense by governments, and laid down for use by the public at large—road systems, electricity and telephone lines, power plants, water and sewage systems, airports, port facilities, etc. Notwithstanding the fact that the Third Industrial Revolution infrastructure requires a smart national power grid—a digitally managed Continental Electricity Internet—that can mediate and manage the flow of green electricity coming and going between millions of players in their homes, automobiles, offices, factories, and communities, as mentioned earlier, many of the actual infrastructure components that feed into and off that grid are highly distributed in nature and are paid for and belong to literally millions of individuals and families, hundreds of thousands of small businesses, and municipal, county, and state governments.

Every solar roof, wind turbine, nodal Internet of Things building, edge data center, storage battery, charging station, electric vehicle, etc., is likewise an infrastructure component. Unlike the bulky, top-down, and static one-way infrastructures of the First and Second Industrial Revolutions, the distributed and laterally scaled infrastructure of the Third Industrial Revolution is, by its very nature, fluid and open, allowing literally millions of players to share data, energy, electric mobility, surveillance, news, knowledge, and entertainment, in an emerging "sharing economy" et al., using their own component parts of the infrastructure where they live and work and during their commute, in continuously evolving digital platforms.

While the US investment to transition into a resilient economic infrastructure will need to be significant to reach a goal of being a zero-emission superpower by 2040, the investment in "social infrastructure" will also need to be sizeable to assist the most disadvantaged communities in securing their homes, sources of employment, and general well-being in an ever-deteriorating climate that is wreaking havoc and destroying lives and property.

The poorest communities are the most vulnerable to the impacts brought on by climate change and related pandemics. Helping at-risk communities transition into the new America 3.0 infrastructure and take advantage of the new business and employment opportunities that accompany it should be the highest priority in the transition to a zero-emission green economy.

Considerable attention has been focused on putting disadvantaged communities at the front of the line in securing the benefits of a green economic infrastructure transition. Yet, social infrastructure is equally critical in ensuring that marginalized populations are not left behind. What has often gone unnoticed is there is an inseparable relationship between the economic infrastructure and the social infrastructure, with each feeding off the other. Social infrastructure includes broad investments in education, public health, affordable social housing, environmental protection, and other community services, all essential to assuring upward mobility.

The smart infrastructure transition, if prioritized to benefit disadvantaged communities, will provide numerous benefits to poor families and neighborhoods. However, without a comparable improvement in public education, public healthcare, public housing, and other social services, the very poor will be unable to break out of the cycle of poverty. And because climate change disproportionately affects the poor, their lot is likely to continue to deteriorate in an era beset by climate change disruptions.

Current investment in social infrastructure in the US is far below what is needed to raise the prospects of the poor and disadvantaged communities whose lives are becoming ever-more precarious in a climate change world. For example, in 2018, the United States only spent 18.7% of its GDP on social infrastructure, below the OECD average of 20.1% and far behind countries such as France (30.1%), Germany (25.1%), and Japan (21.9%).[33] Failure to fill the "investment gap" in social infrastructure will mean that the most disadvantaged will not have available to them the educational opportunities and the accompanying business prospects and employment options that accompany a resilient infrastructure transition. Nor will they be provided with climate-resilient affordable low- and moderate-income housing or the social services that will be necessary as climate change ravages their

[33] OECD, "Social spending (indicator)", 2020, doi: 10.1787/7497563b-en.

neighborhoods and communities.

A significant increase in social infrastructure spending will be necessary to retrofit multifamily public housing and low- and moderate-income homes across America to make residences more resilient to climate impacts. Fuel poverty – not being able to afford heating and air conditioning – has become a critical public policy issue, as has overcrowding in the wake of increased unemployment, pandemics, and forced climate change migration. According to the Department of Energy (DOE) in a December 2018 overview, the burden of energy bills on a low income household varies from state to state, but generally falls between 4% and 14% of a household's income. The same DOE overview found however that the primary source of this burden is a lack of efficiency, and determined that low income households could see savings of between 13% and 32% through such measures as access to renewable energy, weatherization, and perhaps most importantly, large scale retrofitting.[34]

Nowhere will the impact of social infrastructure investment be more critical than in providing sufficient means to assure public health in disadvantaged communities whose populations have the least access to adequate health services and the financial wherewithal to undertake remediation of infrastructure initiatives brought on by climate change. Already, the radical change in the climate is exacting an ever-mounting adverse effect on public health, with exposure to ozone and particulate matter pollution brought on by greenhouse gas emissions leading to diminished lung function, most notably asthma, and exposure to smoke from spreading wildfires; increased exposure to allergens with warmer seasonal temperatures; heat-related sickness and death, including heat stroke and cardiovascular disease; increased exposure to vector-borne diseases induced by a shift in the geographic range of insects; and a range of diseases brought on by the contamination of water systems, et al. Here again, the poor are the most vulnerable because their communities generally have the oldest and most compromised infrastructures, the least access to adequate public health services, and are the least serviced by remediation and adaptation programs.

The resilient social infrastructure also comes with new opportunities in public education and employment, especially in the most disadvantaged communities. Reliable access to broadband internet service is a necessity for a meaningful public education and gainful employment in the modern economy. Despite the economic benefits of access to broadband internet, many low- and moderate-income households in both urban and rural areas do not have the very technological tools that could enable them to escape impoverishment.

In a 2019 Pew Research Center report, only 18% of low income households were considered to have a high level of technology access defined by having home broadband internet, a smartphone, a personal computer, and a computer tablet, compared to 64% of upper class households in the United States. In urban settings, many poor citizens are only able to access the internet through their smartphone

[34] The United States Department of Energy, "Low-Income Household Energy Burden Varies Among States — Efficiency Can Help In All of Them," Published December 2018, https://www.energy.gov/sites/prod/files/2019/01/f58/WIP-Energy-Burden_final.pdf (accessed May 4th, 2020).

cellular network, which does not allow for the sophisticated professional tasks that require a personal computer and home broadband internet connection. According to the Pew Research Center report, 26% of low income households fall under this category of smartphone dependence, while another 29% do not own a smartphone at all.[35]

This lack of access to broadband internet services, which is especially severe in poor rural areas where many cellular networks do not have consistent service, directly inhibits the ability of disadvantaged households to increase their family income. The Federal Communications Commission estimates that a total of 21 Million Americans, or approximately 6.5% of the population, do not have any access to the internet according to its 2019 Broadband Internet Report. Other studies suggest that the number could actually be as high as 42 Million Americans, or over 12% of the American population.[36] Without universal access to broadband, the youth in disadvantaged communities will be unable to secure adequate careers in the America 3.0 infrastructure transition.

Failure to meet the funding gap in social infrastructure across America will dramatically increase inequality and social and political disenfranchisement, with less access to quality public education, fewer employment opportunities, less upward mobility, inadequate housing, and insufficient public health services, leaving the most disadvantaged communities without sufficient social assets to adapt to climate change.

There are countless other examples across the economy and in every aspect of daily life in which resilience can be built into the very fabric of our existence. But to get there will require a new social contract on the scale of The Progressive Era that accompanied America 1.0 and The New Deal that accompanied America 2.0. America's 3.0 social contract – The Resilient Society – will need to be comparable in scope. The great mission at hand is to bring together every level of government with the business community and civil society to establish blueprints, customized to the needs and aspirations of each locality and state, toward the buildout of a Resilient 3.0 infrastructure, while connecting regions in a distributed continental matrix that can operate glocally, regardless of disruptions, to sustain daily life. This is the heart of the Resilient Society and the new social contract for America in the 21st century.

11 FINANCING AMERICA 3.0

Infrastructure improvements generally add $3 to the US GDP for every dollar invested and create thousands of new businesses and millions of new jobs.[37] In all of the debate currently swirling in

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[35] Monica Anderson and Madhumitha Kumar, "Digital divide persists even as lower-income Americans make gains in tech adoption," *The Pew Research Center*, May 7th, 2019 (accessed May 4th, 2020). https://www.pewresearch.org/fact-tank/2019/05/07/digital-divide-persists-even-as-lower-income-americans-make-gains-in-tech-adoption/

[36] BroadbandNow, "FCC Reports Broadband Unavailable to 21.3 Million Americans, BroadbandNow Study Indicates 42 Million Do Not Have Access," February 3, 2020, (accessed May 4th, 2020) https://broadbandnow.com/research/fcc-underestimates-unserved-by-50-percent.

[37] Jeffery Werling and Ronald Horst, *Catching Up: Greater Focus Needed to Achieve a More Competitive*

Washington political circles about the role of the federal government in building out and managing a smart new national infrastructure, the reality is that the federal government plays a relatively small role in maintaining the nation's infrastructure. It's worth noting that state and local governments—and not the federal government—own 93 percent of the country's infrastructure and pay 75 percent of the cost of maintaining and improving it.[38] Therefore, while the Federal government will likely have to do much of the heavy lifting in financing the high voltage direct current Continental Electricity Internet, as it did with the US Interstate highway system, the burden of financing a significant portion of the rest of the America 3.0 transition is going to fall primarily on states, counties, and municipalities.

In regard to the rest of the smart America 3.0 infrastructure, a portion of it is going to come online because of the reprioritizing of federal, state, county, and municipal government budgets, as well as the inclusion of generous tax credits and other incentives, combined with the exponentially falling cost curve of the infrastructure components and processes.

Much of the remaining investments will come from the financial sector and especially institutional funds and, particularly, public and private pension funds – the largest pool of capital in the world in 2018, worth over $40 trillion.[39] US public pension funds are beginning to divest their funds from the fossil fuel sector and related industries that service and/or depend on it, like the petrochemical industry, and would like to reinvest in the green opportunities that constitute the smart Third Industrial Revolution economy. Their concern over climate change and the prospect of their funds remaining in a fossil fuel-based economy should be a wakeup call for all of us.

The global insurance industry is likely to be the other significant provider of investment funds for the America 3.0 transformation. The insurance sector has assets of $25 trillion under management, "which is more than fifteen times bigger than the projected private sector gap that needs to be closed to achieve all seventeen United Nations Sustainable Development Goals by 2030."[40] Like global pension funds, the insurance industry has much to lose, with climate-related floods, droughts, wildfires, and hurricanes and typhoons devastating ecosystems, killing human beings, and destroying property around the world. Eighteen insurers, mostly in Europe, with assets of at least $10 billion each, have already begun to divest from the fossil fuel industry. Several of the biggest insurers— AXA, Munich Re, Swiss Re, Allianz, and Zurich—have either limited or eliminated insuring coal projects. AXA and Swiss RE have also limited underwriting tar sands projects.[41]

Infrastructure, report to the National Association of Manufacturers, September 2014, https://www.nam.org/Issues /Infrastructure/Surface-Infrastructure/Infrastructure-Full-Report -2014.pdf (accessed March 12, 2019), 9.

[38] Elizabeth McNichol, *It's Time for States to Invest in Infrastructure*, Center on Budget and Policy Priorities, 2017, https://www.cbpp.org/sites /default/files/atoms/files/2-23-16sfp.pdf (accessed March 23, 2019), 5

[39] Willis Towers Watson, Thinking Ahead Institute, *Global Pension Assets Study 2018*, https://www.thinkingaheadinstitute.org/en/Library/Public /Research-and-Ideas/2018/02/Global-Pension-Asset-Survey-2018 (accessed April 5, 2019), 9.

[40] Alexander Braun, "Use the Insurance Industry to Capitalize Low-Carbon Tech," *The Pennsylvania Gazette*, January & February 2020, 38.

[41] Peter Bosshard, *Insuring Coal No More: The 2018 Scorecard on Insurance, Coal, and Climate Change*, Unfriend

Yet, only two of the ten largest American insurance companies—AIG and Farmers—have modified their investment strategies in response to climate change, which is remarkable considering the US West Coast has been devastated by climate change–induced droughts and wildfires for years, with $12.9 billion in insured losses in 2017 alone.[42] Texas and the southeastern states of Louisiana, Florida, Mississippi, Georgia, South and North Carolina, and Virginia have been ravaged by hurricanes, and the midwestern states of Nebraska, Iowa, Wisconsin, and Missouri have experienced ever-worsening 1,000-year historic floods yearly, all brought on by climate change in just the past decade, with loss of lives and property damage. Industry watchers, however, suspect that the reality of the impacts of climate change will draw American insurance companies into the divest-invest fold over the course of the next two to three years.

To facilitate the reinvestment of pension funds, insurance funds, and other institutional funds in a massive build-out of a digital resilient society infrastructure, the federal government will need to establish a national green bank that can provide funds to state, municipal, and county green banks. These regional Green Banks, in turn, can leverage those funds and other funds in securing sufficient financing via the issuing of green bonds that can be purchased by pension funds and other institutional funds, the insurance industry, sovereign funds, et. al. to invest in scaled green Third Industrial Revolution infrastructure build-outs. Already, Green Banks have been established by California, New York, Connecticut, Hawaii, Rhode Island, and Montgomery County, Maryland.[43] The federal government will also need to provide a wide range of generous incentives ("carrots") and mandates ("sticks") to help states, municipalities and counties expedite the financing of the infrastructure transformation.

Pension funds and other institutional investors, and insurance companies, banks, sovereign funds, credit unions, and endowments are quickly divesting from the stranded assets piling up across the fossil fuel complex and closely coupled industries (more than $11 trillion have either exited or are in the process of exiting the fossil fuel industry in just the past few years). They would like to reinvest in the green infrastructure opportunities that constitute a smart Third Industrial Revolution build out. Still, fund managers and the financial community complain that the real problem is a lack of camera-ready largescale America 3.0 infrastructure projects in which these freed up funds might invest. Unfortunately, cities, counties, and states are tinkering with thousands of small, unconnected pilot projects with little incentive to scale a massive infrastructure transformation. Missing is the Third Industrial Revolution narrative which describes the nervous system that would connect all of these isolated projects.

Coal, December 2018, https:// unfriendcoal.com/2018scorecard/ (accessed March 23, 2019), 4–6

[42] Consumer Watchdog, "Top Ten U.S. Insurance Companies' Investment in Climate Change," https://www.consumerwatchdog.org/top-ten-us -insurance-companies-investment-climate-change; Aon Benfield, Weather, Climate & Catastrophic Insight: 2017 Annual Report, http://thoughtleadership.aonbenfield.com/Documents/20180124-ab-if-annual-report-weather-climate-2017.pdf (accessed March 23, 2019), 30.

[43] Coalition for Green Capital, "Example Green Banks," http://coalitionfor greencapital.com/green-banks

Infrastructure, at the deepest level, is not just an incidental appendage to commerce and social life. It is always new infrastructure that is the indispensable framework that binds society together as a collective whole and provides the new economic opportunities and employment. To date, the missing link is sufficient political will at the federal, state, municipal, and county governing levels to embrace a bold new social contract – The Resilient Society – and begin to scale up and deploy a smart America 3.0 infrastructure.

12 ENERGY SERVICE COMPANIES: A NEW PUBLIC-PRIVATE BUSINESS MODEL

Private enterprise has vast technical and economic expertise that will be invaluable in the conception and deployment of a Third Industrial Revolution infrastructure across the US. A new business model is emerging alongside a Resilient Society social contract, which, in recent years, has enjoyed a track record of success. The business model is the “energy service company” (ESCO). It’s a novel approach to conducting business that relies on what’s called “performance contracting”. Performance contracts do away entirely with seller/buyer markets, replacing them with provider/user networks in which the ESCO takes 100 percent of the responsibility for financing all of the work and secures a return on its capital investment based strictly on its success in generating the new green energies and aggregate efficiencies being contracted, leaving the physical assets in the hands of the users. Public-private partnerships between governments and ESCOs put the technical expertise and best practices of private enterprise at the service of the public, in a win-win mode, creating a powerful new dynamic between the public and private sectors.

Here’s how the new collaboration works. First, state, county, or municipal governments issue a call for tender. ESCOs bid for the contract to build out part or all of the infrastructure, with the following conditions. The company that wins the bid is responsible for financing the infrastructure. The ESCO’s return on capital investment comes from the revenue earned from the installation of solar and wind technologies and the generation of green electricity, the efficiency gains in electricity transmission in the build-out and management of the smart US high-voltage direct current Continental Electricity Internet, the energy efficiencies generated by the upgrading of fresh water and waste water systems, as well as the energy efficiencies brought on by other types of performance-contracting work: retrofitting buildings and making them more energy-efficient and resilient to climate-related events; installing energy storage equipment in and around facilities; embedding IoT sensors to monitor and improve energy efficiencies; erecting charging stations for electric vehicles; and reconditioning production facilities, manufacturing processes, and supply chains to upgrade aggregate efficiencies at every stage of business operations in an increasingly circular economy.

Performance contracts can also allow for the client to begin sharing the benefits of the green electricity being generated and the aggregate energy efficiencies coming online as the work is being done and before the ESCO’s investment is fully paid back. These modified performance contracts are called “energy savings contracts.” Generally, the ESCO will receive the lion’s share of the energy efficiencies attained—usually 85 percent—until the company's investment is fully returned and the contract terminated, after which the client receives all future benefits.[44] The cities, counties, and states and local businesses and homeowners end up with a smart, efficient low-carbon infrastructure without liability for either the capital investment or any financial losses incurred during the project.

ESCOs function in the private realm as well as the public realm. Privately held residential real estate and particularly low- and moderate-income housing, older commercial business districts and aging industrial and technical parks, which are often in disadvantaged communities, will have to transition their infrastructures into a green Third Industrial Revolution paradigm. The ESCO business model operates the same way in the government space, the commercial domain, and in civil society. Government targets and mandates along with generous tax credits and graduated tax penalties will need to be established for residential, commercial, industrial, and institutional infrastructure transitions in every city, county, and state to encourage the resilient transformation.

ESCOs are a business model that blends a social commitment into its very business plan. The ESCO is continuously in pursuit of breakthrough technologies and improved management practices that will return its investment, and the community benefits from this in a number of ways: cheaper utility bills for their homes and businesses; clean renewable energy to power their homes and businesses at near-zero marginal cost; green electricity to power electric and fuel-cell vehicles; increased aggregate efficiencies in the production and distribution of goods and services; less waste in an ever more sustainable circular economy; more efficient use of water systems; a less polluted environment to advance public health; and new business opportunities and employment, with the revenue and benefits recirculating back into the community to enhance its economic and social well-being.

The performance-contracting model is a hybrid affair, in which both the control over the build-out of the new infrastructure and its ownership remain in the hands of homeowners, local businesses, and state, county, and municipal governments as public commons serving the general welfare of communities, while shifting responsibility to private-sector ESCOs to shoulder the financial responsibility to ensure the success of the erection and management of the infrastructure. The "buyer beware" in seller/ buyer markets gives way to the provider "doing well by doing good" in provider/user networks.

13 THE FEDERALIZATION PRINCIPLE AND PEER ASSEMBLY GOVERNANCE

The Resilient Society in every state goes hand-in-hand with distributed peer governance. While each state will be charged with the task of building out and scaling up a Third Industrial Revolution to usher in a resilient society, the goals and deliverables in each jurisdiction will need to be customized to the specific priorities of that region. But to be effective, all of the states will need to connect across their

[44] Hawaii State Energy Office, "Pros & Cons of Guaranteed Energy Savings vs. Shared Savings Performance Contracts," fact sheet, February 2013, https://energy.hawaii.gov/wp-content/uploads/2012/06/Pros-and-Cons-of-guaranteed-vs.-shared-energy-savings-2013.pdf (accessed March 23, 2019).

borders and collaborate on a smart Continental Electricity Internet to create lateral economies of scale and network effects.

With this consideration in mind, states, counties, and municipalities should establish resilient “peer assemblies”, overseen by elected officials of the states, counties, and cities, and comprised of representatives from local chambers of commerce, labor unions, economic development agencies, public and private universities, and civic organizations. These peer assemblies will be tasked with establishing resilience roadmaps to transition their economies and communities into the green era. It’s not necessary for every state to sign on initially, but at least to have a number of first movers step forward in order to create a threshold effect. Other states will likely come on board quickly as public pressure builds for The Resilient Society in their communities.

The distributed nature of the Third Industrial Revolution infrastructure makes its speedy adoption and scaling more likely if it is conceptualized by the states, counties, and municipalities where it will be deployed. Prioritizing regional control over the governance of America’s 3.0 infrastructure transformation aligns with the very core principle of America’s federated constitutional governance.

The states will have to work with each other, and with the federal government, to determine the codes, regulations, and standards of operations that will need to be put in place to ensure that the distributed green infrastructure can be quickly installed and connected across governing jurisdictions. At the same time, the states, counties, and municipalities, for their part, will need to establish local peer assemblies and develop their own customized Third Industrial Revolution roadmaps and deployment plans.

The European Union’s experience with establishing peer assemblies in the three test regions of Hauts-de-France, the 23 municipalities of Rotterdam to The Hague, and the Grand Duchy of Luxembourg suggests that the optimum peer assembly should not exceed three hundred citizens within any given region participating and providing input and feedback at every stage of engagement. Peer assemblies are not focus groups or stakeholder groups but, rather, a cross-section of the public that will be intimately involved in the ongoing deliberations, and the preparation of the proposals and initiatives that will be incorporated into their jurisdiction’s resilience roadmap.

Elected officials at the municipal, county, and state level become the facilitators and are responsible for selecting the cross-section of peer participants in their respective jurisdictions and overseeing the operations of the peer assemblies as well as passing appropriate legislation that comes forth in the recommendations that emanate from the peer assemblage process.

Each regional peer assembly will want to reach out and secure technical support. The states’ universities might be tasked with bringing together professional and technical talent from both their own institutions as well as from trade and technical institutes, think tanks, research institutes, civil society organizations, and local charitable foundations to provide valuable expertise from across the academic and professional disciplines.

Within six months of establishing resilient society peer assemblies, the governor of each state should convene his or her own weeklong "climate emergency summit" with several thousand peer assembly representatives in attendance from their respective counties and cities. The summit should cover all of the various aspects of green mobilization, including professional and technical expertise, the preparation of peer-managed roadmaps, and financing of projects and initiatives.

The Resilient Society begins with preparing a detailed America 3.0 roadmap, which typically takes ten months. Regional peer assemblies should each undertake their own roadmap. The success or failure of The Resilient Society roadmap preparations and project deployments depends on whether the process itself is viewed from its inception as a truly collaborative, open, and cross-disciplinary exercise. It's recommended that every peer selected by these assemblies sign a socially responsible ethics agreement to collaborate rather than compete and to act impartially rather than lobby for a special interest or cause. The peers need to come to the task with a civic-minded community spirit if they are to succeed. Roadmaps create a community esprit de corps—a feeling among the peers that they are engaged in something bigger than themselves that will deeply affect their families, communities, and generations to come.

The chairpersons of the regional peer assemblies should meet periodically with the governor's office and the state legislature to report on progress in their roadmap deliberations and receive feedback and assistance. After the ten-month process, each peer assembly will publish an extensive roadmap detailing its customized Resilient Society plan and next steps for initiating financing and local deployment of scaled green infrastructure mega projects. They will also share their views on the codes, regulations, standards, incentives, and penalties that need to be forthcoming from their state legislatures to expedite a statewide transition into The America 3.0 paradigm.

The roadmap mission is not just to create a grab bag of favorite green projects but, rather, to develop a comprehensive and systemic Third Industrial Revolution infrastructure plan that can be deployed across the states over a period of two decades. This integrative approach to scaling infrastructure is what has been sorely missing in previous green proposals. We need to visualize the build-out of an America's 3.0 revolution as a multigenerational construction site that will evolve over time and branch out in many directions as circumstances dictate. Failure to understand the mission will lead to fragmentation and ultimately descend back to small, siloed favorite green projects without a transformational impact.

Many cities and counties across America have prepared green sustainability roadmaps, and a few have even involved some form of peer assembly in the deliberations; these localities will be an important source of expertise in sharing best practices. None of the already existing green development plans in play in counties, cities, and at the state level are discarded in the Third Industrial Revolution roadmap process and subsequent deployment; rather, they are embedded into the green infrastructure that connects these projects in a seamless new economic paradigm. Absent this unifying vision across each county, city, and state, we are back to thousands of well-meaning green programs that remain attached to the dying fossil fuel infrastructure of the twentieth century.

Cities, counties, and states might want to establish websites to share their Resilient Society roadmap deliberations and deployments in real time across the United States. Engendering a national dialogue on best practices and accompanying opportunities and challenges can spin off multiple collaborations across traditional political borders, creating a wholly new distributed political dynamic to advance infrastructure alignments across the 50 states.

Peer assemblies continue to work beyond the roadmap stage, through the entire scale-up of a zero-emissions green infrastructure transition over time, with peers rotating in and out of the process and across generations, ensuring continuity beyond the turnover of elected officials every two or four years, guaranteeing that the peer process itself is not held hostage by whatever political party or elected official is holding office.

While the executive and legislative branches of municipal and county governments and each of their respective state governments are responsible for initiating and overseeing peer assemblies, and have the ultimate responsibility of converting their recommendations, projects, initiatives, and proposals into laws, protocols, and initiatives, robust representation from the citizenry will be critical to the long-term success of transitioning into The Resilient Society. Peer assemblies are informal bodies that bring the voice of the public into the process and encourage elected officials and government agencies to be more responsive and integrative in their missions and assignments and to be more systemic and attentive to the multiple perspectives rising up from their communities. Peer assemblies lateralize governance by bringing the public into continuous engagement with government to advance the commonweal. Their presence requires a new generation of elected officials and government employees who are comfortable with informal sharing of governance between elections rather than exercising an exclusive territorial reign.

The fear of climate change is very real, and the conditions for living on Earth are going to deteriorate far into the future and beyond our current imagination. Cities, counties, states, and the Federal Government will all have to be engaged in a political process without a closure date. Climate change is going to require the ongoing engagement of the entire body politic. No single elected official or head of a government agency is going to be able to go it alone. The model that comes to mind is disaster response and relief during emergencies. The entire community comes together in these moments and often for extended periods of times—local organizations, NGOs, religious bodies, schools, neighborhood associations, and the business sector – to address the crisis. Between disasters, civil society organizations and the business community are in continuous collaboration with public authorities, learning from past emergencies, sharing best practices, and introducing new response mechanisms into the planning for future climate disruptions. Climate change now puts every community in the world in harm’s way in a continuous disaster mode. In the Age of Resilience, everyone is engaged in a new kind of lateral peer assembly governance and will need to take collective responsibility for stewarding their portion of the biosphere and securing their community’s well-being.

Without peer assemblies, citizens everywhere in America and around the world are going to feel less listened to, more abandoned and left to their own wits, and deeply alienated from their governments. That combination of fear and isolation, if left to simmer, is potentially explosive and could easily tear apart the very fabric of civilized life. Peer assemblies are a way to channel a community's sense of powerlessness in the face of climate change into a sense of shared responsibility for the biosphere that we will need in the years ahead and centuries to come.

It's important to stress the timetable for ushering in a glocal resilient society and the transition into a smart Third Industrial Revolution to address climate change. The juvenile infrastructure for the First Industrial Revolution was laid down across the United States in thirty years, between 1860 and 1890. The juvenile infrastructure for the Second Industrial Revolution was built out in twenty-five years, between 1908 and 1933. The shorter time is due, in part, to the fact that the Second Industrial Revolution infrastructure was able to build on a First Industrial Revolution infrastructure already in place. The Third Industrial Revolution infrastructure can likely be built out in twenty years—a single generation—by building off the two industrial revolution infrastructures that preceded it and that are still partially in place to facilitate the transition.

By 2040, the United States should be fully transitioned into a near zero emission post-carbon economy if every American pulls his or her own weight and carries their own load, with grit and determination, as part of a community-wide and global commitment.

The Resilient Society is not just about mobilizing the public to pressure governments to loosen the purse strings, pass legislation, and incentivize green initiatives. Rather, it's the first call for a new kind of peer political movement and commons governance that can empower entire communities to take direct charge of their futures at a very dark moment in the history of life on Earth.

PART 2: THE PLAN

AMERICA 3.0

INTERCONNECTED INFRASTRUCTURE

BLACK & VEATCH

*See Appendix for a description of Black & Veatch's scope of work

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

Introduction and Context

America was founded on the vision and ambitions of those bold enough to pursue unconventional approaches to common challenges. While the global COVID-19 pandemic presents its own near-term challenges, the United States is still able to implement a new vision for our core infrastructure platforms that address both our near-term recovery, as well as our longer-term transformation to a more resilient, sustainable, and economically viable system for generations to come. It is this cathedral-like thinking that Black & Veatch is pleased to support with this infrastructure plan, *America 3.0 A Pathway to the Next Generation, Interconnected Infrastructure*.

Black & Veatch developed this brief paper to provide a narrative on the possibilities to invest in the transformation of U.S. infrastructure in the power, telecommunications, mobility, and distributed energy domains. Ideally, the visioning, design, and buildout for this plan will necessitate a view towards long-term resiliency, rather than short-term savings. This perspective will therefore challenge the current paradigm for justifying large-scale investments.

Setting the Scenario (2020 to 2040)

As outlined in *America 3.0*, building a smart, integrated, national infrastructure will not be straight-forward. It will require an approach that transforms the American economy well beyond “business-as-usual” and enables new thinking, adoption of new methods and technologies, and a high degree of collaboration among numerous stakeholders from the public and private sectors. The 20-year deployment pathway/timeline assumes that county, municipal, state, and federal regulatory authorities and the critical industry sectors of ICT/Telecom, power utilities, mobility and logistics, and the buildings sector are all in alignment.

This buildout will also require overcoming or addressing several key hurdles across relevant domains, including the following factors for success:

- Utility Industry Regulation
- Transportation and Mobility
- Standards/ Interoperability
- Capital Availability
- Skilled Workforce Availability
- Permitting and Legal Rights-of-Way
- Raw Material Availability
- Pace of Technological Advances
- Adoption of Internet-of-Things (IoT)
- Clean Energy Policy Adoption

For example, regulation of the U.S. power sector is currently overseen by a complex network of federal, state, and local oversight bodies. The buildout of an underground, high-voltage direct current (HVDC) Continental Electricity Internet will require unprecedented levels of collaboration across many of these regulatory bodies. The good news is that this type of collaboration is being addressed already in places like the United Kingdom (UK).

The National Infrastructure Commission[45] (NIC,) was established in the UK as an executive agency of the Treasury to provide impartial, expert advice, and make independent recommendations to the government on economic infrastructure. The NIC will operate independently, at arm's length from government.

The establishment of a U.S. national commission, like the National Infrastructure Commission in the UK, would provide a strong foundation to support the broad ambitions of *America 3.0*. This commission would ideally be made up of county, municipal, state, and federal regulatory authorities and the critical industry sectors of ICT/Telecom, power/gas/water utilities, mobility and logistics, and the buildings sector. The national commission would apply sophisticated modeling approaches, such as integrated complex adaptive systems (CAS) modeling, to recommend regulatory changes necessary to support an integrated, connected, and seamless America 3.0 infrastructure across the United States.

Deploying this infrastructure requires a considerable focus on successfully integrating and optimizing numerous hardware, software, and firmware systems from an ecosystem of multiple vendors and service providers. The *America 3.0* vision depends on a high level of interoperability and data sharing across power, telecom, and the mobility sectors. It also suggests that consumer-owned, distributed energy resources[46] (DER) capacity will exceed utility-owned power generation in a fully integrated and distributed electricity infrastructure across the United States.

Building infrastructure at this scale also requires considerable capital, for which availability will need to be addressed in multiple formats. The fully funded buildout will be supported by the establishment of green banks and the issuing of green bonds, along with tax incentives, low interest loans, and grants, provided at every level of government. Energy Service companies (ESCOs) are already viable sectors in the economy and will become primary business models for building and financing the infrastructure deployment, with innovative forms of financing, design, ownership, and operating options.

Building the *America 3.0* infrastructure will take large numbers of newly skilled and re-trained workers across the U.S. We have delineated a large number of the expected job categories here. Training centers will need to be established in all 50 states and major metropolitan regions, on an accelerated basis, to prepare a new generation workforce with the skills and talents that will be necessary to fulfill the millions of new, semi-

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[45] NIC, https://www.nic.org.uk/

[46] Distributed Energy Resources include distributed generation, microgrids, EV charging, demand response, and distributed battery storage systems.

skilled, skilled, professional, and technical jobs that will be required to manufacture infrastructure components and scale, deploy, operate, and manage the 3.0 smart infrastructure.

The *America 3.0* infrastructure plan will also require new approaches to sourcing raw materials and finished components. From a U.S. economic perspective, this would be accomplished by prioritizing sustainable, onshore sourcing and regional manufacturing and installation of critical components of supply chains, with significant expansion of regional production capacity. It may also come to depend on new advances, including 3-D printing (otherwise known as additive manufacturing) and robotics, to replace many gaps in our supply chains.

Other technological advances will further support this infrastructure buildout, including new innovations in the power, telecom, and mobility sectors. Rapid advances in aggregate efficiency[47], brought on by smart infrastructure, can reduce fixed and marginal costs and accelerate productivity, while significantly reducing emissions, with commercial benefits extending across every sector and industry. Unfortunately, the power utility industry has historically spent much less than 1% of total revenue on research & development, with most of the technology advances coming from technology firms.

On the consumer side, we would expect this infrastructure to also stoke the widespread adoption of an IoT neural network across a smart nodal residential, commercial, and industrial building stock. This would be comprised of edge computing, micropower generation, charging stations, and electric vehicles, alongside smart road and rail systems, and agricultural lands, transforming business models, and hastening the partial shift from vertical ownership to platform-driven lateral access, and from seller/buyer markets to provider/user networks.

In short, the America 3.0 infrastructure transformation will be disruptive and challenging, as were the earlier transitions that took the United States from a largely agricultural society into the First Industrial Revolution in the 19th Century and the Second Industrial Revolution of the 20th Century. And like the former, the new smart green Third Industrial Revolution will come with a myriad of benefits to the American economy and society, as well as unanticipated negative externalities along the way, as Is always the case with every great paradigm shift in history.

[47] Aggregate efficiency is the ratio of potential work to the actual useful work that gets embedded into a product or service. The higher the aggregate efficiency of a good or service, the less waste is produced in every single conversion in its journey across the value chain, https://www.strategy-business.com/article/Jeremy-Rifkin-on-How-to-Manage-a-Future-of-Abundance?gko=5fad8.

2 EXECUTIVE SUMMARY

Our physical and digital worlds are converging at an exponential pace, disrupting nearly every industry and community across the United States. This transformation is driving rapid urbanization and straining infrastructure that is already in decline. With increasing pressure on state and municipal budgets, civic leaders are concerned about delivering essential services to their citizens and staying competitive in our ever-evolving, data-driven economy. At the same time, connected citizens are influencing the pace of innovation, pushing leaders to try new approaches and technologies.

By digitizing their physical infrastructure, leaders build community resilience and change the very nature of their systems. The result is an agile governance that can flex to respond quickly to changing community conditions and citizen needs. All communities—including states, municipalities, universities, medical campuses, utilities, telecommunication carriers, and mobility managers—can capture the many benefits of digital technology. Although still early, many communities have started to pursue a digital pathway and are realizing the value of a nimble infrastructure, strengthened service delivery, and enhanced citizen quality of life.

To advance the deployment of an America 3.0 paradigm shift, communities across the country will need to create planning roadmaps to deploy their infrastructure, bringing together telecommunications, smart sensors, cybersecurity, and data science and analytics. With a digital foundation, local communities can configure resilient and sustainable operations that evolve alongside innovation no matter how the community changes over time. This plan, as outlined in the remainder of this document, is called *America 3.0 A Pathway to the Next Generation, Interconnected Infrastructure*.

As described in Chapter 3, a key component of *America 3.0* rests on the foundation of an underground cable, high-voltage direct current (HVDC) Continental Electricity Internet. The CEI network would overlay the existing power system to interconnect every municipality, county, and state across the U.S. The envisioned pathway includes, for the most part, traversing the nation's interstate highway and rail systems to facilitate right-of-way access to every community.

Chapter 4 introduces the notion of microgrids as a cleaner and more resilient source of electric power, bringing power generation closer to its point of consumption. The introduction of microgrids provides the opportunity to optimize the design of the electric grid from the load side of the distribution network. With this approach, power supply and demand are matched at the local level, in a design format as a microgrid. The building blocks that make up the "grid as a system of microgrids" are many of the same components in use today – transmission and distribution networks, and feeders that service loads from neighborhoods, buildings, and electric vehicles. As these load points begin to add microgrids, they become more flexible, active participants in the electric distribution system acting, at different times, as suppliers and demanders of electric energy. These building blocks will stack to form the overall grid, will manage themselves and participate in energy market transactions, and run independent of a grid connection as an electrical "island" for periods of time. The grid becomes a "system of microgrids" that can operate independently and in cooperation with other microgrids, providing increased resiliency and a cleaner energy footprint to local energy users.

The CEI is connected to power transmission and distribution utilities, a nationwide network of broadband telecommunications, and an interconnected, alternatively fueled transportation network of electric vehicles, EV charging stations, and hydrogen refilling stations in a single multi-dimensional system to manage, power, and move the economy, society, and governance.

As further outlined in Chapter 5, the telecommunications network includes a fully integrated and highly responsive infrastructure, which will be critical to manage and control the flow of electricity on the network and to support demands for reliability and efficiency. The primary method to achieve these objectives will be to create a nationwide fiber optic network connecting edge data centers. The initial phase of the national network would be built with enough fiber capacity to allow future connections to the backbone, as each new region and community is "lit" or activated on the CEI. The last phase of the national broadband network will extend to the end user and to edge computing locations using fiber technology. Edge computing will enable the CEI communications system to become more efficient and extend deeper into the distribution system, and create a distributed fog network that processes data at the source.

As a final component of *America 3.0* infrastructure, Chapter 6, addresses the transportation sector of the U.S. This sector is expected to transition from high dependence on fossil fuels to an electricity and hydrogen-fueled network of vehicles across all sizes and classes. Once considered niche technology, electric vehicles (EV) are breaking into the mainstream market. All major automotive manufacturers are introducing electric vehicles into their fleets globally. As battery density and first costs continue to decrease, consumer adoption will rapidly increase. City fleet operators are electrifying transit and light duty fleets and are piloting everything from garbage trucks to police cars. Electric medium-duty vehicles and heavy-duty vehicles generally have a higher upfront purchase price than conventional models, but some EVs, like transit buses, are now cost-competitive to conventional vehicles based on total cost of operation. Black & Veatch believes that, within two decades, EVs will dominate the mainstream vehicle market[48].

For each component of *America 3.0*, Black & Veatch has provided high-level cost estimates in current 2020 dollars. These high-level cost estimates are only intended to provide a relative indication of the magnitude of the infrastructure investment involved. This includes initial estimates of one-time capital buildout costs, some of which follows a typical S-curve deployment pattern, plus estimates for annual maintenance expenses. No additional assumptions are made relative to equipment life expectancy (affecting capital replacement costs), improved designs and construction methods, nor to any increased efficiencies or benefit streams to offset these estimates. Additional treatment and refinement of such estimates would entail a logical next step for those who wish to pursue economic impact assessments.

In summary, the estimated 20-year infrastructure costs, both in terms of capital buildout and ongoing maintenance expenses, for the national HVDC, microgrid, telecom, and mobility networks total

[48] "Who's Driving Electric Vehicle Charging?", Black & Veatch, 2017.

approximately $4.2 trillion, in current 2020 dollars. Key assumptions and more detailed descriptions of these high-level cost estimates are provided in the individual chapters that follow.

While industry and political leaders may not always agree on timing, cost, and development priorities, it is feasible to suggest that the infrastructure components outlined in this document will have considerable, transformational impact on our lives, economies, and societal well-being for generations to come.

3 ROADMAPPING THE CONTINENTAL ELECTRICITY INTERNET (CEI)

The existing electrical transmission system was designed to accommodate electrical generation from large power generation plants (many thermal plants with energy derived from fossil fuels) located near electrical load centers. With the deployment of large-scale solar and wind generation projects, which are often geographically constrained due to the locational favorability of environmental conditions (wind and sunshine), the initial design of the America 2.0 transmission system is no longer serving the needs of today. Large-scale electrical power generation can be categorized into renewable and non-renewable, based on the fuel source. There are increasing signposts that this shift in power generation is accelerating, aided by a mixture of policy and technology advancements.

Figure 3-1 illustrates historical electrical power generation trends along with predictions for future generation, based on a complex model which considers fuel prices, electricity demand, and costs associated with development of electrical power generation facilities.

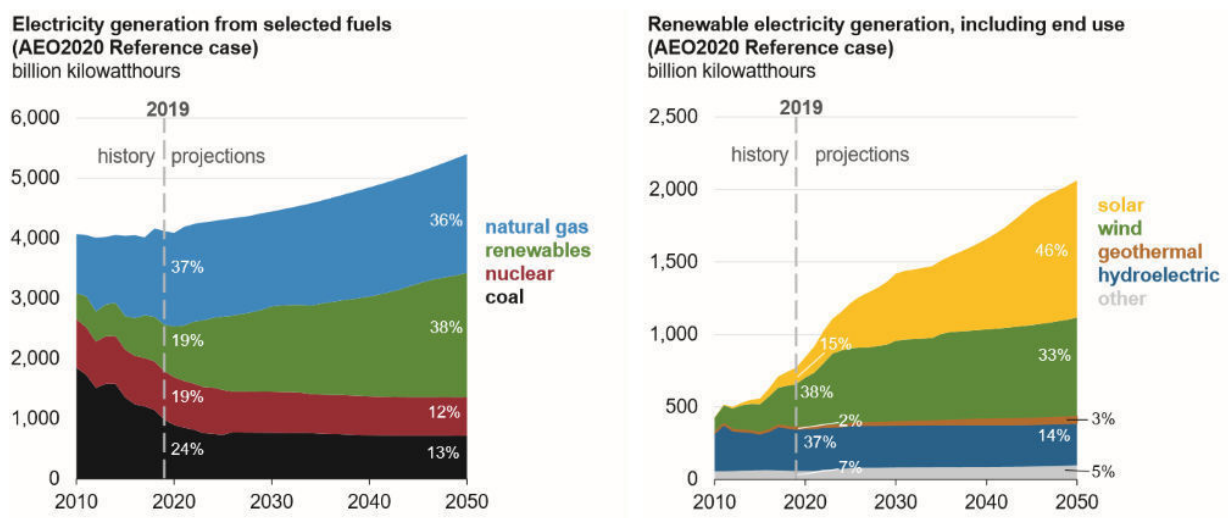

Figure 0-1: Electrical Power Generation Energy Mix

(U.S. Energy Information Administration Office of Energy Analysis, 2020)

These generation forecasts do not consider the stated policy objectives of many Electrical Utilities to decarbonize their generation fleet.

Electrical Energy Delivery Constraints

Natural Gas and Oil delivery continues to occur from centralized production centers near the naturally occurring resources to the point of consumption via a vast network of interstate pipelines. As the large-scale generation of electricity migrates from fossil plants which can rely on an established fuel transport system(s) to one in which the fuel (wind and sunshine) is geographically constrained, a Continental Electricity Internet can fulfill the energy delivery analogue to the interstate pipeline system. Development of this electrical energy delivery system requires vision and action at multiple levels of government and private enterprise.

3-1 Design Philosophy

Investigations into a Continental Electricity Internet (aka Macro Grid) have been completed through studies sponsored by National laboratories and Governmental organizations. These investigations have shown that investment in a Macro Grid overlay on our existing Transmission System can deliver significant societal and economic benefits.

Interregional Power Flows

A hallmark of the present power market is dramatic price swings on a daily and hourly basis due to the constrained movement of power in the existing transmission grid. Further to this, as the existing grid has developed and expanded there remains three large interconnections (Eastern, Western and ERCOT – Texas). These interconnects have limited connections between one another. This limited connection impedes the movement of high quality regionally derived renewable power across the continent. Illustrative of this limitation is the total transfer capacity between the Eastern and Western interconnects which cumulatively amounts to 1,300MW (NREL, 2018). This capacity is on par with the generation capacity of one large fossil fuel generation plant.

Increasing the transfer capacity between these two interconnections has been illustrated to yield economic and reliability benefits (Armando L. Figueroa, 2020):

Movement of high-quality wind and solar energy between the Eastern and Western interconnects can reduce generation fuel costs and increase renewable generation penetration to the transmission grid, which will result in lower power generation emissions.

Interconnected Macro Grid

Realizing benefits from increased interregional power flows requires the overlay of a Continental Electricity Internet on the existing transmission system. Accomplishing this requires the use of High Voltage Direct Current (HVDC) technology. Most of the interconnected North American transmission system relies on High Voltage Alternating Current (HVAC) technology. Implementation of HVDC lines enjoys substantial benefits in terms of power transfer capability over long distances, enhanced controllability of power flows and interconnection of asynchronous regional grids. Buildout of this system would allow for presently unthinkable grid operation scenarios:

Movement of low-cost wind/solar from the central part of the continent to the western portion of the United States prior to the sunrise in the west

Movement of low-cost solar in the west to the eastern portion of the continent to cover the evening peak thereby avoiding negative inter-day price movements

An initial build-out of the Continental Electricity Internet as envisioned in a study completed by NREL is shown in figure 3-2.

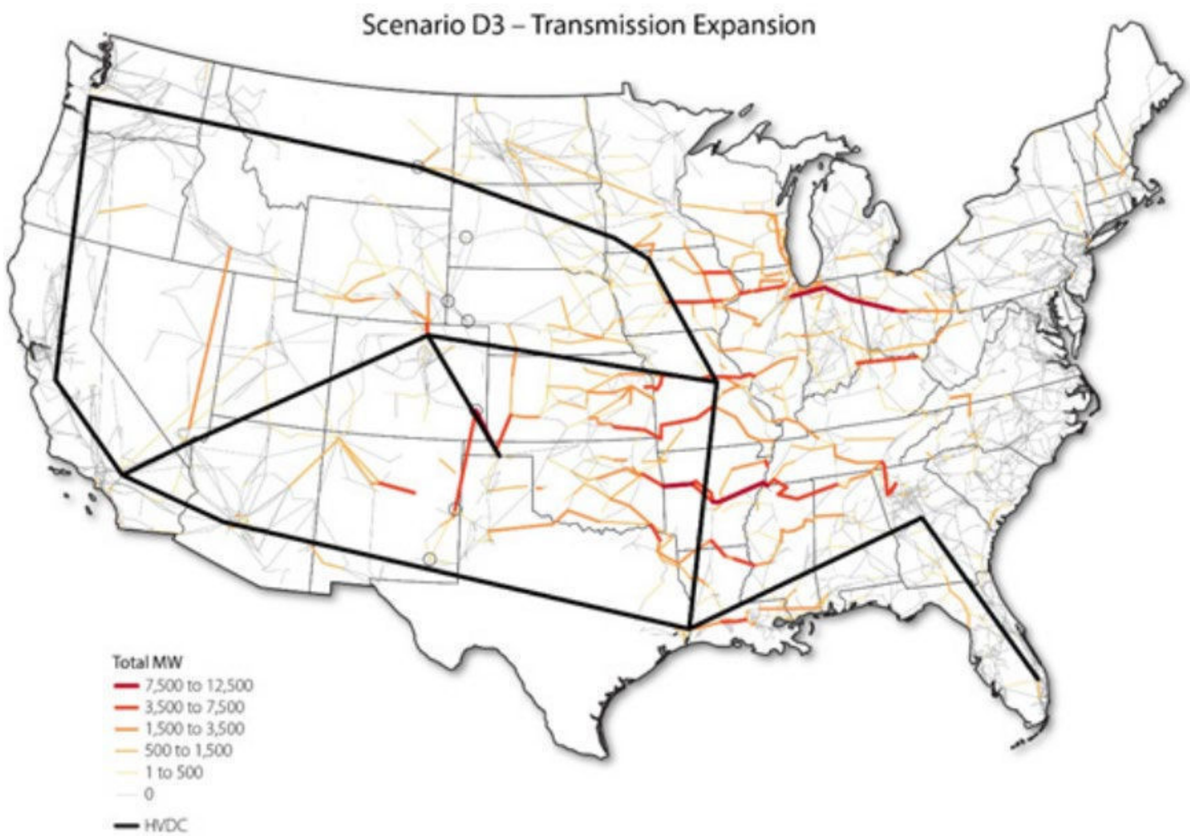

Figure 0-2: Conceptual HVDC Build-Out

(Armando L. Figueroa, 2020)

Absent from this conceptual buildout is any expansion into the eastern portion of the Continent. However, with the announcement of significant generation in the form of offshore wind capacity off the eastern continental shore there are compelling cases to be made for expansion of the Continental Electricity Internet to the east coast to efficiently move large amounts of offshore power into the continent.

The Continental Electricity Internet will interconnect with the existing HVAC system which has been undergoing significant updates and investment to leverage to the latest communication and computing technology for enhanced grid control and visibility. Through this interconnection, the HVAC system will be able to deliver high-quality renewable energy generation to every state, county and city on the continent.

Resiliency and Security

The Continental Electricity Internet will be critical infrastructure for maintaining the stability and functioning of the nation's power system. Ensuring the uninterrupted generation of electricity on this critical infrastructure against the existential risks of climate-related disasters and cyberterrorism will require the implementation of a host of resilient measures to assure 24/7 power generation.

Resiliency

Inherent to HVDC transmission is electrical parameters which support the use of high voltage cable over significant distances. For this reason, HVDC is the preferred technology for numerous submarine HVDC links installed throughout the world. High voltage cable allows for buried infrastructure, which insulates electrical infrastructure from numerous risks which are otherwise unmitigated in an overhead infrastructure installation. Risks can include exposure to wind and ice loading, which can result in transmission line failure. Lightning strikes can result in line faults, which must be cleared through line de-energization. Fire risks can emerge through the incidental contact of energized lines with combustible vegetation.

Recent legislation passed in the State of Florida, Senate Bill 796: Public Utility Storm Protection Plans, is seeking to transform the power transmission and distribution infrastructure into a storm-hardened, more resilient network. The economic cost to the State due to major storm-driven, large-scale power outages is considerable. As of 2017, 79 tropical hurricanes have affected the State of Florida. Collectively, hurricanes in Florida during that period resulted in more than $123 billion in damages, most of it from Hurricane Irma[49]. These events and future threats provide a significant driver for the legislative leaders to pass this legislation, requiring regulated power utilities to develop storm hardening plans to reduce outage times and restoration costs associated with extreme climate change-related weather events. Resiliency is best seen through the economic and societal value of preventing substantial losses of the power grid, rather than nearly through the cost to harden the network alone.

Therefore, the Continental Electricity Internet will utilize HVDC, underground cable as the electricity transport medium.

Security

HVDC transmission, like the more common HVAC transmission, leverages sophisticated control and protection hardware to enhance reliable operation of the assets. With modernization of transmission infrastructure, microprocessor-based technology (which leverages routable computing protocols deployed on the internet) has exposed transmission assets to cyber threats which were previously unthinkable. For this reason, the Continental Electricity Internet must leverage isolated networks with the latest network security protocols to provide immunity from malicious actors intent on compromising the nation's critical infrastructure.

3-2 Technology

The Continental Electricity Internet will leverage the latest in HVDC, high voltage cable and communications technology.

HVDC Technology

HVDC technology leverages power electronics and like most other technologies which leverage electronics, it is experiencing substantial performance improvements in capabilities. These performance improvements ultimately lead to enhanced power transfer capability of HVDC links. The Continental Electricity Internet will utilize the latest voltage-source converter (VSC) technology at each interface with the existing HVAC network. Through this implementation, multiple terminals on each link can be achieved with appropriate tuning of control systems.

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[49] https://en.wikipedia.org/wiki/List_of_Florida_hurricanes

Underground Cable

At present, tests have been conducted which prove +/- 525 kV to be a viable HVDC technology with high voltage cable. Further to this, there have been announcements of higher voltages from preeminent manufacturers of high voltage cable systems. With these voltages it is possible to achieve over 2,000 MW of power transfer with a single Bi-Pole HVDC link which exceeds the total installed transfer capacity between the Eastern and Western transmission interconnects in today's transmission system. Advanced monitoring technologies are also available with HVDC cable systems to ensure that local cable hot spots are monitored and mitigated. With this technology advanced cable analytics can be run to optimize the amount of power which can be transferred over a given HVDC line segment. Using the latest proven technology will be critical to ensuring the Continental Electricity Internet is moving the maximum amount of power to ensure the quickest return on investment by way of increased power movement for each HVDC segment.

Telecommunications

As the Continental Electricity Internet will be installed underground, there are significant opportunities to co-locate fiber optic within selected infrastructure corridors to not only move power but also information at the highest speeds achievable with the latest telecommunications technologies. While some fiber within this corridor will be utilized for control and monitoring of the Continental Electricity Internet, there will be ample bandwidth in additional fiber optic cable to allow additional information movements to key telecommunication nodes in the vicinity of Continental Electricity Internet corridors.

3-3 Conceptualizing Success

Throughout history, the United States has been able to muster the necessary political will and financing to move critical infrastructure forward. A great example is the Interstate Highway System which through the passage of the Federal Aid Highway Act, set in motion a concerted nation-wide mobilization to build out a highway system capable of moving people and commerce at a scale which is the envy of other nations around the world. The vision to set in motion a similar system for the movement of power, which is the lifeblood of modern commerce, is within our collective societal grasp. In order to accomplish the task of building out the Continental Electricity Internet, two key considerations must be secured to achieve deployment of the infrastructure in a meaningful timeline: Right-of-Way (ROW) utilization and the regulatory framework that governs the project's operation.

ROW Utilization (Continental Electricity Internet Superhighway)

The Interstate highway system along with Rail corridors offer readymade ROW for the Continental Electricity Internet. The terminus of the Continental Electricity Internet will rely on critical HVDC transmission nodes designed to deliver bulk power from generation sources to load centers, which happen to be the terminus of both the Interstate Highway System and the Rail System.

Regulatory Framework and Benefits

Through appropriate policy and incentives between Federal, state and local governments, a streamlined process can be implemented to leverage existing infrastructure ROW for the buildout of the Continental Electricity Internet. These incentives can lead to the ultimate build-out of the infrastructure by a governmental entity. Alternatively, expertise exists today in the electrical power industry in the form of Investor Owned Utilities and their unregulated businesses and project developers to finance, build and operate this infrastructure. In large part, what is needed is some certainty with a regulatory framework that leads to streamlined approval from all stakeholders.

Phased Timeline

A phased approach will be needed to implement a substantial HVDC build out to ensure the addition of new capabilities and market services as the build-out continues. Over the 20-year build-out period extending to 2040, four phases lasting approximately 5 years each are recommended.

The fully developed CEI would build a nationwide network, as shown in the following figure.

Figure 0-3: US HVDC Continental Grid Full Deployment (2040)

Phase 1

Phase 1 focuses on improving existing East West running seams, with six key segments covering approximately 3,466 miles of transmission lines.

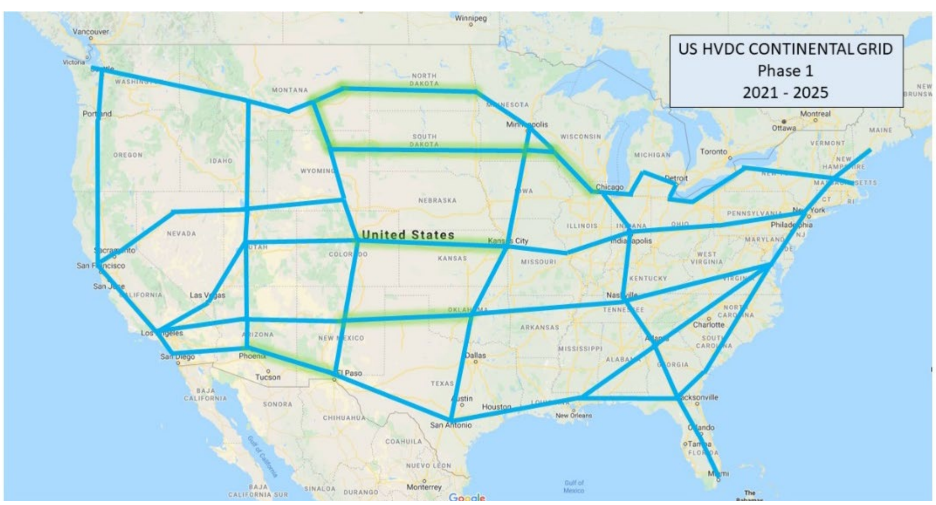

Figure 0-4: US HVDC Continental Grid Phase 1 (2021-2025)

Phase 2

Phase 2 enables the transport of wind power from origination sites in the Midwest and off the eastern seaboard to areas of demand respectively on the west coast and the I-95 east coast corridor and the transport of utility-scale solar from the southwest and southeast to points north across the country.

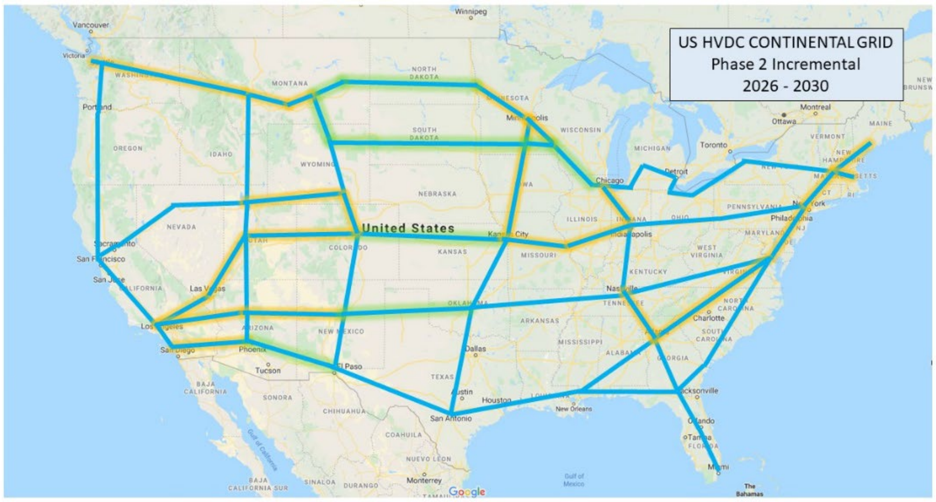

Figure 0-5: US HVDC Continental Grid Phase 2 Incremental (2026-2030)

Phase 2 encompasses the construction of 18 segments and 6,714 miles of transmission lines.

Phase 3

Phase 3 focuses on continuing the expansion of renewable energy generation to provide green electricity to more distant regional markets. This phase focuses on increasing the reliability of key North-South transmission corridors. In this phase, 16 segments cover 5,552 estimated miles of transmission lines.

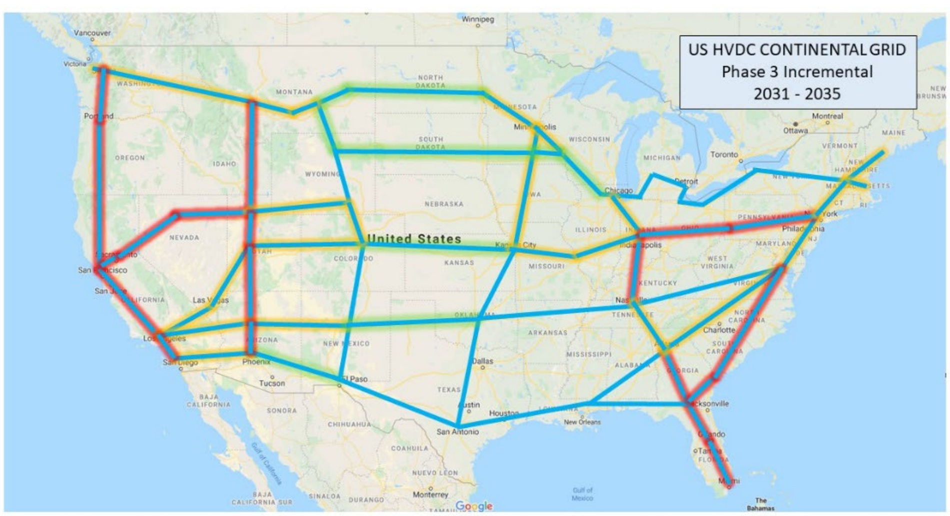

Figure 0-6: US HVDC Continental Grid Phase 3 Incremental (2031-2035)

Phase 4

Phase 4 of the Continental Electricity Internet will focus on the Texas ERCOT interconnection. This interconnection will provide increased transmission capacity and resiliency through the southern Interstate 10 corridor. Lastly, in this phase, connecting the Great Lakes region with the eastern seaboard provides renewable offshore wind resources. This final phase represents 15 segments and 6,183 estimated miles of HVDC transmission lines.

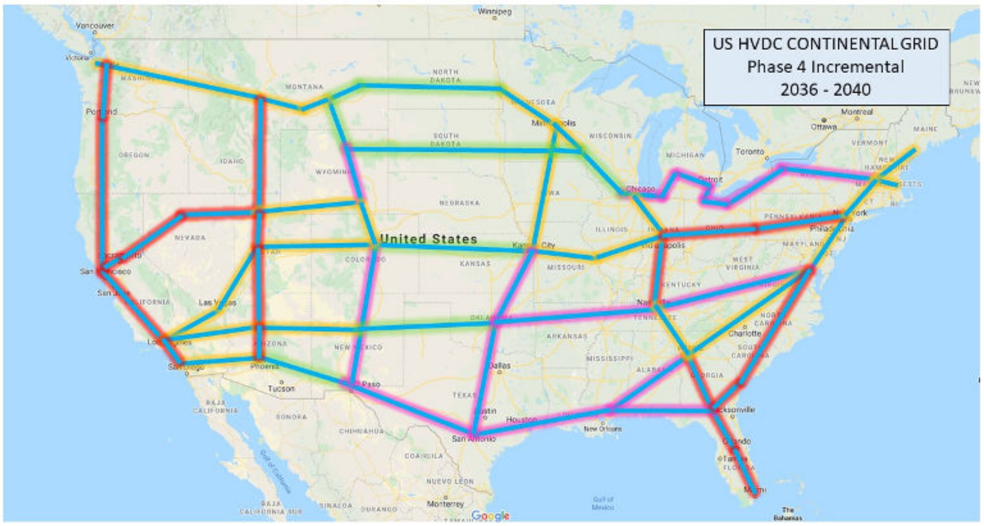

Figure 0-7: US HVDC Continental Grid Phase 4 Incremental (2036-2040)

3-4 High-level estimated costs

The following high-level cost estimates are only intended to provide a relative indication of the magnitude of the infrastructure investment involved, in current 2020 dollars. This includes initial estimates of one-time capital buildout costs, plus estimates for annual maintenance expenses. No additional assumptions are made relative to equipment life expectancy (affecting capital replacement costs), improved designs and construction methods, nor to any increased efficiencies or benefit streams to offset these estimates. Additional treatment and refinement of such estimates would entail a logical next step for those who wish to pursue economic impact assessments.

Several key assumptions are outlined to derive these high-level estimates.

Achieving the goal of building a resilient HVDC Continental Electrification network will require significant investment over the course of the 20-year project. This buildout will (1) Incorporate an increasingly geographically diverse energy generation portfolio, (2) Meet growing power demand, and (3) Enable the integration of variable power resources (e.g., solar, wind). Based on Black & Veatch's experience in installing underground HVDC, the cost of cable is estimated at $12.7 million per mile installed, with an estimated 21,915 miles of cable expected.

In addition to the HVDC cable, the use of terminals at key junction points will be necessary to manage power flows across the network. The cost of terminals is estimated at $370 million per terminal, with an anticipated need of 65 terminals to complete the project. These per mile and per terminal costs are based on 2020 current dollars and the current technology landscape. Changes in the technology landscape through parallel investment, innovation in the advancement of material science, or reduction in manufacturing costs associated with increased automation and/or other capabilities, may reduce the per mile and per terminal costs over the lifecycle of the 20-year project.

In consideration of the technology and solution design – underground cable – overarching maintenance costs can be minimized, to an estimated 1.5% of capital costs per year, as the infrastructure will be less subject to environmental interruption from storms, vegetation, and fire. It is noted that California's Investor Owned Utilities spend more than $250 million a year on vegetation management on above-ground distribution lines alone[50][51].

For total costs, buildout plus annual maintenance, the 20-year cycle for the CEI's four phases is shown in the following table. The total amount of this projected cost is $377 billion in 2020 current dollars.

Table 3-1: High-Level Estimated Costs for HVDC Buildout and Annual Maintenance Expense

HVDC	2021-2025	2026-2030	2031-2035	2036-2040	20-YEAR TOTAL
Phase 1	$50,620,627,472	$165,762,892	$183,015,627	$202,064,041	$51,171,470,032
Phase 2	N/A	$107,705,503,422	$322,576,937	$356,151,004	$108,384,231,363
Phase 3	N/A	N/A	$98,729,987,357	$309,924,915	$99,039,912,272
Phase 4	N/A	N/A	N/A	$118,616,902,106	$118,616,902,106
HVDC Total	***$50,620,627,472***	***$107,871,266,314***	***$99,235,579,922***	***$119,485,042,066***	**$377,212,515,774**

50 https://www.power-grid.com/2018/05/24/powergrid-cover-story-rethinking-utility-vegetation-management/#gref

51 https://www.power-grid.com/2018/05/24/powergrid-cover-story-rethinking-utility-vegetation-management/#gref

The following graph illustrates the capital buildout costs for each of the four phases.

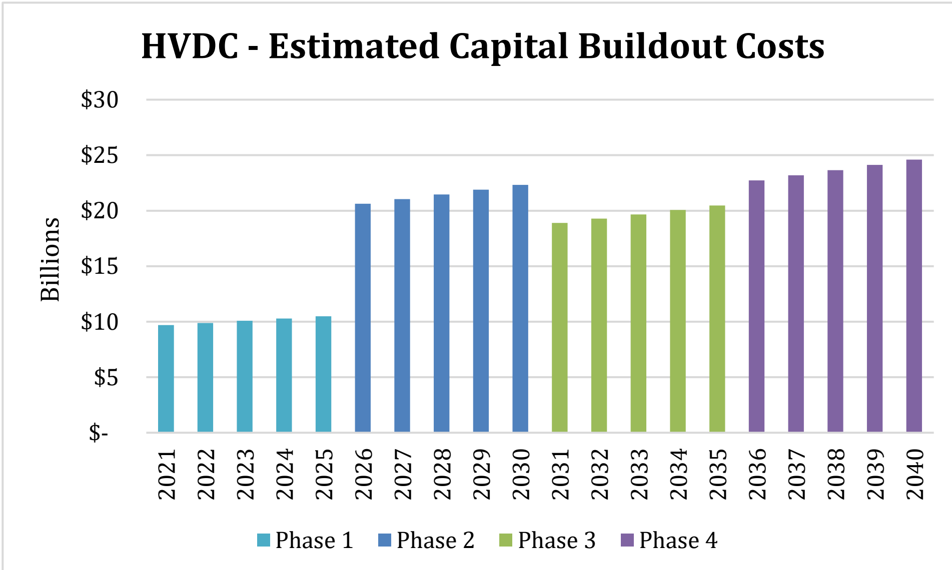

Figure 0-8: HVDC - Estimated Capital Buildout Costs

The following is the estimated annual maintenance costs for each year.

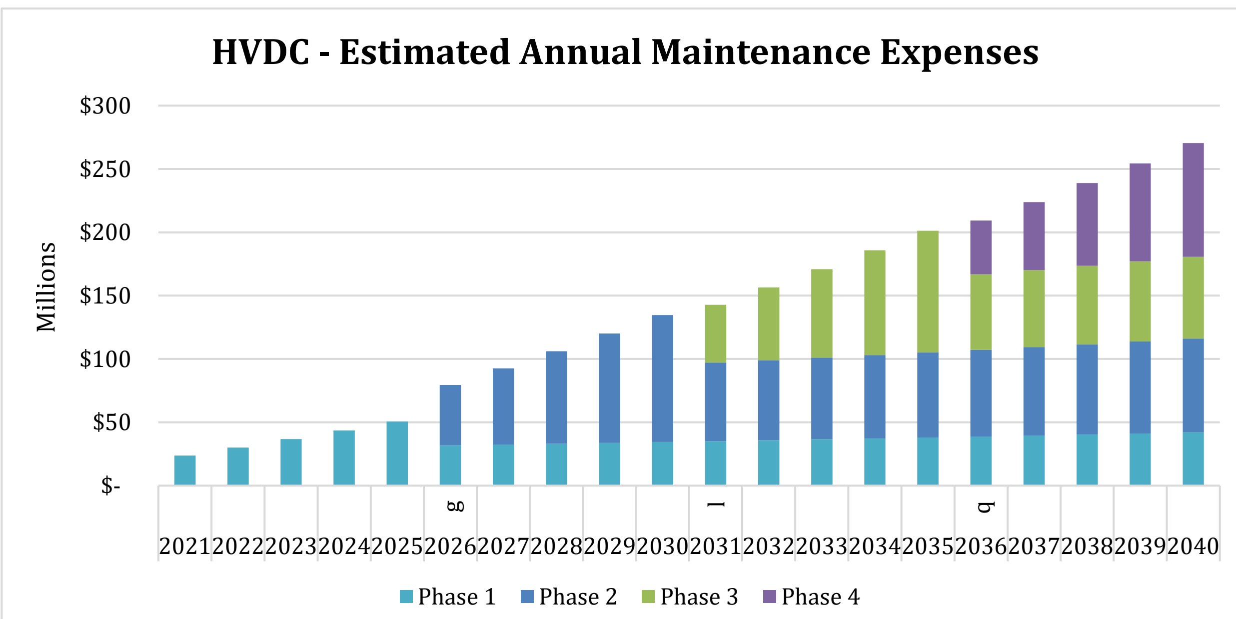

Figure 0-9: HVDC - Estimated Annual Maintenance Expenses

4 MICROGRIDS AND DISTRIBUTED ENERGY RESOURCES

As we continue to transition toward powering the continental US with 100% renewable energy, large scale solar and wind generation and the CEI will create and distribute an estimated 40-50% of the expected new power capacity additions. Regional, community, and local Distributed Energy Resources (DER) will be expected to fill the gap and support a contiguous network of more resilient power infrastructure.

DERs consist of small-scale power generation, controllable loads, and/or distributed energy storage systems that are physically located close to the area being served. DERs can include:

- Distributed generation – typically, these assets are rooftop or other solar PV installations, wind generation, flywheel energy storage, or spinning mass generators. These include larger wind and solar PV installations that are usually utility or third-party owned assets.
- Demand-side management assets – these controllable load assets provide energy management systems the opportunity to reduce (or increase) loads through demand response market signals. In today's technology paradigm, they are tied to specific utility customer incentive programs that pay customers for the option of allowing a third party (utility or aggregator) to execute load reduction of assets like HVAC systems, pool pumps, and smart appliances. It is likely that in the future demand side management assets will play a bigger part in power distribution markets and in balancing supply/load needs at local levels.
- Distributed Energy storage – Distributed energy storage is a special type of DER that deserves additional discussion. Batteries are the "swiss army knife" for energy systems with the ability to consume, supply, condition, and store electric energy. This is especially true in today's world of intermittent renewable supply sources and unpredictable (and sometimes mobile) load profiles. The ability to store energy in a DER-rich environment is profoundly important, especially when balancing the potential overgeneration of photovoltaic (PV) systems during daylight hours and the rapid ramping loads when the sun goes down and people transition from work to residential premises.

Microgrids are a more advanced type of distributed asset. Microgrids are integrated systems of different load and distributed generation types that can function both in parallel with the electric grid, or as an island apart from the grid. To the utility, a microgrid looks like a single point on the network that can be a source of distributed generation, or that can be remotely disconnected to operate independently to reduce load during times of high demand or grid disruption. The large-scale introduction of microgrids to the nation's energy network will both provide a path to higher penetrations of renewable green energy and improve energy system reliability, resiliency, and flexibility.

Microgrids can be broken down into 3 categories based on where they are deployed and use case:

- Residential/Small Commercial – Is fully interconnected with a local utility grid but can also maintain some level of service in isolation from the grid. Serves smaller, single load structures like homes or small commercial buildings.

- Commercial/Industrial/ Campus – Is fully interconnected with a local utility grid but can also maintain some level of service in isolation from the grid. Serves a discreet geographic footprint like a college campus, hospital complex, business park, industrial complex, or residential park.
- Utility/Community Scale - Integrated into utility networks and serves critical facilities in a larger geographic area. Its primary purpose is to ensure power to services that people can't live without for an extended period.

4-1 Design Philosophy

Legacy electric grid architecture is based on moving power from central power generation sources at the "top", via high voltage transmission and lower voltage distribution networks to serve customer loads. The system was built for power to flow in one direction. As power generation is increasingly distributed across the network, much of it in the form of renewables, this top down architecture must change to address complexities like intermittency and bi-directional power flow. To add complexity, there is no consistent starting point for this exercise, as the nation's electric grid is owned and operated by thousands of investor owned utilities, municipal utilities, and cooperatives. As no single entity oversees the planning, design, or execution of the nation's grid architecture, government leadership at every level will be required to affect this change.

Grid Architecture

The introduction of microgrids provides the opportunity to rearchitect the electric grid to a bottoms-up model. With this approach, everything will eventually behave as a microgrid. The building blocks that make up the "grid as a system of microgrids" are many of the same components in use today – transmission and distribution networks, and feeders that service loads from neighborhoods, buildings, electrics cars, etc. As these load points begin to add microgrids, they become more flexible, active participants in the electric distribution system. These building blocks will stack to make up the overall grid, will manage themselves, will participate in markets, and will be able to run independent of a grid connection as an electrical "island" for an extended period. The grid becomes a "system of microgrids" that can operate independently and in cooperation with other "microgrids".

Electric vehicles are a great example of a "mobile microgrid" that is an architectural component and actor in a larger microgrid when it is plugged in. When it is not, it is an islanded microgrid with the capability of operating independently for some period. This "distributed intelligence" begins at the grid edge and propagates outwards and upwards to support larger and larger grid structures.

When implementing a bottoms-up "microgrid" building block type of architecture, energy storage is a critical piece of maintaining supply and demand balance and ensuring power quality within each building block. Conceptually, energy storage systems (e.g. batteries) can be charged during low demand or overgeneration conditions, then at dusk their energy discharge can be combined with Demand Response programs to accommodate the increase in demand. This could be achieved without additional stress to the grid and within allowable thermal limits.

Interconnected Micro Grid

A hallmark of the present distribution grid is the difficulty balancing load and generation at local levels. DERs are often providing excess generation in some areas while grid constraints are leaving other areas with difficult to serve loads that require use of temporary fossil generation like fast-start, peak power plants to meet demand. Changes to grid architecture will be required to provide a more segmented distribution grid that allows automated switching and islanding at both medium and low voltage levels. This will require investments in additional infrastructure such as medium-voltage switchgear, automation technologies, network sensing devices, advanced metering infrastructure, and supervisory control and data acquisition systems (SCADA). Adding these grid components will allow operators to shift loads to alternate generation sources, or request via market signals that certain loads be “islanded” to reduce overall demand or that DERs provide grid support via injection of generation or ancillary services.

Low Cost Clean Energy

Current grid architecture requires lengthy, expensive, and complex planning, approval and implementation processes to add renewable energy to a home or business. The processes become even more complex when adding grid-scale assets. The changes to grid infrastructure, telecommunications, and operational systems required to implement a microgrid-centric network will lay the foundation for integrating higher volumes of renewable energy assets.

To hasten the adoption of “green” technologies for microgrids, the following should be considered:

- Investment in research and development for energy storage technologies to lower cost, increase capacity and long-term storage capabilities, and develop additional technologies
- Investment in next generation protection and control technology research and development to meet the challenges of a more flexible, dynamic grid and the changes associated with renewable energy sources
- Incentives and/or policy to accelerate the conversion of conventional forms of distributed generation to greener alternatives in existing backup generation and microgrid installations
- Investment in the development of plug-and play standards, processes, and building codes for connection of DERs in buildings

Resiliency and Security

As with the Continental Electricity Internet, the distribution network will be critical infrastructure to ensure the stability and functioning of the nation’s power system. Measures will need to be implemented by many stakeholders to secure the orderly transition of this critical grid infrastructure.

Resiliency

Individual microgrids provide a measure of resiliency by providing the ability to island and sustain some level of service during grid disruptions. Full system resilience is increased as these individual microgrids work in a coordinated fashion as a “system of systems” with other DERs like demand response and distributed generation.

During blue sky conditions, system coordination will be used to address grid constraints by incentivizing grid assets via market signals to provide the services required to balance the grid. During significant grid disruption events, the priority will shift to maintaining the most critical loads for the community. Services like hospitals, fire and police departments, wastewater treatment and water supply, transportation centers, data centers, and facilities critical for supply chains will need to be prioritized over other utility loads. Building and home energy management systems could be signaled to reduce loads to emergency levels, significantly extending the period that residential and commercial microgrids could sustain loads as an island. These same systems could be used to reduce loads in buildings without the ability to island, thereby lowering the demand that utility scale assets would need to serve. All these scenarios require an advanced system and telecommunications layer to orchestrate data gathering, decisions, and actions.

Pre-event planning for microgrids should be included to increase resiliency. Grid operators should be able to send an automated signal to affected areas to request event prep (like charging a battery prior to a storm).

To hasten increased grid resiliency via deployment and coordination of residential, commercial, and utility microgrids, the following should be considered:

- Investment in research and development for orchestrating residential, commercial, and utility microgrid systems, including demonstration projects
- Investment in research and development for advanced planning tools to support planning and design of this next generation grid architecture
- Development and/or enhancements to existing standards to facilitate market and operational signals and drive consistency across the industry

Security

Today's transmission and distribution networks leverage sophisticated control and protection hardware to ensure reliable operation of the assets. As this infrastructure is modernized, microprocessor-based technology which leverages routable computing protocols deployed on the internet has exposed transmission and distribution assets to cyber threats which were previously unthinkable. For this reason, the Continental Electricity Internet must leverage isolated networks with the latest network security protocols to ensure immunity from malicious actors intent on compromising the nation's critical infrastructure. In addition, new DERs being added to the network as increasingly critical assets are no longer exclusively owned or fully managed by utilities. Investment must be made in standards, policy, monitoring and maintenance of security across these assets to ensure a secure national grid.

Regulatory Framework and Benefits

Expertise exists today in the electrical power industry and in the commercial area to build and maintain the Distributed Energy Resources and Microgrids required to move the nation toward 100% renewable energy. As more critical assets are added to the Distribution grid, consideration needs to be given to a more nationalized approach to ensuring system reliability like what exists today in the bulk power system.

4-2 High-level estimated Costs

The following high-level cost estimates are only intended to provide a relative indication of the magnitude of the infrastructure investment involved, in current 2020 dollars. This includes initial estimates of one-time capital buildout costs, plus estimates for annual maintenance expenses. No additional assumptions are made relative to equipment life expectancy (affecting capital replacement costs), improved designs and construction methods, nor to any increased efficiencies or benefit streams to offset these estimates. Additional treatment and refinement of such estimates would entail a logical next step for those who wish to further pursue economic impact assessments.

Across all three categories of micro/macrogrid systems, a high-level estimate of the 20-year buildout and annual maintenance expenses totals $2.3 trillion, using 2020 current dollars. Further estimated cost details can be found in table 4-1 and in the figures that follow.

Several key assumptions are needed, in order to develop these estimates.

First, in order to recognize that some of the technologies involved in micro and macrogrids are still emerging on the product learning curve, Black & Veatch has made assumptions around solar, wind, and battery storage as components of both micro and macro grids. Looking back at the past decade, wind energy costs seem to have declined about 14% annually[52], solar PV has declined around 13% annually[53], and lithium ion batteries around 15%/year[54]. Therefore, assuming other microgrid components (and labor) are not on the same learning curve, Black & Veatch applied an average annual cost decrease to total microgrid development costs of 10% annually.

In addition, other key assumptions were made to derive a total micro and macrogrid capacity for the U.S., as well as derive total costs across four sizing categories as identified in the previous section. Costs of new power generation from wind and solar technologies were referenced from the U.S. Energy Information Administration's Annual Energy Outlook 2020 (AEO2020) Assumptions document[55].

Key assumptions include the following:

- Electricity usage growth remains flat and that 1022 GW solar, 954 GW wind, and 1003 GW storage needs to be constructed to replace remaining conventional generation[56][57]
- 80% of total wind capacity would be allocated to macrogrids and 20% would be allocated to microgrids
- Solar capacity would be allocated evenly – 50% to macrogrids and 50% to microgrids

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[52] https://rameznaam.com/2015/08/30/how-steady-can-the-wind-blow/
[53] https://www.seia.org/solar-industry-research-data
[54] Bloomberg New Energy Finance, "Tumbling Costs for Wind, Solar, Batteries Are Squeezing Fossil Fuels", March 2018.
[55] https://www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf
[56] https://www.americanactionforum.org/research/what-it-costs-go-100-percent-renewable/
[57] https://www.instituteforenergyresearch.org/renewable/cost-of-transitioning-to-100-percent-renewable-energy/

- Energy storage would be allocated evenly – 50% to macrogrids and 50% to microgrids
- Microgrids contain 50% solar, 20% wind, 50% storage for new construction
- O&M costs for solar, wind, and battery storage average 2% of capital expense annually, with 1% for the first year only
- Utility-scale energy storage includes both macro and micro estimates
- Total microgrid capacity would be distributed as follows:
    - Residential = 20% of total capacity (74,030,769 microgrid units)
    - Commercial/industrial = 30% of total (90,225 microgrid units)
    - Utility-scale = 50% (12,030 microgrid units)

Table 4-1: High-Level Estimated Costs for Microgrids Buildout and Annual Maintenance Expense

MICROGRID	2021-2025	2026-2030	2031-2035	2036-2040	20-YEAR TOTAL
Residential/ Small Commercial Scale	$7,551,404,961	$51,126,429,481	$92,758,069,989	$29,679,437,576	**$181,115,342,006**
Commercial/ Industrial/ Campus Scale	$22,165,154,570	$103,274,885,874	$172,216,811,599	$91,044,510,859	**$388,701,362,902**
Utility Scale (Micro/Macro)	$72,204,269,204	$489,637,161,592	$893,968,902,373	$297,487,304,791	**$1,753,297,637,960**
20-Year Totals	***$101,920,828,734***	***$644,038,476,947***	***$1,158,943,783,961***	***$418,211,253,227***	***$2,323,114,342,868***

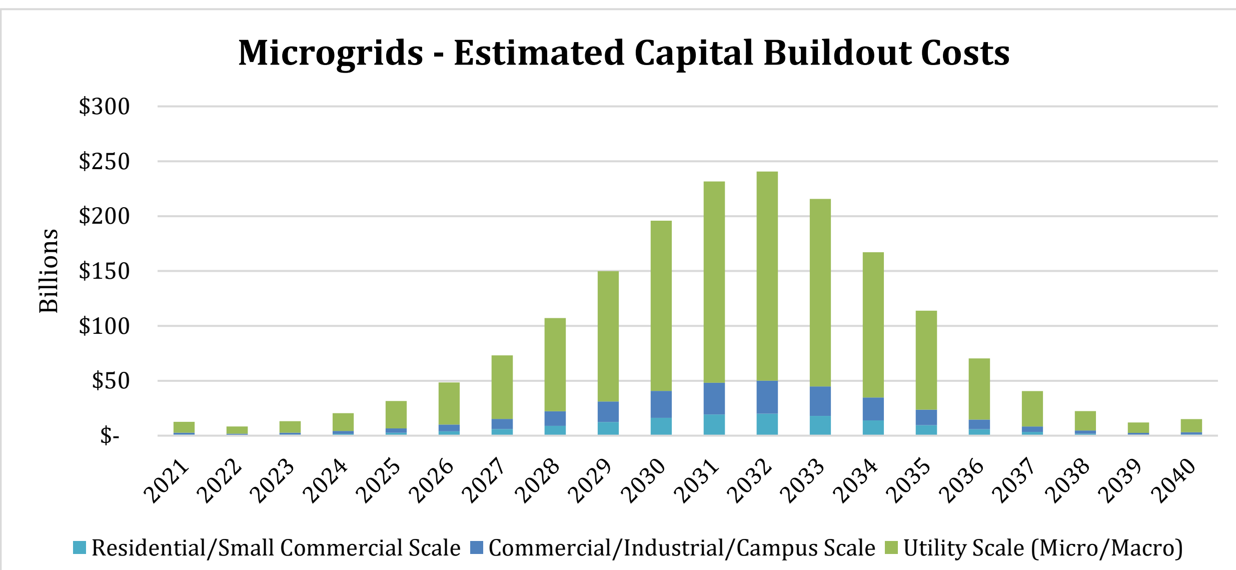

Figure 0-10: Microgrids - Estimated Capital Buildout Costs

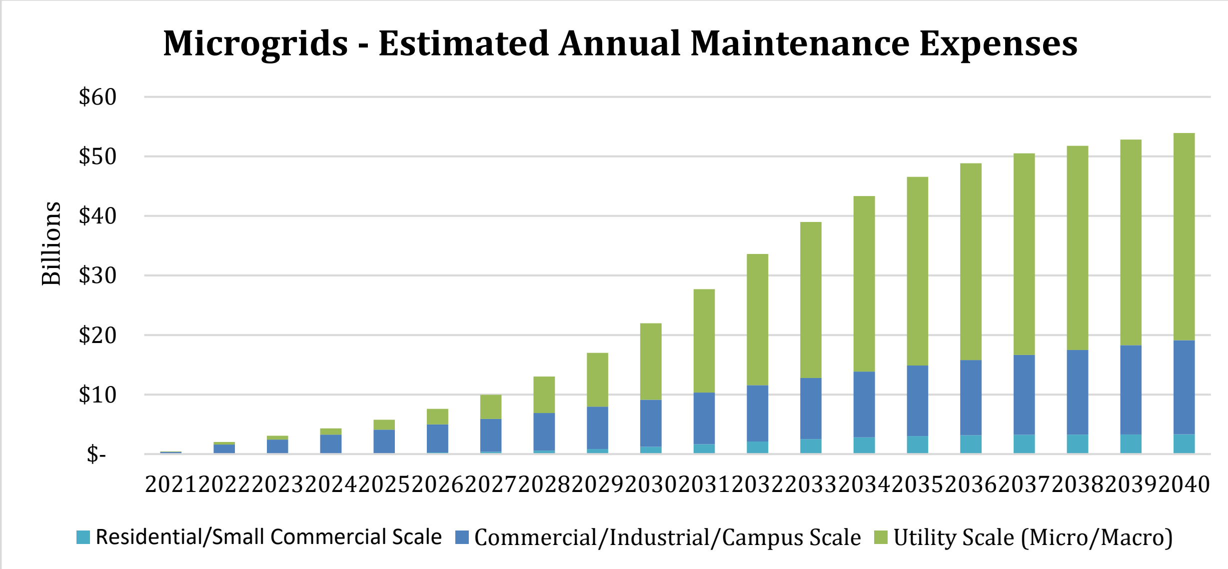

Figure 0-11: Microgrids - Estimated Annual Maintenance Expenses

5 NATIONAL BROADBAND

5-1 Deploying Broadband Infrastructure- supported by CEI

5-1-1 Design Philosophy

One of the base requirements of the CEI is that it will be a fully integrated and responsive communications infrastructure to manage and control the flow of electricity on the network and to support consumer demand for a reliable and efficient telecommunications platform. This will require implementing advanced communications systems capable of supporting millions of digital devices required for the future distributed energy system. The modernized grid of tomorrow must be built on a strong communications network that is fully resilient to natural and man-made threats by effectively employing essential applications — automation, analytics, asset management, and security. In addition, advanced communication at the grid level is essential to support consumer demand for widely available broadband. The present economy, educational system, and societal interaction all rely heavily on the presence of continuous communication that can support a good quality of life and a resilient society. The most effective and resilient approach to achieving these objectives is to develop a nationwide fiber optic network connecting edge data centers.

While the smart community conversation frequently centers on digital technology, the essence of a digitally connected community is people. A community's digital platforms unlock communication pathways, enabling citizens and smart devices to connect and share information in entirely new ways. This "distributed insight" helps local government understand what's happening across neighborhoods and make better decisions. Communities are already making digital connections and elevating their essential city services like public safety, healthcare, mobility, education, and utilities. Equally important, they are preparing their networks for future innovations.

If energy is the blood that runs through the nation to keep the economic engine running, the communications network will be the nervous system, the brain and spine of the network. It will monitor and control the operations of this nationwide power network. The initial phase will be to build the spine, the backbone of the communications network that will have a nationwide reach and can connect each region to the overall network. The second phase will be to connect each community to this spine so that the true vision of the nationwide grid can be achieved. The third phase is the push to embed Edge computing into the building infrastructure by bringing fiber directly to the premises.

The CEI communications network will be founded on a network that extends to the edge. The converged network will use internet protocol (IP), multi-protocol label switching (MPLS), and an advanced field area network (FAN) to be more efficient. This type of network architecture reduces network congestion, giving utilities speed, visibility, and control deeper into the distribution system where it's most needed, at the edge computing sites, to control the flow of electricity. Existing communications networks are inadequate. Deploying a dedicated fiber optic network will be the essential communications solution to support this critical function.

There are two additional key elements that will be needed to establish a resilient nationwide communications system. First, to manage and control the CEI and the Energy IoT, a reliable communications network with low latency and reliability is a must. The only way to achieve this is to create a network designed for that purpose – a dedicated fiber network that will be used to control and monitor the national grid. This network would not only provide the low latency, but also the secure network required for this function. The patchwork of current internet connections across multiple private vendors will not provide the same level of reliability, consistency and security. Second, the importance of Edge Data Centers or edge computing will be critical to the CEI as described elsewhere in this report. When a network of this size and complexity comes under pressure due to the sheer size of the network and volume of devices, efficiency in data transmission will become increasingly necessary. This is where edge computing becomes vital to the resiliency of the network.

5-1-2 Construction Plan

The initial phase of the national network would be to create the "spine" or backbone of the communications network. This network must be both robust and redundant, with extremely low latency across all points. It will be built with enough fiber capacity to allow future connections to the backbone as each new region and community is "lit" or activated on the CEI. The design of the network would follow the following basic underlying principles –

Network Routing – The initial backbone network will need to have a flexible and comprehensive route to cover all areas of the United States. This network must follow established Rights-of-Way (ROW) to avoid the unnecessary use of public property. As already mentioned, the national interstate highway system and the national rail system will be the likely sources of ROW to use in the routing for the network.

The National Interstate Highway System – The most efficient and simple method to determine the route of this fiber-based broadband network will be to follow the Rights-of Way of the National Interstate highway system. These highways were built during the second industrial revolution with a very similar purpose – to provide a seamless interconnectivity for mobility across the United States. The Interstate Highway System provides multiple paths across the continent allowing for the redundant paths required for resiliency. The use of this Right of Way is not unprecedented, as states are currently building their own fiber optic networks along these highways for their own uses. The ROW offers virtually open access to US Interstate highways that totals approximately 47,000 miles and reaches coast to coast and border to border. Ideally, this nationwide broadband fiber network to be built alongside the interstate highways will directly follow the same path of the HVDC network and would follow the construction of that portion of the network.

The National Rail System – As the network expands into more rural areas not served directly by an interstate highway, the highway system can also be supplemented with use of the existing railroad system. Use of this ROW is also not unprecedented. It is currently used by multiple telecom companies. The railroads cover over 140,000 miles allowing for greater flexibility in determining the routes needed for this fiber optic network, particularly when extending it from the backbone to more rural areas.

Construction of the Fiber Network – The base design of this network will be to place the fiber optic cable underground in a conduit and vault system. It has been proven that the most reliable and protected fiber networks have been placed underground as opposed to being placed on poles and structures above ground. The underground network is more reliable because it would not be subject to weather events such as wind, ice, and snowstorms. It would also be protected from manmade hazards such as motor vehicle accidents and deliberate disruptions of service.

Construction will have the following characteristics:

- It will be the design intent to embed the HVDC network with the communications network, gaining efficiencies in building them concurrently and in the same path and trench.
- The communications network will install a conduit bank with sufficient quantities of ducts to place fiber optic cable for both the initial requirements, future growth, and spare maintenance conduits. This will allow for expansion and for the ability to replace sections of cable with no loss of service.
- The national network path considers the "jumping off" points of the network, so that each region and community will be served from this network including vault locations and fiber allocation plans.

Fiber counts – It will be important to have an overall plan in place to allocate the number of fiber optic strands in each leg of the network. This will provide the redundancy and capacity that will be required for current and futures needs. The amount of fibers in each leg of the network will vary based on the capacity required. Currently manufacturers are producing cables with as many as 3,456 fibers per cable. This size or multiple cables will be required in some legs of this network. It will also be critical to manage the capacity of the network in a GIS based fiber allocation system that will allow easy provisioning of network services at endpoint locations.

Construction of the Networking Equipment – The fiber optic cable must be terminated in networking hubs that will contain the networking and transmission equipment to power the network. These hub locations would provide redundant locations in which traffic can be groomed and re-routed in the event of an outage in one or more segments. The transmission equipment would have lasers that use the latest photon technology to transmit the data and the networking equipment that will provide for the self-healing nature required for the network. These networking hubs will contain network transmission equipment that will have the following attributes –

- The equipment will support Ethernet networking, full redundancy and self-healing and routing capability.
- The transmission equipment will support full DWDM capabilities to maximize the data on each fiber strand. Currently capabilities are to handle up to 800G on each DWDM channel for a total of 38 Tb/s per fiber.
- The transmission equipment must also have the capability to perform Add/Drop functions to allow for the distribution of the data.

As the network evolves, the "backbone" of the communications network will have "branches" that will connect from the national network in to regional and community networks. Just like the national highway systems that has on ramps and exit ramps, so to must the national network have locations that the data can exit and enter. This is the purpose of having the vault where the fiber can be "branched" off the backbone and for the Add/drop capabilities in the electronic transmission gear. These "branches" of fiber can be built from the network using the Interstate highway and/or the railroad system as rights of way. Construction of this portion of the network will be very similar to the backbone, underground in conduit, but will not need the size and number of conduits and fiber strands. They will be more appropriate for the region or municipality that they serve. It is also expected that these branches will utilize the same construction path as the HVDC network where possible to gain efficiencies in construction.

The last phase of the Network will be to build the communications network all the way to the end user and to the edge computing locations to fully deploy the CEI. This portion of the network has more flexibility in how the data reaches these sites. Fiber can still be used and will be most effective in long term capacity. In addition, these end-user connections may also have a better ability to use current and planned private industry networks to supplement the national communications network designed in this document.

The “last mile” of fiber networks is sometimes referred to as fiber to the home (FTTH), Fiber to the business or building (FTTB) and many other names. In short, it brings the fiber directly to the end user through a series of passive fiber splitters that can distribute the data on one fiber stand to many end points allowing for high speed data connections at each of these points. There are current fiber build outs being installed in major metropolitan areas by existing service providers. It may be possible to leverage these existing networks to connect this last mile of fiber. Even rural areas are beginning to use community fiber networks, mainly through current USDA incentive programs. To encourage fiber investment in rural areas, these grants and incentives need to be increased just as the original Rural Electrification Administration (REA) grants that brought modern telephone service to all rural communities. Once again, these networks can be leveraged for the last mile.

5-2 High-level estimated Costs

The following high-level cost estimates are only intended to provide a relative indication of the magnitude of the infrastructure investment involved, in current 2020 dollars. This includes initial estimates of one-time capital buildout costs, plus estimates for annual maintenance expenses. No additional assumptions are made relative to equipment life expectancy (affecting capital replacement costs), improved designs and construction methods, nor to any increased efficiencies or benefit streams to offset these estimates. Additional treatment and refinement of such estimates would entail a logical next step for those who wish to further pursue economic impact assessments.

Several key assumptions are also outlined in the subsequent paragraphs.

Based on April 2020 Producer Price Index statistics from the U.S. Department of Labor, fiber optic cable prices have declined only slightly by approximately 21% over the past 17 years, and we would expect a similar decline for 2020 through 2040. However, the largest portion of the capital costs to construct a fiber network will be the construction costs, not the fiber itself. Using the same PPI statistics, labor costs have increased by 20% over the past 10 years. Therefore, we would reasonably assume that the cost to buildout the nationwide network will increase by approximately 1 to 2% per year, based on this historical data.

Using the same three segments of the fiber network referenced in section 5.1: backbone, branches, and the last mile, the cost of each segment is reflective of the advantages and challenges each of the build cycles will encounter during development.

Backbone

The backbone of the fiber network is intended to be a parallel entity to the Continental HVDC transmission infrastructure. As such the projected costs anticipate that these technologies be installed in parallel, thus minimizing the individual construction costs of the fiber network by using the same trenches, conduit, and right of way where possible. Based on these assumptions, it is anticipated that the fiber backbone costs will be approximately $120,000 per mile.

The backbone would also require that the networking hubs be established. It is estimated that 21 Hub locations would be required across the national network. These hub locations would provide redundant locations in which traffic can be groomed and re-routed in the event of an outage in one or more segments. Each site would require approximately $45M in electronics and fiber optic terminals which would add $945M to this phase of the network. The costs of these centers would be distributed during the project and built as each section of the network is constructed.

Branches

As the backbone fiber infrastructure is built out in situ with the underground HVDC discussed in Section 3, the branches extended out will incur additional per mile costs to account for the set of unique construction objects that will need to be embedded to facilitate the expansion of the network into more regional and local junctions. Specifically, the branches will not be able to leverage shared trench, conduit, and land use permitting of the HVDC transmission lines. To minimize cost in labor and materials where possible, the build out of the branches should be executed in conjunction with the backbone to allow the junction points of the branches to the backbone to be vetted and built out in consideration of both paths of fiber. Based on these assumptions, the per mile cost of branches is estimated at 1.5 times the cost of the backbone or approximately $350,000 per mile.

Last Mile

As noted in section 5.1, last mile programs are already present in today's landscape of technology infrastructure investment. These programs look to build on existing infrastructure, when available, and therefore have seen a diverse array per mile or per household costs based on the density of the population served and the presence of existing infrastructure. The goal of this infrastructure plan is to build on or augment those existing programs, reaching all U.S households through the country with broadband capabilities. In order to maximize cost efficiency in the last mile, planning, siting, and construction should occur in conjunction with the branch buildout to ensure that interconnection points, speed, and labor/materials economies of scale are realized. The estimated cost of the last mile initiative is $1,500 per premise, with an anticipated need to support 160 million premises across the US, at a rate of 5% adoption per year over the 20-year project lifecycle.

Over the 20-year lifecycle of this continental, fiber based, broadband telecom infrastructure buildout, total high-level costs are estimated to be $97 billion in 2020 current dollars, as shown in table 5-1.

Table 5-1: High-Level Estimated Costs for National Broadband Buildout and Annual Maintenance Exp.

BROADBAND	2021-2025	2026-2030	2031-2035	2036-2040	20-YEAR TOTAL
Backbone Network	$439,838,726	$941,818,731	$861,246,284	$1,061,203,107	$3,304,106,847
Lateral Network	$1,923,095,065	$4,119,455,837	$3,766,949,807	$4,641,758,741	$14,451,259,451
Fiber to Premise	$16,909,582,088	$18,699,034,962	$20,677,644,064	$2,879,366,577	$79,165,627,692
Telecom Total	***$19,272,515,880***	***$23,760,309,530***	***$25,305,840,156***	***$28,582,328,425***	***$96,920,993,990***

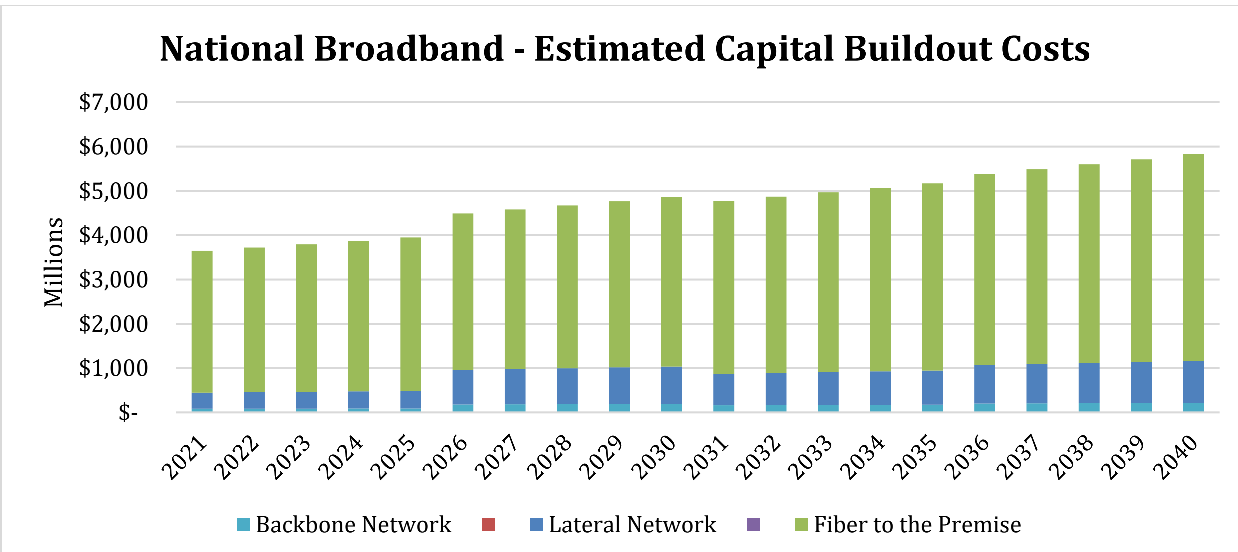

Figure 0-12: National Broadband – Estimated Capital Buildout Costs

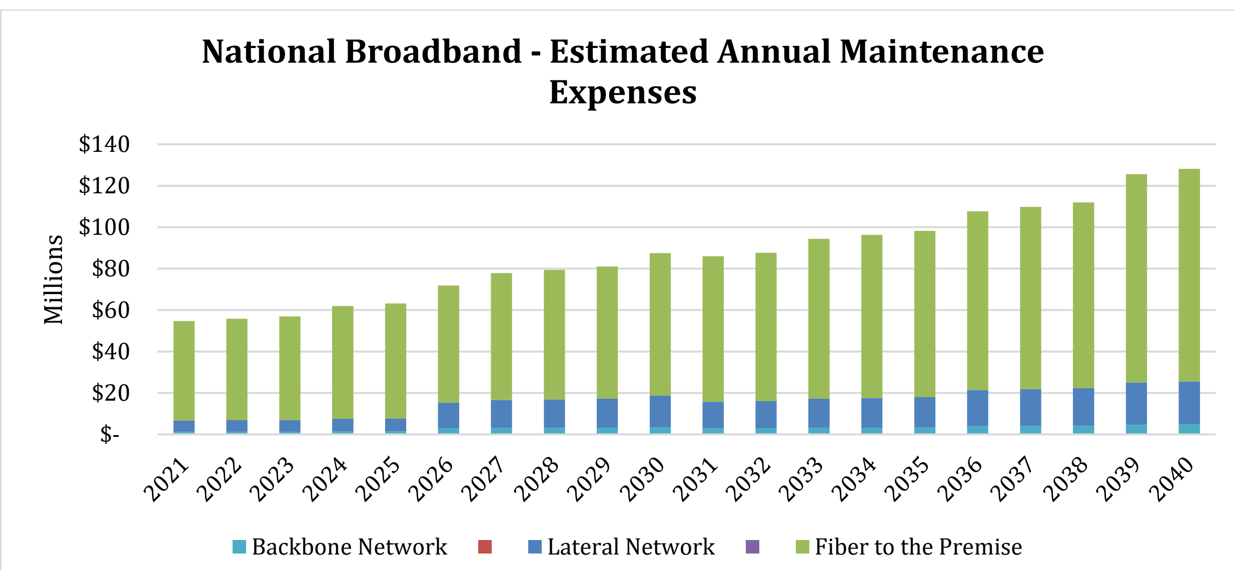

Figure 0-13: National Broadband – Estimated Annual Maintenance Expenses

6 ADVANCED MOBILITY

The transportation of goods, people, and raw materials is an ever-changing landscape with economic advances spurring growth in transportation needs, specifically via infrastructure. Today's transportation infrastructure relies on a backbone of investments during the 20th century that is degrading and may not address future demand, bottlenecking potential economic growth. Compounding the aging of America's infrastructure conundrum is the push for carbon-neutral forms of transportation. Although the decarbonation challenge is daunting, the re-investment needed in American infrastructure provides an opportunity to strategically align new developments with a clean, robust transportation system for the future of America.

6-1 Electric Vehicle Support

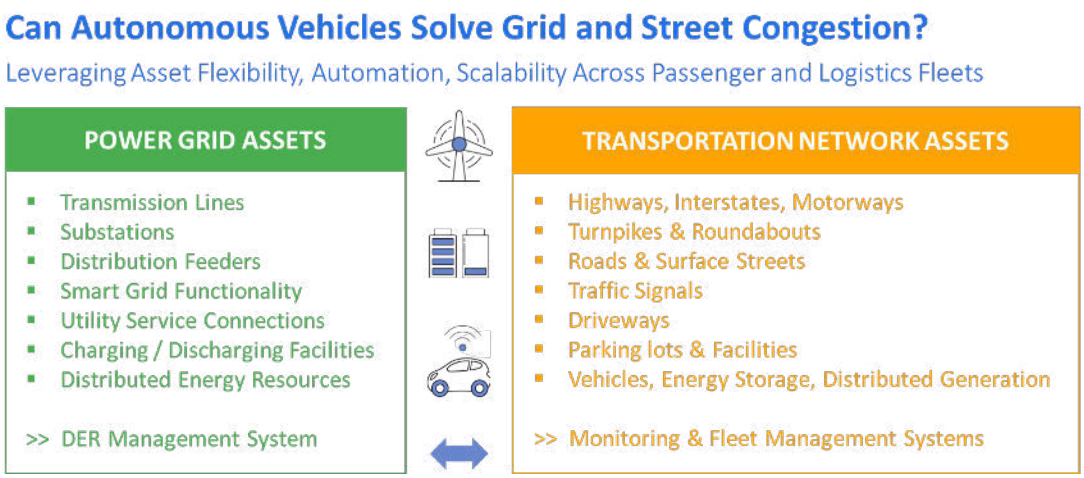

Figure 0-14: Value of Autonomous Electric Vehicles

High adoption of Electric Vehicles brings challenges and opportunities to the grid. As soon as you re-imagine these new vehicles as affordable "Intermittent Flexible Energy Storage" carriers, as well as means of transport, the opportunities open up dramatically to derive value through "Smart Charging" of the largest fleet of batteries in the United States. Smart Charging encompasses several use cases, such as delaying or expediting charging based on grid conditions and the cost of energy. In its simplest form, vehicles and charging stations have features today to program charging to take advantage of Time of Use rates offered by the host utility that encourage charging during off-peak hours. Several utilities have demonstrated Demand Response programs, the most advanced of which is San Diego Gas & Electric's dynamic VGI rate that provides pricing signals in advance based on projected supply and load down to the distribution grid feeder level. These programs have shown Electric Vehicle drivers can meet their fueling needs *and* provide benefit to the grid.

> In the future, Autonomous Electric Vehicles could further maximize local and regional grid value by not only by adjusting their charging patterns but physical location on the grid.
>
> Source: Black & Veatch

Valuation models continue to evolve, including the model recently developed for the California Public Utilities Commission (CPUC). This model demonstrates that vehicles connected to the grid can provide value. Furthermore, if the vehicle is capable of bi-directional charging, so called Vehicle-to-Grid (V2G), the value can be 8 to 12 times greater due to the ability to continually import and export energy while connected.

The now famous "duck curve" which represents the rapid ramping up/down of solar production on a mild Spring day, will provide abundant and inexpensive energy that will be stored by charging vehicles in the workplace and other settings. Several studies, including *Clean vehicles as an enabler for a clean electricity grid*[58], illustrate the ability to offset grid investments with electric vehicles.

It's important to note that the batteries are already "paid for" based on their primary role as a transportation asset, thus avoiding additional capital costs. Note: Once a concern, battery degradation worries are fading as technology unlocks capacity and boosts cell durability, and best practice battery warranties and cycling techniques are adopted.

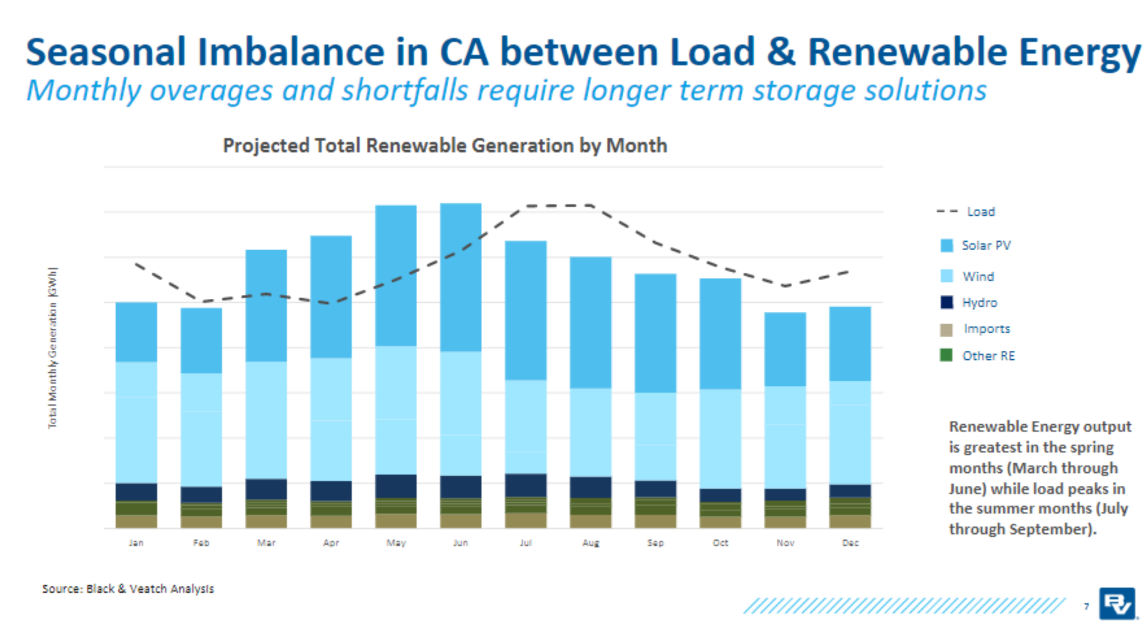

Figure 0-15: Seasonal imbalance of load and supply of renewable energy highlights the need for energy storage.

[58] https://iopscience.iop.org/article/10.1088/1748-9326/aabe97/pdf

> Important to each of these use cases is the fact that the vehicle batteries are already "paid for" based on their primary role as a transportation asset, thus avoiding additional capital costs.

High renewables adoption will require significant investments in capacity in order to account for seasonal variation. Research by Black & Veatch estimates, for example, that California could require twice the capacity to power loads across the state under SB100's 100% Renewable Energy by 2045 scenario (reference Figure 6-2). The investment can be offset substantially by the deployment of Energy Storage.

As illustrated in Figure 6-3, low cost, "Intermittent Flexible Energy Storage" provided by electric vehicles can further reduce capital and the amount of stationary energy storage required. As more of these vehicles become bi-directional Virtual Power Plants, on-demand energy becomes a reality.

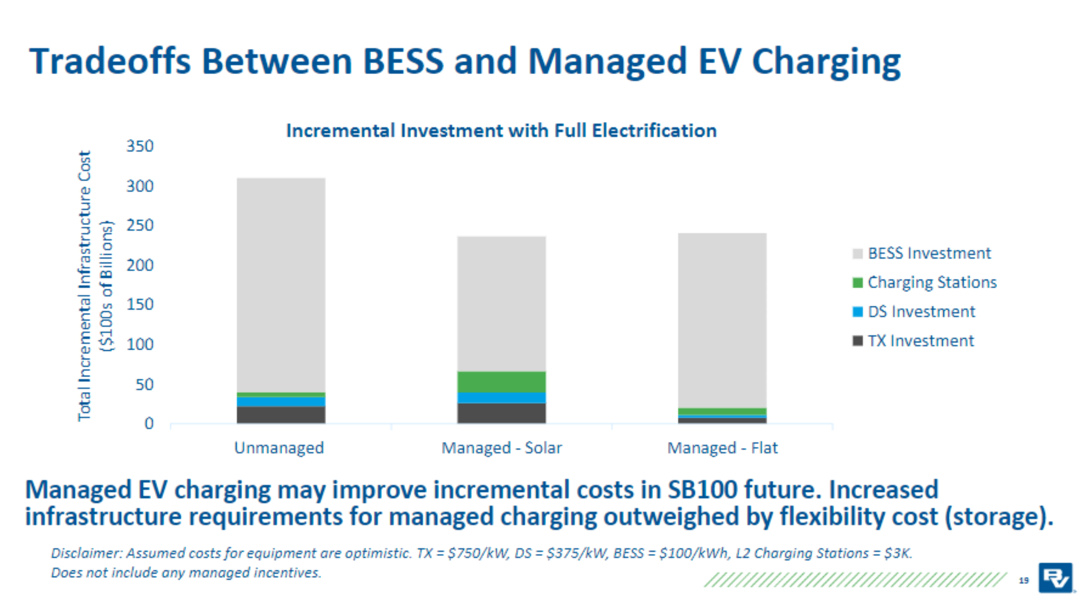

Figure 0-16: High-penetration EV can take advantage of a large portion of otherwise curtailed electricity through workplace and public charging in California to save $60. Source: Black & Veatch

6-2 Hydrogen Opportunity

The utilization of Hydrogen as a transportation fuel to further reduce emissions associated with transportation has been demonstrated for many years in light duty through heavy duty application and remains a promising choice for many transportation mediums. The technology converts the chemical fuel – hydrogen – to electric energy, with the only waste byproduct being heat and water. Utilizing small, high-powered batteries in-line with the fuel cells allows the vehicle to capture energy through regenerative breaking, resulting in a more economically optimal fuel cell operation.

Compared to electric vehicles, hydrogen fuel cell vehicles have lower total efficiency on a well-to-wheels basis.[59] However, hydrogen, once widely available in the market, is a compelling zero emission technology with the ability to significantly reduce transportation-based emissions in many applications.

Hydrogen fueling stations (at an estimated cost of $2 to 3 million each[60]) would need to be widely available along transit routes to ensure that fuel cell vehicles are not limited by refueling availability. All consumers and supply chains leveraging transportation mediums, from long haul trucks to personal vehicles, maintain the expectation of widely available refueling stations along a variety of route options. In order to consider the adoption of fuel cell technology, hydrogen fueling stations must be made widely available, starting with the major transit corridors of the interstate highway system. Some studies[61] have estimated the need to build as many as 21,000 filling stations should hydrogen vehicle penetration reach its full potential.

Barriers to the adoption of hydrogen fuel cell technology include high initial purchase costs of the on-vehicle technology, as well as high equipment costs for hydrogen production, compression, storage, and infrastructure deployment. Producing “green” hydrogen is a more cost-effective option, whereby abundant renewable electricity (which usually occurs during an off-peak time of the day) is used in an electrolyzer to break apart water molecules into their component elements of hydrogen and oxygen.

Black and Veatch has started delivering on the goal of wider availability of hydrogen fueling stations by supporting FirstElement Fuel, leveraging investments from Honda and Toyota, to build 19 hydrogen filling stations across California. In the northeast region of the U.S., Black & Veatch has designed, permitted, and installed five hydrogen fueling stations for a leading gas company, including the design and installation of an electrolyzer and the provisioning of liquid-to-gas conversion equipment at regional hub locations.

6-3 High-level estimated costs

The following high-level cost estimates are only intended to provide a relative indication of the magnitude of the infrastructure investment involved, in current 2020 dollars. This includes initial estimates of one-time capital buildout costs, plus estimates for annual maintenance expenses. No additional assumptions are made relative to equipment life expectancy (affecting capital replacement costs), improved designs and construction methods, nor to any increased efficiencies or benefit streams to offset these estimates. Additional treatment and refinement of such estimates would entail a logical next step for those who wish to further pursue economic impact assessments.

Several key assumptions were made to derive these cost estimates.

The costing of infrastructure required to electrify all transportation began with determining the total energy projected from 2021 to 2040. The EIA Annual Energy Outlook 2020: Table 7. “*Transportation Sector Key Indicators and Delivered Energy Consumption*” was used for all BTU projections going out to 2040 and was

[59] https://electrek.co/2020/04/22/daimler-ends-hydrogen-car-development-because-its-too-costly/

[60] https://h2stationmaps.com/costs-and-financing

[61] Melaina, M., B. Bush, M. Muratori, J. Zuboy and S. Ellis, 2017. National Hydrogen Scenarios: How Many Stations, Where, and When? Prepared by the National Renewable Energy Laboratory for the H2USA Locations Roadmap Working Group. http://h2usa.org/sites/default/files/H2USA_LRWG_NationalScenarios2017.pdf.

converted into kWh using an efficiency factor of around 50%, as electrified modes of transportation are more efficient using energy to propel mass[62]. For generation capacity needed to reach 100% electrification, Black & Veatch used IRENA's projection[63] to 50% electrification and doubled the values to account for 100% electrification with uncontrolled charging (no smart charging), which led to an 18% increase in generation capacity. The NREL Annual Technology Baseline was used to determine an average cost of capacity going out to 2040 that would be added outside of what capacity build out was already expected from EIA.

The remainder of costs were based off capital and operations and maintenance estimates of charging infrastructure of the eight major EIA categories. For Level 2 and Level 3 charging infrastructure, a declining factor was added to account for decreases in costs for hardware and operational costs over time, as existing technology is still relatively nascent. Forward projections of growth or declining rates of numbers of vehicles were based on historic increases from the U.S. Department of Transportation: Bureau of Transportation Statistics. The number of U.S. vehicles historical numbers were used to project future growth using historic data. In some cases, when vehicle stock data was unavailable, statistical data was sourced from various U.S. government agencies to determine a growth rate for vehicles. Hedges & Company data was used to determine a percentage of sales per category to determine the number of vehicles per EIA category.

Numerous industry forecasts suggest that the U.S. will have a high penetration of alternative-fueled vehicles, both electric and hydrogen fuel-celled. The Edison Electric Institute (EEI)[64] forecasts annual sales of electric vehicles (EV) of 3.5 million vehicles in 2030, reaching more than 20% of U.S. annual vehicle sales in 2030. Bloomberg New Energy Finance[65], with one of the more assertive EV forecasts, predicts that 57% of all passenger vehicle sales, and over 30% of the global passenger fleet, will be electric. Missing in these forecasts is the expectation that the demand for new vehicles is likely to decline in the coming decades with the advent of on-demand autonomous vehicles, transport-as-a-service business model, and the introduction of alternative transportation modes in dense urban areas. Total U.S. vehicle ownership could drop by as much as 70% by 2030[66]. If this reasoning holds true, this reduces the total number of passenger vehicles from 247 million to closer to 44 million, based on 2017 figures. For the Black & Veatch cost estimates, we apply a more conservative value of 32% reduction in the total number of passenger vehicles over the 20-year forecast period, which is derived at a declining rate of 2% annually.

Finally, despite today's higher incremental costs for hydrogen fuel cell vehicles (as outlined in section 6.2), we could assume modest adoption rates in passenger (5%), light-duty (10%), and heavy-duty (10%) vehicles, as a percentage of all vehicles. However, the all-electric vehicle scenario that drives the high-level cost estimates in table 6-1 presents a more conservative infrastructure buildout cost, until hydrogen vehicle technology reaches higher volumes and associated infrastructure costs stabilize.

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[62] https://www.fueleconomy.gov/feg/evtech.shtml
[63] IRENA (2019), Innovation outlook: Smart charging for electric vehicles, International Renewable Energy Agency, Abu Dhabi. ISBN 978-92-9260-124-9
[64] Electric Vehicle Sales Forecast and the Charging Infrastructure Required Through 2030, EEI press release, November 2018.
[65] https://about.bnef.com/electric-vehicle-outlook/#toc-viewreport
[66] Rethinking Transportation 2020-2030, RethinkX, May 2017.

Altogether, the 20-year high-level estimated costs to buildout and maintain electric vehicle infrastructure across the U.S. totals approximately $1.4 trillion, in 2020 current dollars, as shown in table 6-1. Estimated capital buildout and annual maintenance expenses for the same time period are shown in figures 6-4 and 6-5, respectively.

Table6-1: High-Level Cost Estimates for Electric Vehicle Charging Infrastructure (Total Buildout Capital and Maintenance Expense)

MOBILITY	2021-2025	2026-2030	2031-2035	2036-2040	20-YEAR TOTAL
Light-Duty Vehicles	$3,055,729,307	$34,092,639,076	$135,965,246,431	$158,167,237,053	$331,280,851,867
Commercial Light Trucks	$786,339,703	$9,754,389,362	$42,680,061,233	$54,627,682,614	$107,848,472,912
Bus Transportation	$624,211,586	$6,343,019,122	$23,564,659,670	$25,174,098,715	$55,705,989,093
Freight Trucks	$8,284,953,789	$94,977,464,418	$389,754,730,698	$443,282,267,003	$936,299,415,907
Mobility Total	***$12,751,234,385***	***$145,167,511,978***	***$591,964,698,032***	***$681,251,285,385***	***$1,431,134,729,780***

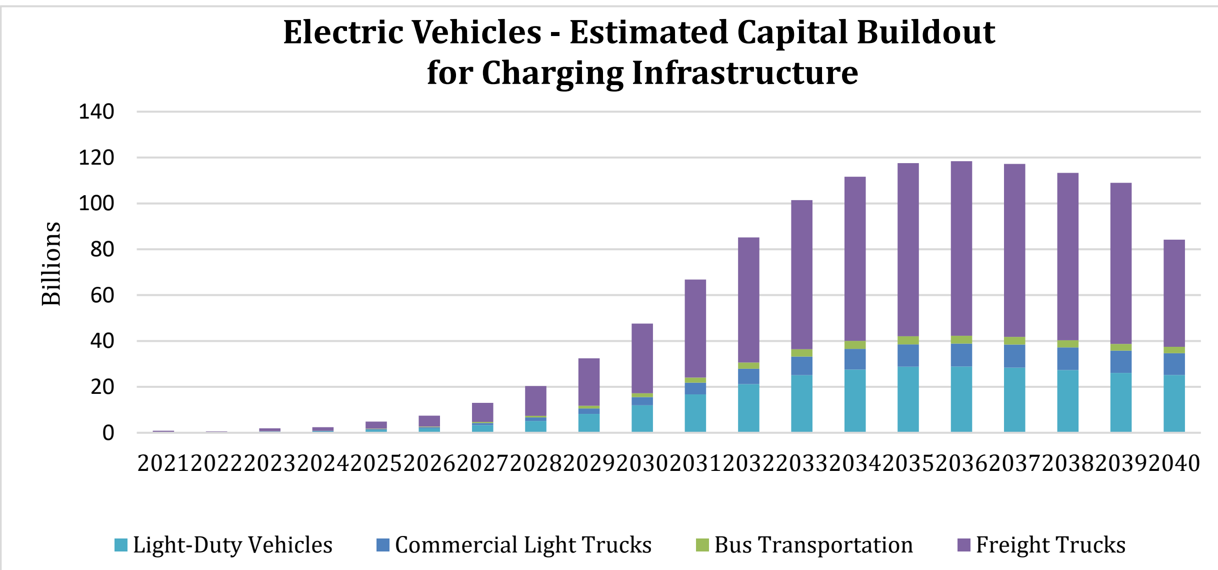

Figure 0-17: Electric Vehicles - Estimated Capital Buildout for Charging Infrastructure

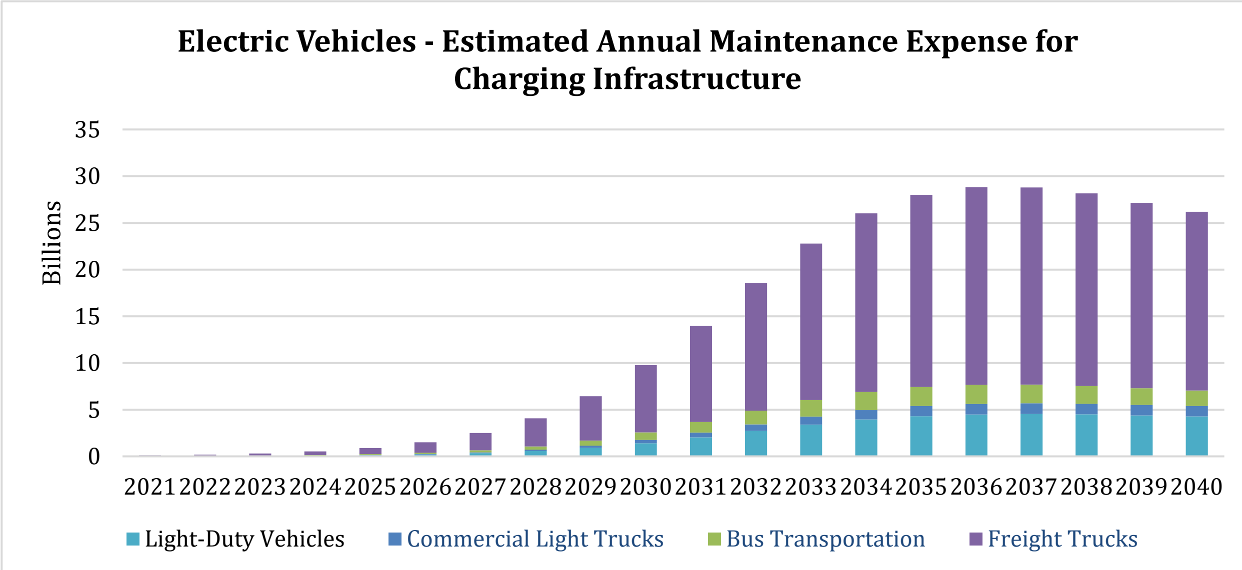

Figure 0-18: Electric Vehicles - Estimated Annual Maintenance Expense for Charging Infrastructure

6-4 Additional Electrification Considerations

On Highway Charging Hubs

In collaboration with the States, numerous Alternative Fuel Corridors have already been established. These corridors have benefited from targeted investments; however, they require significant additional investment in order to match the needs of regional and long-distance consumer and commercial traffic.

Fueling hubs of the future will be designed based on the applications and communities they serve and will be tightly coupled with their energy supply. In order to appeal to mainstream consumers, charging vehicles must be returned to the road more quickly. Future fueling hubs at travel centers along the U.S. Interstate Highway system will need to be capable of rapidly dispensing megawatts of energy consistent with the capacity of today's gasoline fueling experience. Based on specific locations and requirements, these travel centers may include EV charging, battery energy storage, renewable power generation, and integration of hydrogen fueling, comprising a microgrid design that is self-sufficient and meets clean energy standards. the four largest travel center companies[67], with more than 1730 U.S. locations currently in operation between them, already provide an ample network across the country for installing these fueling hubs of the future.

Black & Veatch is a leading contributor to the CharIN working group[68], which seeks to define acceptable standards for megawatt power levels for commercial vehicles required for these duty cycles, and regularly participates in industry forums such as those hosted by NREL [69]on Extreme Fast Charging.

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[67] Pilot Flying J (750+ locations), Love's Travel Stops & Country Stores (500 locations), TravelCenters of America (271 locations), and Roady's Truck Stops (216 locations).

[68] https://www.charinev.org/membership/members-of-charin-ev/

[69] Walkowicz, Kevin, Andrew Meintz, and John Farrell. 2020. R&D Insights for Extreme Fast Charging of Medium- and Heavy-Duty Vehicles: Insights from the NREL Commercial Vehicles and Extreme Fast Charging Research Needs Workshop, August 27-28, 2019. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-75705.

Dense Urban Hubs, Logistics

As EV availability rolls out, there needs to be additional emphasis placed on overcoming the barriers to adoption in urban environments. For example, 40% of Americans do not live in single-family homes, where a personal charger could be located[70]. Land utilization, core infrastructure capacities, and regulatory hurdles are key challenges facing broader adoption of EV technologies. Urban planners should consider the concept of designated "curb" space for vehicle parking and charging stations placed close to residences, for greater adoption of charging into normal daily routines. Ideally, multifamily buildings with onsite parking would be adapted to ensure the capability to support EV charging stations.

As noted in Section 6.1, the growing adoption of EV technology increases the demand on local electricity distribution networks. To support this increased load, urban environments will need to plan for additional distribution network transformers and associated switching equipment to support and manage the increase in power demand due to EV charging.

Multi-Modal Hubs, Ports, Airport

Logistics form the backbone of all commercial and consumer goods movement across the country and around the world. Multi-modal hubs, ports, and airports make the connections that provide access to the cost-effective options to move materials and finished products to their next destinations based on schedule.

Electrifying these mega-sites to power thousands of trucks, marine, rail, and aviation applications will require significant investment. However, it will also provide compound returns on efficiency and emission reductions in regions that often have the worst air quality.

Hyperloop Systems

Beyond the need to upgrade the nation's core infrastructure, such as power transmission and distribution and telecommunications networks, there is a continued need to develop alternative forms of transportation technologies. One of the more promising technologies that is being considered today is the hyperloop system.

The hyperloop is a form of linear infrastructure. Said to be faster than trains, safer than cars, and less damaging to the environment than aircraft, the hyperloop is a new form of high-speed surface transportation currently in development by several companies.

The connectivity is simple. It is a point-to-point transportation system for people and light freight. The system utilizes levitating vehicles (pods), which can carry passengers or freight within low-pressure vacuum structures (tubes). By reducing most of the air from the system to minimize friction and harnessing magnetic levitation technology, pods can travel at exceptionally high speeds. The system's design also results in environmental benefits, such as near-zero operational emissions, and a level of energy efficiency unmatched by current forms of mass transportation. Hyperloop moves travelers two to three times faster than high-

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https://www.nrel.gov/docs/fy20osti/75705.pdf

[70] https://www.nytimes.com/2020/04/16/business/electric-cars-cities-chargers.html

speed rail. The engineering behind hyperloop renders it immune to bad weather, resistant to earthquakes, and one of the safest modes of transportation.

While still in the early stages of development, there are limited studies to support rule-of-thumb estimates to project nationwide development costs for Hyperloop transportation systems. Based on early Black & Veatch experience, preliminary estimates can range from $30 to $40 million per mile or more. Such costs can be comparable with optional transportation choices of expanding existing highway passages or installing high speed rail. Naturally, these estimates will vary considerably across individual projects. They will also change over time as the U.S. gains experience with deploying this technology, and engineering design, construction, and supply chain economies of scale impact future projects.

Intelligent Transportation Systems

While conventional transport has been viewed in the past as a civil engineering challenge, it is fast becoming digitally enabled with communication advances. Roads no longer will be viewed as static infrastructure but, rather, an 'intelligent grid' that is integrated with the environment and it will be aware of its surroundings.

The buildout of the Continental Electricity Internet will include smart roads, smart streetlights, smart cars, electrification, and smart traffic signs. Empowered with this intelligence and sensing capabilities, these roadways will provide a level of safety that we don't currently experience. A common challenge with roads today is poor visibility of traffic signs and placement of traffic signs. Wireless digital traffic signs eliminates this challenge. Traffic monitoring officials also have the option of using drones or UAVs to help with identifying trouble spots and using broadband connectivity to interconnect the data network.

Sensors along smart roads can be used for many purposes, including monitoring gunshots, riot detection, air quality, traffic congestion, EV charging points, public safety, roadside parking, and trash and littering, to name a few examples.

Smart roads will also be able to harvest energy through several methods. Solar highway PV collectors and mechanical vibrations produced by moving vehicles that generate electrical energy and store it in battery systems are among the new smart technologies expected to come online during the twenty-year deployment of the America 3.0 infrastructure. The stored energy, in turn, can be used to power streetlights, digital signage, and traffic signals. For northern locations, this energy can also be used to melt ice and snow on the pavement.

As electric vehicles become more common, smart roads will have an electrified lane that automatically charges your car, bus, or truck for a seamless ride. Many governments are looking into magnetic induction technology. The idea is to have cables buried beneath the pavement to generate electromagnetic fields that are picked up by a receiver device in the car, creating electric energy for powering the vehicle.

The overall benefits of smart roads are greater automation, lower costs, improved public safety, increased energy efficiency, cleaner air, lower traffic congestion, fewer accidents and fatalities, and improved quality of life overall.

7 ENSURING OPERATIONAL EFFICIENCY, RESILIENCY, AND SECURITY (IOT)

Underlying all the advances discussed herein is the need for increased investment in the supporting infrastructure needed to ensure reliable, resilient, and secure continuous operation of the energy distribution network, mobility infrastructure, and telecommunications networks.

7-1 Architecture Discussion

A primary means to protect the nation's infrastructure is to align the technologies implemented with the Internet of Things (IoT), to include virtualization and containerization, standard information models and message buses, DevOps techniques, microservices, and the flexibility and scalability provided by cloud computing and fog computing. Information systems should be designed with the intent of fully leveraging the latest mobile and wired communication technologies (e.g., 5G), delivering improved communication capabilities, and the ability to safely run autonomously when communication and electricity are interrupted. Adoption of Digital Twin Asset[71] technology and adapter standards to abstract and simplify communications between remote asset types is required, in order to enable simulation capabilities for enhanced forecasting models and support distribution market capabilities.

This special form of a microservice is a critical element when scaling grid networks and Energy Systems to support millions of DER. Consider Digital Twin Agents as containers that spin up when you talk to a physical asset and go away when you are done – meters and switches are examples of Digital Twin Agent microservices that could live in the cloud and fog and come and go only when you are talking to the asset. Some Digital Twin Agents may remain resident in memory all the time if they are real-time mission critical pieces of the overall system and are likely to be physically located within or near the asset they virtualize. One major advantage to this approach is the ability to manage Digital Twin Agent container upgrades that provide additional functionality or bug fixes. The upgrade changes can be performed one time and propagate immediately out to all assets of that make and model.

These technology changes will help minimize the increase of operational costs for utilities, as well as separate operational overhead and control functions. Adoption of common standards, like IEC 61850 for substation communication, and peer-to-peer device communications standards, like OpenFMB, will be required to deliver the information necessary to operate and optimize the grid.

Digital Twin Agents provide redundancy/fail-over capabilities. They also provide distributed intelligence so that, when communications are lost, the Agents continue to operate independently in the last command set they were provided from a parent or authority Agent. This is currently a technology gap since there is no energy standard for digital twins.

New assets need to provision themselves and become active dispatchable system elements quickly and simply. The system needs to be secure and resilient to local outages and to prevent cascading events, whether the failure is device driven, weather related, or an intentional physical or cyber-attack. Transmission and distribution systems must remain in balance by leveraging both distributed

[71] https://en.wikipedia.org/wiki/Digital_twin

generation and demand response DER resources. Customers of all sizes and new business entities should be able to choose to participate in markets allowing open access. All of this must be done carefully and practically - enabling brownfield legacy assets and systems to continue to operate while the transformation occurs.

The EnergyIoT Conceptual Architecture is designed with these fundamental ideas as its guiding principles. In addition, advanced forecasting models will need to be developed at a much more localized level that enable grid operators to anticipate conditions and deliver proper market signals to incent device participation, as required to balance the grid. Standard sets of information will be required to flow between third-party and utility owned devices and grid operator systems, to feed forecasting and grid control systems. This is just one example of how standards, data models, and IT systems will need to keep pace with physical grid

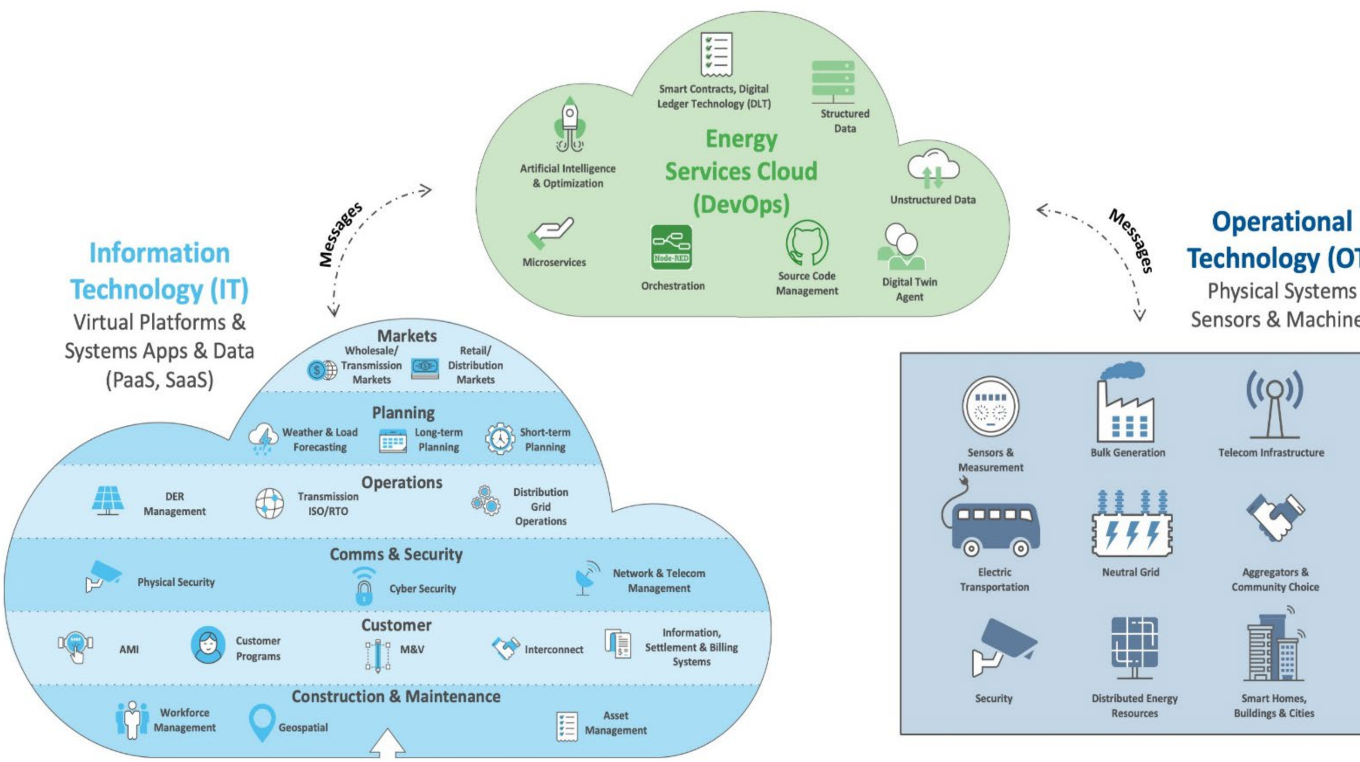

Figure 0-19: Energy IOT Conceptual Model

architecture changes to deliver a smooth transition from current to future state.

The conceptual drawing in Figure 7-1 is a simple representation of some very complex system-of-systems relationships. The Figure is abstract enough to represent a broad perspective, but also considers each of the components individually and identifies the primary roles they perform, the data they generate, and how each element interacts with other ecosystem components. The architecture is event-driven and data-centric. At its core, the architecture is loosely coupled and includes state-of-the-art security and access control techniques that minimize the probability of cascading events, due to natural disruptions or a physical or cyber-attack.

Each of the items outlined in Figure 7-1 are the domains of the conceptual architecture. The two IT domains (Energy Systems Cloud and Energy Services Cloud) include virtual components of the EnergyIoT ecosystem – software, middleware, core services, and data. The IT domains can live anywhere – on premise at utility data centers, hosted in the cloud, or deployed on physical grid assets. The OT domain includes the physical components – the grid, sensors, and machines. The physical and virtual domains work together.

Operational Security

Protecting the physical grid from sabotage, energy theft, and tampering will always be an important foundation for providing inexpensive, reliable, and safe power. The NISTIR 7168[72] standard presents an analytical framework that organizations can use to develop effective cybersecurity strategies tailored to their combinations of Smart Grid-related characteristics, risks, and vulnerabilities. This industry standard for smart grid applications may need to be expanded or amended to cover next generation grid-edge security practices.

In a data-centric ecosystem, there is the ability to inspect every bit of information as it travels through the system. The data can be filtered to check that it is within appropriate operational limits, searching for potential spoofing of an authenticated data publisher. Intelligent analytics can be trained to search for "bad actors", tampering, theft, and intrusions. Any anomalous system behavior can be detected, flagged, quarantined, and/or have a human dispatched to inspect in person. The EnergyIoT ecosystem has security designed-in that enables developers to apply the most sophisticated analytics the industry has to offer, which will continuously improve, learn, and adapt from larger and larger data sets. These capabilities will continuously evolve and learn to provide enhanced security benefits to the grid and its stakeholders.

72 https://csrc.nist.gov/publications/detail/nistir/7628/rev-1/final

8 AMERICA 3.0 JOB DESCRIPTIONS

The creation of nationwide infrastructure, as outlined in the critical components identified for America 3.0, will naturally entail the creation of new job categories during both the buildout (during implementation) and subsequent maintenance (steady-state position) of this infrastructure. Many of the envisioned, high-tech and digital-based skills outlined in table 8-1 will be different from the skills in place to build and manage today's infrastructure for the power, telecom, and mobility sectors.

While there are numerous unknown factors as to how America will fully source the large numbers of newly-skilled and re-trained workers across the U.S., we do believe that a reasonable list of expected job categories would create a starting place for further analysis. Black & Veatch views the positions and skill sets outlined in table 8-1 as a starting place for further study.

The total number of positions will depend on the final sequencing of infrastructure spending, supply chain sourcing suppliers, regional staffing availability, training facilities, and further technological advances not already envisioned as of this writing (May 2020).

Table 8-1: America 3.0 Job Categories and Skill Sets

AMERICAS 3.0 INFRASTRUCTURE PROPOSED JOB AND SKILLS CATEGORIES	DURING IMPLEMENTATION	STEADY-STATE POSITION
PROGRAM OFFICE LEADERSHIP		
Program Manager	X	
Executive Assistant	X	
Deputy Program Manager	X	
Lead Consultant	X	
PROGRAM SUPPORT		
Scheduler(s)	X	
Budget Analyst	X	
Contacts Administrator	X	X
Resource Manager	X	
Communications Manager	X	
Change Management Lead	X	
QUALITY ASSURANCE		
Vendor Management	X	
Test and Verification Supervisor	X	
Performance Analysis	X	
PLANNING		
Requirements Development Mgr.	X	
Business Case Manager	X	
Telecom/Communications Mgr.	X	

AMERICAS 3.0 INFRASTRUCTURE PROPOSED JOB AND SKILLS CATEGORIES	DURING IMPLEMENTATION	STEADY-STATE POSITION
Grid Upgrade Design & Planning	X	X
Right of Way Planning and Acquisition	X	
Regulatory support for rate planning	X	
Site Acquisition Specialist	X	
Marketing and Outreach planning	X	
FUNCTIONAL SUPPORT		
Rate Design Implementation	X	
Marketing Implementation	X	
Public Relations	X	
Technical Consulting Services	X	
NEURAL GRID OPERATIONAL TECHNOLOGY & SUPPORT		
Supply Chain and Inventory Mgmt.	X	X
Logistics	X	X
Factory Acceptance Testing	X	
Asset disposal	X	
Asset Installation Mgmt.	X	
DER Asset Installation (incl. SAT testing)	X	
Transformers (incl. SAT testing)	X	
Reclosers (incl. SAT testing)	X	
Breakers (incl. SAT testing)	X	
Net Meters (incl. SAT testing)	X	
PMU/Weather/Sensors (incl. SAT testing)	X	
Intelligent Electronic Devices (Controllers)	X	
Batteries (incl. SAT testing)	X	
Telecom/Communications	X	
Building Retrofit	X	
CLOUD DEVELOPMENT		
Use Case Development	X	X
Cloud Architect	X	
Data Modeling Architect	X	X
NoSQL / Blockchain / Data Lake Development	X	X
Generic Asset Digital Twin Development	X	
Vendor Digital Twin Development	X	X
Microservices Development	X	X
Container Development	X	X
Orchestration (Kubernetes) Development	X	X
Pub/Sub and Messaging	X	X
Interconnect Development	X	

AMERICAS 3.0 INFRASTRUCTURE PROPOSED JOB AND SKILLS CATEGORIES	DURING IMPLEMENTATION	STEADY-STATE POSITION
HAN/HEM/BEMS Interoperability	X	
Machine Learning Forecast Development	X	X
Standards & Reference Model Development	X	
Asset & Commodity Digitalization Development	X	
DER Interoperability	X	X
Cyber Security	X	X
Identity Management	X	X
Building Automation Integration	X	
HAN/Home Energy Management Integration	X	
FUNCTIONAL SPECIALISTS AND SKILL SETS		
Net Metering	X	X
Battery Integration	X	X
Solar PV Integration	X	X
Wind Integration	X	
Demand Response	X	X
ADMS/SCADA	X	X
PMU/Sensors	X	X
DERMS	X	X
OMS	X	X
Market Design	X	
Generation Dispatch	X	X
Mobility & Workforce Management	X	X
Distribution Automation	X	X
Graphics Technician	X	
GIS specialist	X	
Fiber Design Specialist	X	X
Civil/Field Engineering Specialist	X	
System Planners & Engineers	X	X
Network Architect	X	X
Asset Management	X	X
Power Quality	X	X
Physical Security	X	X
Artificial Intelligence	X	X
Measurement & Verification	X	X
Building Automation	X	X
Energy Efficiency	X	X
Electric Vehicles	X	X
Community Choice Aggregators	X	

AMERICAS 3.0 INFRASTRUCTURE PROPOSED JOB AND SKILLS CATEGORIES	DURING IMPLEMENTATION	STEADY-STATE POSITION
LEGAL, REGULATORY, AND PROCUREMENT SUPPORT		
Policy Support	X	
Legislative Analyst	X	X
Government Procurement Administrator	X	
Legal Support	X	
Stakeholder Communications Manager	X	
Regulatory Support	X	
State and Community Support	X	
Funding and Grant Coordinator	X	
Industry Association Coordinator	X	
Import/Export Coordinator	X	X
Compliance Manager	X	X

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AMERICA 3.0

THE BUILDINGS INFRASTRUCTURE

ADRIAN SMITH + GORDON GILL ARCHITECTURE

*See Appendix for a description of Adrian Smith and Gordon Gill Architecture's scope of work

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

The United States is home to over 329 million people and is the third largest Country in the World in terms of population[73]. In terms of carbon emissions, it ranks second behind China in terms of total carbon emissions and fourth, behind Saudi Arabia, Australia and Canada, in per capita emissions (China ranks 12th)[74].

While the ICT/communication sector, the electricity sector, and the mobility and logistics sector are in the process of decoupling from the fossil fuel industry, so too is the real estate sector. Commercial and residential buildings in the United States account for approximately 40 percent of the nation's total energy use[75] and 12 percent of CO2 emissions.[76]

To complicate matters, the US building stock is aging and the majority of the current building stock will still be in place in 2030. The older building stock uses more energy than newer buildings. This means that the emphasis in the real estate sector will need to be on renovating the existing buildings if America is to reach its global warming emission targets. Even here, renovations of buildings fall far short of optimizing potential energy savings, leaving the United States woefully behind in achieving a net-zero emission building stock.[77]

The global real estate market in 2015 was valued at $217 trillion, nearly 2.7 times the GDP of the world, and represents 60 percent of the investment assets of the global economy.[78] The building stock, by any account, is the most vulnerable to becoming the largest stranded asset in the coming decades. Unlike the provisioning of energy generation for electricity, the residential, commercial, industrial, and institutional building stock is locked in with only 2 percent of total property holdings turning over each year, making it the least agile global asset.[79]

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[73] United States Census Bureau, "U.S. Census Bureau Current Population", June 2020 (accessed June 6, 2020) https://www.census.gov/popclock/print.php?component=counter

[74] Union of Concerned Scientists, "Each Country's Share of CO2 Emissions", published July 16, 2008, updated May 11, 2020 (accessed June 6, 2020) https://www.ucsusa.org/resources/each-countrys-share-co2-emissions

[75] United States Energy Information Administration, "Monthly Energy Review", May 26, 2020 (accessed June 6, 2020) https://www.eia.gov/totalenergy/data/monthly/

[76] United States Environmental Protection Agency, "Sources of Greenhouse Gas Emissions", April 11, 2020 (accessed June 6, 2020) https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[77] M. J. Kelly, "Britain's Building Stock— A Carbon Challenge" (London: DCLG, 2008).

[78] Yolande Barnes et al., "Around the World in Dollars and Cents, Savills World Research", 2016 (accessed March 23, 2019) http:// pdf.savills.asia/selected-international-research/1601-around-the-world-in-dollars-and-cents-2016-en.pdf, 5.

[79] Kevin Muldoon- Smith and Paul Greenhalgh, "Understanding Climate- related Stranded Assets in the Global Real Estate Sector," Stranded Assets and the Environment: Risk, Resilience and Opportunity, ed. Ben Caldecott (London: Routledge, 2018), 154; Kevin Muldoon- Smith and Paul Greenhalgh, "Suspect Foundations: Developing an Understanding of Climate- Related Stranded Assets in the Global Real Estate Sector," Energy Research & Social Science 54 (August 2019), 62.

It is estimated that to maintain the temperature of the planet under the 1.5 degree Celsius redline set forth by the UN Intergovernmental Panel on Climate Change, the nation's building stock will need to be retrofitted to save current energy use.

California has established an aggressive agenda to decarbonize its building stock, which should be replicated across America. In September 2018, Governor Jerry Brown signed a bill into law that prepares the ground for reducing greenhouse gas emissions from California's existing residential and commercial buildings by 40 percent below 1990 levels by 2030.[80] The California Public Utilities Commission is also preparing initiatives that will ensure that all "new" residential buildings be zero net energy by 2020 and all commercial buildings be zero net energy by 2030.[81]

Buildings in the future will no longer be passive walled-off private spaces but, rather, potentially actively engaged nodal entities sharing their renewable energies, energy efficiencies, energy storage, electric mobility, and a wide range of other economic and social activity with one another at the discretion of their occupants. But, the laying-on of all of the digital infrastructure depends first-and-foremost on decarbonizing every building.

Millions of existing buildings will have to undergo a complete retrofit to seal interiors, minimize energy loss, optimize efficiency, and buttress structures to be resilient to climate-related disruptions. Gas and oil heating, which is a big source of global warming emissions in buildings, will need to be replaced by electrical heating powered by green energy across the residential, commercial, industrial, and institutional building stock. The return on a building's retrofit investment in energy efficiency and energy savings takes place over relatively few years, after which the owner or renter enjoys a reliable stream of savings on energy costs for decades.[82]

Transforming the building stock also means millions of jobs. Each $1 million of spending on the manufacture and installation of building improvements generates 16.3 jobs when adding together direct employment, indirect employment, and induced employment.[83]

Building retrofits are absolutely necessary to decarbonize the American and global economy. A cautionary note…the International Renewable Energy Agency (IRENA) projects that stranded assets in a fossil fuel dependent global building stock could reach $10.8 trillion over the coming decades.[84]

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[80] Assembly Bill No. 3232, "Chapter 373", Cal. 2018 (accessed March 23, 2019) https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml ?bill_id=201720180AB3232.
[81] California Public Utilities Commission, "Zero Net Energy", 2020 (accessed February 8, 2019) http://www.cpuc.ca.gov/zne/
[82] Jeremy Rifkin, "The Green New Deal", (New York: St. Martin's Press, 2019)
[83] Heidi Garrett- Peltier, "Employment Estimates for Energy Efficiency Retrofits of Commercial Buildings", University of Massachusetts Political Economy Research Institute, 2011 (accessed March 24, 2019) from: https://www.peri.umass.edu/publication/item/426-employment-estimates-for-energy-efficiency-retrofits-of-commercial-buildings, 2.
[84] Ben Caldecott, "Introduction: Stranded Assets and the Environment," in Caldecott, Stranded Assets and the Environment, 6.

What if we could tap into the latent potential of the United States by using the existing built environment as a carbon asset?

What if we could redefine energy as a commodity to be traded between buildings, neighborhoods, cities, and rural communities?

What if we could transform The United States of America's electric utility grid into a net zero carbon distributed network?

Today, we know that moving forward in a sustainable manner requires more than simply building new energy-efficient buildings or increasing the number of hybrid cars on our roads. We must make significant, demonstrable changes to our existing urban, suburban, and rural landscapes, altering not only how our communities look but how they operate.

An urban ecosystem relies on the smooth integration of each of a city's elements. Smart buildings rely on smart transit networks; smart energy systems rely on the creation of smart, distributed, and decentralized infrastructure. The America 3.0 infrastructure transformation aims to improve the performance of every major metropolitan system to create a healthier, more sustainable, more livable, and more resilient country.

The America 3.0 infrastructure transformation aims to simultaneously reduce the carbon emissions of American communities while creating smart digitally-enhanced and vibrant urban, suburban, and rural environments. The initiative requires a distributed, continental infrastructure that improves the economic and cultural vitality of each of our neighborhoods from an energy and carbon perspective. The decarbonization of society makes possible the continued viability of metropolitan areas and rural communities, with the assurance that quality of life can continue to improve in an ever more environmentally sustainable and resilient society.

A strong decarbonization plan addresses more than energy use and carbon emissions; it also addresses the state of the existing building stock. The transformation of building stock creates an opportunity for a paradigm shift in the way citizens engage with their communities. The creation of new parks and public spaces, improvements to both the existing infrastructure and the integration of new methods of transit, the growth of community action groups and the education of our younger citizens are all critical components of a strong decarbonization plan.

The current building stock consumes much more energy than necessary, largely due to the age of the majority of structures. Still, it does not make economic or ecological sense to demolish and replace the real estate that has been developed over the past 100 years.

Upgrading existing buildings will both reduce carbon emissions and ensure their future economic viability. Beyond aggregate efficiency savings for owners and tenants, changing the building stock to be sustainable creates an opportunity for a shift in the economic culture of real estate. By their transformation into high-performance zero-emission structures, aging buildings increase in value and tap into the potential to transfer excess energy loads back to the grid—all while offsetting the need for new construction.

In addition to upgrading of buildings, there are numerous parallel initiatives that need to be undertaken including a reassessment of real estate and land use; the positioning of Smart Infrastructure to connect buildings; an exploration of digital systems designed to optimize resource performance; a re-look at mobility in an era of autonomous electric vehicles and car-sharing services in which buildings serve as transport hubs and are equipped with batteries to store power and fuel electric and fuel cell vehicles as well as send surplus electricity back to the electricity internet to share with other buildings across the country; an assessment of the infrastructure that connects the IoT building stock with transit and intermodal connectivity; and a prioritizing of existing and new energy sources.

Unfortunately, these issues are often addressed independently and in silos when, in fact, they need to be viewed as components of an integrated system – a smart distributed Continental Electricity Internet – that can advance beyond offering only “short term” technological fixes and, rather, identify sustainable innovative methods for how we can better use energy and increase aggregate efficiencies to mitigate climate change and create a more resilient society.

The goal of America 3.0 will be to connect the green Continental Electricity Internet with the residential, commercial, and industrial building stock. Each building will be retrofitted and transformed into an IoT smart node and edge data center, micropower generation site, energy storage facility and charging station for electric vehicles – every building, in essence, becomes a mini smart infrastructure that connects across a seamless IoT nodal building stock that spans the country and serves as an extension of the Continental Electricity Internet, Mobility and Logistics Internet, and ICT/Telecom Internet.

In the United States, buildings account for an average of 40 percent of carbon emissions – approximately three times that of Automobile emissions. This number varies depending on density and a host of interrelated systems which contribute to efficiency and carbon footprint.

New buildings represent only approximately 3% of the building stock, with less than 6% of the commercial buildings in 2012 being built after 2008[85]. Therefore, even if every new building was to be net zero energy, and carbon neutral, it would be impossible to reverse the current trends of emissions. Retrofitting the existing building stock is the only practical approach toward a sustainable and resilient future. Retrofit procedures should transform the existing building stock into a more agile and connected network system comprised of structures that enjoy symbiotic relationships and produce and share energy across a seamless nodal building stock. These platforms can reduce demand load and distribute energy use to be far more adaptive to unpredictable disruptions than the centralized energy feed systems that we have today.

[85] United States Energy Information Administration, "A Look at the U.S. Commercial Building Stock: Results from EIA's 2012 Commercial Buildings Energy Consumption Survey (CBECS)" March 4, 2015 (accessed June 6, 2020) https://www.eia.gov/consumption/commercial/reports/2012/buildstock/

2 BUILDINGS

In large cities such as Chicago, the energy demand on buildings can represent more than two-thirds of total carbon emissions.[86] Modern lifestyles dictate the use of complex technological systems and conveniences in ways that significantly increase our reliance on power supply. But as we move further into the 21st century, there exists a strong opportunity for a paradigm shift: **the transformation of buildings from power consumers to power generators.**

We currently have the technology to transform the existing building stock from being a significant part of the carbon problem into becoming the bedrock of the carbon solution. In Chicago for example, buildings account for upwards of 70 percent of carbon emissions. As in many cities, this disparity is caused by the fact that although Chicago's transportation footprint is relatively small, as in many cities of a similar age, many buildings still operate using inefficient systems supported by an ageing infrastructure that has a high energy demand.[87] According to the US Energy Information Administration (EIA), in 2018 "the residential and commercial sectors accounted for about 40% (or about 40 quadrillion British thermal units) of total US energy consumption".[88]

Even without significant improvements to the buildings and to the energy grid that supports them, with cutting edge smart technology we can look at the energy demand profile throughout the day and adjust systems within buildings so that they operate at times when the grid is at its cleanest. For example, the EPAs eGRID data for 2018 indicates that the total average emissions for the electricity grid sub-region serving Chicago is 1174 lbsCO2e/MWh. Yet, at peak time, this number shoots up to 1840 lbCO2e/MWh[89]. Just by 'levelling the peak' it is likely that significant reductions in CO2 emissions could be realized. This could be a first step, but much more is needed.

In 'Toward Zero Carbon: The Chicago Central Area Decarbonization Plan'[90], Adrian Smith + Gordon Gill Architecture analyze building carbon emission and energy usage by first examining the building components responsible for the majority of energy use:

- The building envelope
- Lighting systems
- HVAC systems

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[86] Adrian Smith + Gordon Gill Architecture, "Toward Zero Carbon: The Chicago Central Area Decarbonization Plan" (2010), 21.
[87] Adrian Smith + Gordon Gill Architecture, "Toward Zero Carbon: The Chicago Central Area Decarbonization Plan" (2010), 22.
[88] United States Energy Information Administration, "Frequently Asked Questions (FAQS) How much energy is consumed in U.S. residential and commercial buildings?", May 14, 2019 (accessed June 6, 2020) https://www.eia.gov/tools/faqs/faq.php?id=86&t=1
[89] United States Environmental Protection Agency "eGRID Summary Tables 2018", March 9, 2020 (accessed June 6, 2020) https://www.epa.gov/sites/production/files/2020-01/documents/egrid2018_summary_tables.pdf
[90] Adrian Smith + Gordon Gill Architecture, "Toward Zero Carbon: The Chicago Central Area Decarbonization Plan" (2010), 38.

- Hot water
- Vertical transportation systems
- Plug loads

They also determine how modifications to those systems could improve building energy performance. By examining different building types that make up the majority of buildings such as Heritage (1880-1945), Mid- Century Modern (1945-1975), Post-Energy Crisis (1975-2000) and Energy Conscious (2000-to date), we can look at a guide for the advantages and disadvantages of energy retrofits in each building type.

Over the past decade, many more buildings have been retrofitted than in previous periods, which means that more aggressive strategies will encourage an increasing number of buildings to be retrofitted in the years ahead in order to reach overall carbon reduction goals.

At the same time, new, energy-efficient buildings are being erected every year, with many more under construction or in design. But, as already mentioned, new buildings account for only 1 - 3% of the entire building stock in urban areas and remain only part of the solution.[91] To address the millions of metric tons of carbon dioxide (CO2) emitted by buildings every year, we must look at sustainable modernizations of existing buildings across the United States.

Commercial buildings typically have higher energy loads than residential buildings. Overall, a combination of density, building size, and building use contributes to a city's high percentage of building carbon emissions. On the other hand, it is important to understand that higher efficiencies of energy use occur in more dense areas. In addition, a bundled approach to energy sharing, such as campuses where distribution can be on-demand, see even greater efficiencies. In order to expand this concept, a fully integrated and connected network of smart IoT buildings, communities, and cities where a fully distributed intelligent network is communicating at all times, would be highly beneficial.

Given the recent health concerns brought on by the spread of the COVID-19 virus, it will become ever more important to establish an IoT sensor network within and across the building stock to identify viral hot spots and improve mitigation. We need to better understand how we can decrease density within cities, rather than create a time-bomb waiting for the next infectious disease outbreak.

In 2008, The Chicago Climate Action Plan (CCAP)[92] stipulated that Chicago should reduce its carbon emissions in half of the commercial building stock to 30% by 2020, a total equivalent to 4.6 million metric tons of carbon dioxide (4.6 MMTCO2e) each year for the entire city.

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[91] United States Energy Information Administration, "Annual Energy Outlook 2020", January 29, 2020 (accessed June 6, 2020) https://www.eia.gov/outlooks/aeo/

[92] City of Chicago, "Chicago Climate Action Plan", 2008 (accessed June 6, 2020) https://www.chicago.gov/content/dam/city/progs/env/CCAP/CCAP.pdf

The architecture 2030 Challenge[93], supported by the American Institute of Architects 2030 Commitment, also stipulated a much larger carbon emission reduction of 80% in all new buildings and major renovations by the year 2020 and sets the goal of carbon neutrality by the year 2030. The most recent data published for 2018 by the American Institute of Architects shows that the average reduction of energy is at 46% which is lagging behind the 2018 goal of 70%[94] and illustrates the urgent need for pressing action. For the Chicago Loop pilot area, studied in the Chicago Central Decarbonization Plan, it was proposed that the goal of a 30% average reduction be set for all buildings.

To meet this goal, the City would need to reduce building emissions by 0.8 MMTCO2e. Additional savings mandated by the 2030 Challenge would need to be made up using methods including land use, transit, waste and water as well as a through using a significant amount of off-site renewable energy.

In 2017, Mayor Rahm Emanuel announced that Chicago had reduced its carbon emissions by 7% from 2010 to 2015[95]. In his statement, he declared this reduction in greenhouse gases came at the same time Chicago saw a 25,000 person increase in its population and 12 percent growth in the region's economy and jobs within the city. He noted the emissions reduction, equivalent to shutting down a coal power plant for 8 months, compares to a 1 percentage increase in nationwide emissions from 2009 to 2014.

The Mayor noted that in an earlier 2015 emissions inventory conducted for the city that Chicago generated 30.9 million metric tons of carbon dioxide equivalent in 2015, compared to 33.3 million in 2010. On a per capita basis, emissions were reduced by 8%. The most significant reductions came from the energy used in buildings and construction. Together, the energy used to power residential, commercial, and institutional buildings comprises 73% of Chicago's greenhouse gas emissions, and emissions from this sector have been reduced by 10%. Mayor Emmanuel concluded that many of the decreases are due to lowered electricity consumption as well as switching to a less carbon-intensive fuel mix to power the electricity supply.

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[93] Architecture 2030, "The 2030 Challenge", 2018 (accessed June 6, 2020) https://architecture2030.org/2030_challenges/2030-challenge/

[94] America Institute of Architects (AIA) "2030 by the numbers: The 2018 summary of the AIA 2030 Commitment", September 2019 (accessed June 6, 2020) http://content.aia.org/sites/default/files/2019-10/AIA_2030_BytheNumbers_2019.pdf, 2.

[95] City Of Chicago Mayor's Press Office, "Mayor Emanuel Announces 7 Percent Reduction in Chicago Carbon Emissions as Emissions Increased Nationwide", January 24, 2017 (accessed June 6, 2020) https://www.chicago.gov/city/en/depts/mayor/press_room/press_releases/2017/january/7_percent_reduction_in_emissions.html

3 POLICIES

Strategies to encourage retrofitting across each state should include consistent means of benchmarking as well as comparisons of other systems. Governing jurisdictions also need to set appropriate standards through codes and retrofit policies that define specific targets. Creating policies whereby existing buildings benchmark their energy use intensity would be a meaningful approach to retrofit policy. This will identify the buildings with the most energy savings opportunities and position owners, managers and users of low performing buildings to report how much energy they are using.

In order to achieve advanced standards of carbon emissions, specific goals for building emission reduction across the country would need to be set.

The European Union has established a protocol that our municipalities, states, and counties might want to adopt, called the Energy Performance of Buildings Directive; it provides a mechanism for monitoring, incentivizing, and penalizing all the parties that need to be engaged in retrofitting the building stock, installing renewable energy on-site, and creating a smart energy infrastructure with adequate energy storage. This law mandates that every building across the twenty-seven member states hold an Energy Performance Certificate and be responsible for monitoring its own heating and air conditioning. Two members of the faculty of the Department of Architecture and Built Environment at Northumbria University, Kevin Muldoon-Smith, lecturer, and Paul Greenhalgh, associate professor, explain the importance of this act:

Energy Performance Certificates (EPCs) have a significant relationship with climate-related stranded assets in real estate. They are a key enabler of building improvements, as they influence decision-making in real estate transactions and provide cost-optimal recommendations for energy performance improvement. They provide the opportunity for governments to enforce minimum energy performance standards, and they are an important information tool for building owners, occupiers, and real estate stakeholders.[96]

The governments of England and Wales have used the EPCs to create an enforceable report card, called Minimum Energy Efficiency Standards (MEES), for nonresidential privately rented property. If a property's MEES score is below E (meaning it has a score of F or G), it would be illegal to rent out. A similar rule is used for residential property. Around 10 percent of residential property, worth £570 billion, and 18 percent of the commercial stock, worth £157 billion, are below the threshold. Both governments are looking at elevating the minimum threshold over time to incentivize physical improvements within buildings.[97]

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[96] Muldoon-Smith and Greenhalgh, "Understanding Climate - related Stranded Assets in the Global Real Estate Sector," 157.
[97] Muldoon-Smith and Greenhalgh, "Understanding Climate - related Stranded Assets in the Global Real Estate Sector," 158.

There are many additional and valuable benefits in issuing minimum energy efficiency standards reports: for example, publicly naming and shaming owners of substandard buildings, not to mention depreciating the value of the property on the market. Continually updated energy performance certificates issued for every building across a city, state, or nation also provide the data set that could be used to determine the value of the property for purposes of assessing property taxes, with more energy efficient properties and properties generating solar electricity receiving tax deductions and less energy efficient properties receiving tax hikes.

Unfortunately, the financing mechanism that accompanies MEES—called, interestingly enough, the "Green Deal Finance Model," which would incentivize the owners of dilapidated residential property to make the efficiency changes—was taken away by the government and never even introduced for commercial property, leaving owners with a penalty but without an incentive to upgrade their properties.[98] Again, the lesson learned over and over is that transitioning the built environment away from the fossil fuel culture and toward a green renewable energy culture, by necessity, must provide equally powerful carrots and sticks to ensure success.

Creating code requirements for existing buildings energy performance criteria has been beneficial to the reduction of energy use in buildings and overall energy consumption in many cities. Data over the past decades shows that retrofit projects make strong economic sense.

In the Retrofit Gateway Roadmap study done in Chicago, retrofits for eighteen million square feet of buildings were simulated. These retrofits yielded an investment return of approximately 5% over a 7.5 year period with an average savings of 24% of total energy.[99] These benefits range from better quality of physical space to higher energy efficiency and improved air quality and daylighting. These test projects allow for the adaptive reuse of the revenue gained for further retrofitting projects.

Implementing separate metering and providing policies that encourage buildings to meter separately can also supply information that is beneficial to analysis. Offering incentives to solve cost issues related to the installation of meters also allows tenants to pay utilities directly, and encourages better tracking and data collection for future implementation. This is the first step in a distributed energy system.

Establishing a physical network of nodal IoT smart buildings, connected to the electricity internet, will require a new smart workforce. Training a cohort of next generation skilled labor and professionals provides a talent pool for the smart retrofitting of the building stock. The introduction of green leasing practices, where tenants become more aware of their energy usage and more willing to become active energy players, will require a more aggressive personal and professional commitment and coordination.

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[98] Muldoon-Smith and Greenhalgh, "Understanding Climate - related Stranded Assets in the Global Real Estate Sector," 159.

[99] Natural Resources Defense Council "Retrofit Chicago Commercial Buildings Initiative: Best Practices Report", July 2014 (accessed June 6, 2020) https://www.chicago.gov/content/dam/city/sites/retrofitchicago/news/NRDC_Retrofit_report_productionREV_0717142.pdf

Opportunities to train operational and management staff in green practices should include regular meetings between those responsible for financing and those responsible for operations to communicate with each other to advance building efficiency and resiliency. Connecting these skill sets and interests across the range of individuals required to accomplish the network effect ensures the ability to execute this platform.

These individuals can be proactive about energy audits and appoint staff members responsible for energy savings. Growing corporate support and business community engagement will increase participation both within large organizations and across organizations through programs such as the Green Office Challenge. These pursuits also inspire healthy competition between corporations to make saving energy and reducing waste more attractive.

4 THE COMMERCIAL BUILDING STOCK

4-1 Design Solutions and Pilot Projects

It is important to encourage all buildings to realize savings using incentives already in place. However, the energy reductions needed to reach the goals set out by the Chicago Climate Action Plan and the 2030 Challenge, for example, are too aggressive to simply rely on existing incentives and on building owners to take the initiative to retrofit. More leadership and more incentives will be required to reach these goals.

The Decarbonization Plan for Chicago and other studies suggest the next necessary steps to begin a trend of retrofitting buildings across the country using a standardized approach to design. In the Chicago example, the approach was based on a 30% savings target, by developing groups of buildings to work together as pilot projects.[100]

For the Decarbonization Study, to have the greatest chance of making a large impact in the target area, a key group of owners and operators of 83 buildings has been identified to create a pilot project, based on the largest square footages. If this group of buildings (about 70% of the Chicago Loop area square footage) can achieve a 30% to 40% reduction, this would exceed the targets set forth by the CCAP. The Chicago Loop should be a leader in reaching the CCAP goals; therefore the reduction goal of .8million metric tons of CO2 for the target area set forth in the plan is more aggressive than the average level of the citywide CCAP goal, which assumes a 30% energy savings in half of all buildings.

Options for pilot projects include the grouping of buildings into energy districts based on their commonalities in use, location, or era they were built. Dividing buildings into target districts is a sensible way to allow for smaller, more focused projects. These pilot projects, in turn, provide essential feedback data that can be studied in order to improve the retrofitting process in the further scale up of the urban building stock.

Retrofitting buildings is not only critical for the reduction of the overall carbon emissions of the city. Renovations and upgrades of the building stock enable older buildings to remain financially viable for decades to come. Once older buildings upgrade to new green standards, they are able to attract new tenants and residents that are increasingly demanding more healthy, comfortable, and efficient spaces.

Identifying and selecting major renovation solutions include:

Systems

- Building envelope upgrades or façade/ glass replacement
- Lighting and lighting control upgrades
- Mechanical system retrofit or replacement

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[100] Adrian Smith + Gordon Gill Architecture, “Toward Zero Carbon: The Chicago Central Area Decarbonization Plan” (2010), 23.

- Hot water systems
- Elevator modernizations
- Plug loads
- Stack effect mitigation (in tall buildings)
- Initiatives Commissioning, tuning or re-engineering equipment
- Existing initiatives - tying into scheduled capital improvements to leverage change for improvement

Incentives

- Identify potential incentive Programs
    - TIF Program (Tax Increment Financing)
    - Tax Credits
    - Utility provider programs
    - ESCOs (Energy Service companies)

Impacts

- Potential Short / Long-term impact
- Identify new methods/procedures that arise due to retrofits
- Lease and tenant impacts

Large impacts can be realized. As an example, the 10 largest buildings (or complexes) in the Chicago Loop account for about 25 million sf or 14% of the square footage[101]. If each one of those buildings saved 30% of its energy, nearly half of the Loop CCAP goal would be attained. If all of the 83 pilot buildings renovated to a 30% savings level, .6MM tons of CO2 would be saved, which is more than one-third of the entire city's CCAP goal for buildings.

4-2 Retrofitting the Commercial Building Stock

To consider how retrofitting of commercial buildings might look nationally requires a deep dive into national data sets. The US Energy Information Administration (EIA) is responsible for compiling the Commercial Buildings Energy Consumption Survey (CBECS)[102], but with the most recent 2018 data, unlikely to be processed until after summer 2020, for an overview of building performance as it relates to age and floor area we have to look at 2012 data. The total floor area in 2012 was 87,093 million square feet, distributed as shown in Figure .

Since 2012, according to reports prepared by the University of Michigan[103], it has risen to approximately

[101] Adrian Smith + Gordon Gill Architecture, "Toward Zero Carbon: The Chicago Central Area Decarbonization Plan" (2010), 62.
[102] United States Energy Information Administration, "Commercial Buildings Energy Consumption Survey (CBECS)", January 22, 2020 (accessed June 6, 2020) "https://www.eia.gov/consumption/commercial/
[103] University of Michigan Center for Sustainable Systems, "Factsheets", 2019 (accessed June 6, 2020) http://css.umich.edu/factsheets

95,000 million square feet, and according to the EIA's Annual Energy Outlook for 2020 (AEO2020) commercial floor space is growing by approximately 1% per year.[104]

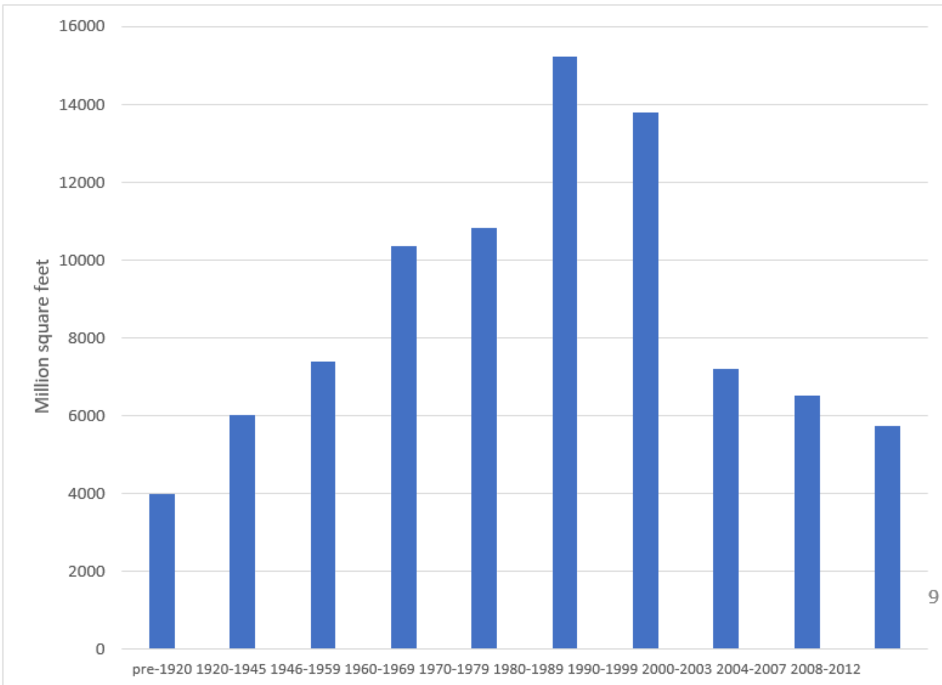

Figure 1 US commercial floor space (from CBECS 2012)

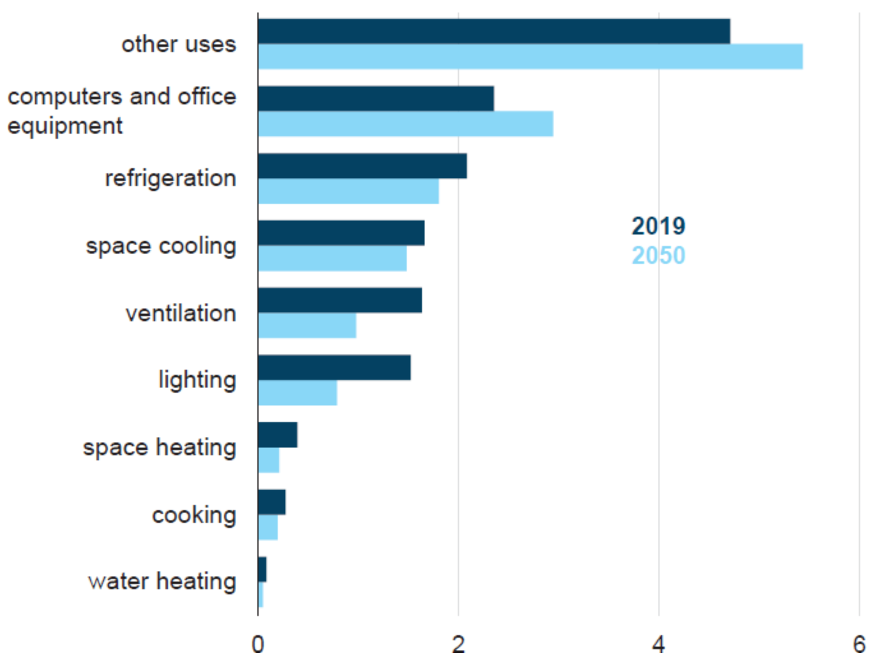

Figure 2 Commercial purchased electricity intensity (Annual Energy Outlook for 2020)

[104] United States Energy Information Administration, "Annual Energy Outlook 2020", January 29, 2020 (accessed June 6, 2020) https://www.eia.gov/outlooks/aeo/

According to the EIA, in 2019 the commercial sector's energy use accounted for 18.2 quad Btu of primary energy.[102] Figure shows the intensity of electricity use in buildings. The 'other uses' include data services, specialist medical equipment, catering equipment etc. and this number is likely to increase. Reassuringly, heating, lighting, cooling and ventilation energy use intensity is projected to decrease in the future.

However, this is mostly because of new building stock coming online. The fact remains that existing stock is by far the most abundant and most inefficient. The conclusion from this is that if we want to integrate a low carbon intelligent energy distribution network with intelligent buildings across America, then we will need to consider retrofitting existing building stock – firstly to improve the efficiency of buildings and secondly to create a local, distributed and decentralized electricity supply that can support the smart electricity grid.

Countless studies have shown that at a macro-scale it is profitable to achieve a large amount of building energy efficiency. In their case for deep retrofits - 2012 report, the Rocky Mountain Institute cites a 2009 report by McKinsey & Company that estimates that the U.S. can reduce 28% of the commercial and residential building energy consumption by 2020, saving $1.2 trillion at only a $500 billion cost. They also cite a National Academy of Sciences report from 2009 that states the U.S. can save 32% of commercial building energy use by 2030. Rocky Mountain Institute estimates the U.S. can reduce at least 38% (up to 69%) of energy consumption in buildings by 2050 for a $1.4 trillion profit.[105]

The Rocky Mountain Institute reported that the range of cost ($/sf) and performance improvement, being dependent on the age of the building and the level of retrofit, showed considerable variation, ranging from $25 - $150 per sqft (see Table 1 Sample cost and benefit data from Rocky Mountain Institute).

ENERGY USE	ENERGY REDUCTION (KBTU/SF/YR)	CAPITAL COST ($/SF)
PLUG LOAD	6-15	0
LIGHTING	6-8	3-5
VENTILATION	4-5	2-5
COOLING	10-25	10-75
HEATING	3-10	10-75
TOTAL	**30-50**	**25-150+**

Table 1 Sample cost and benefit data from Rocky Mountain Institute

To establish a cost basis for retrofitting the US commercial building stock we made the following assumptions:

[105] Rocky Mountain Institute, "Retrofit Depot: Guide to Building the Case for Deep Energy Retrofits", September 2012 (accessed June 6, 2020) https://rmi.org/wp-content/uploads/2017/04/Pathways-to-Zero_Bldg-Case-for-Deep-Retrofits_Report_2012.pdf

1. Buildings constructed between 2013 and 2021 would not be included in an efficiency retrofit program; if any upgrading is necessary this would be incorporated into the building's regular maintenance and upgrading schedule.
2. Buildings built post 2021 will meet a more stringent energy performance requirement that has an overall average of 42kBtu/SF
3. Total floor area subject to potential retrofitting is 87,093 million sq ft (CBECS 2012)
4. The cost of retrofitting ranges from $12.50 to $87.50 /sqft (adapted from RMI 2012 and AS+GG own data)
5. Based on the above, we further assumed that newer buildings would require less investment than older ones. Therefore, that retrofitting 2008-2012 buildings will cost $12.50/sq ft and retrofitting pre-1960 buildings will cost $87.50 /sqft. The cost of retrofitting buildings built between 1960 and 2008 is proportional to their age. See chart below.
6. The target energy improvement for retrofitting is to achieve an average Energy Use Intensity (EUI) of 42 kBTU/sqft/yr post-retrofit. (RMI 2012)
7. EUI of pre-2020 buildings average is 100.2 kBTU/sqft/yr (AEO 2020)
8. Energy cost savings are based on an average electricity cost of 3.9c/kBTU (13.31c/kWh)
9. Retrofitting will take place over 10 years from 2021-2030

Solar panels will be installed as part of the retrofit program, although funding will more likely be in the form of power Purchase Agreements (PPAs). To estimate the cost and energy generation potential nationally we made the following broad assumptions:

1. PV will be installed such that it provides an average of 451 MWh/yr electricity
2. 451 MWh is equivalent to 10% of an average sized office building's energy consumption.
3. Based on average US sunlight (Virginia Beach) this requires an array with installed capacity of 32kW
4. A 32kW array would typically measure less than 2,000 sqft
5. Installation of PV would take place on all new buildings and on 10% of existing buildings each year
6. PV cost data was sourced from NREL and was estimated at $2.10 per installed Watt of AC electricity
7. Average cost per installation is $67,200/building
8. Replacement of ageing (>25yrs old) PV system is not included
9. No accounting for improvement in PV efficiency has been made
10. No accounting for changes in electricity rates has been made

Financials data for the commercial sector are as follows:

1. **Total cost of retrofitting is $ 4.42 trillion with a weighted average retrofit cost of $50.72 /sqft**
2. **Total cost of PV installation is $4.3 trillion**
3. **Total energy saving from 2020-2050 is 250 Quad BTU**
4. **Value of energy saving at 3.9c/kBtu is $9.75 trillion**
5. **Potential profit = $1.03 trillion**

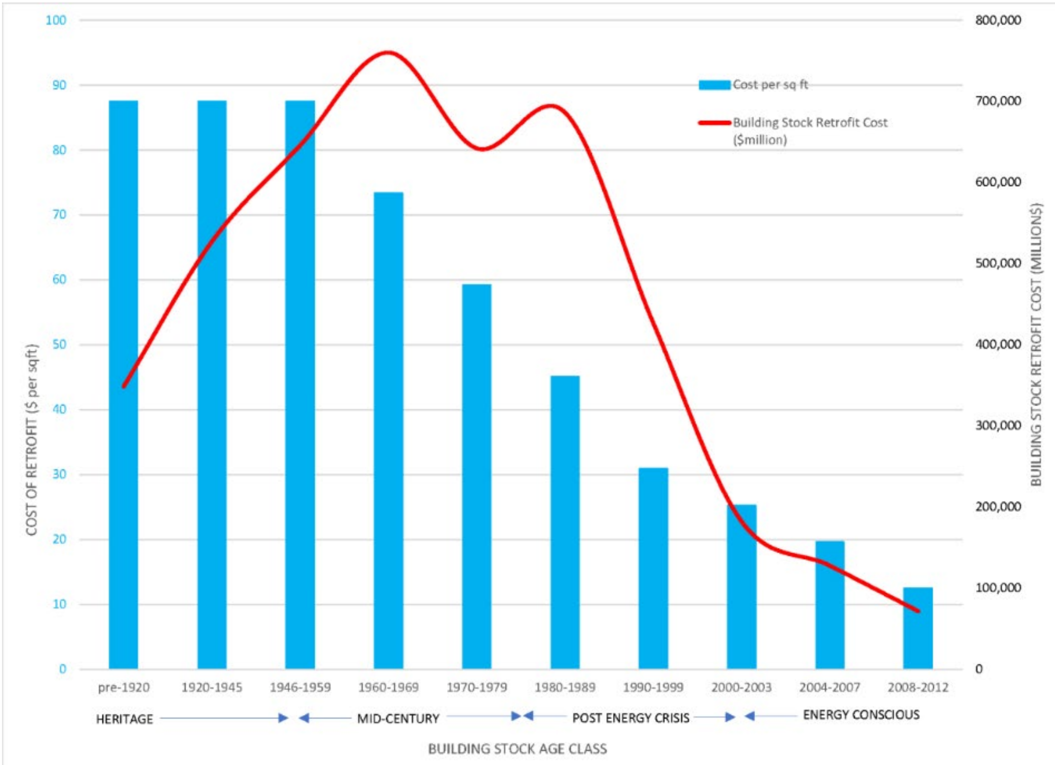

Figure 3 Cost of achieving an EUI of 42 kBTU/sqft/yr (blue bars) and the total cost of retrofitting all building stock within each age class (red line)

Although not all buildings require major renovations, a surprisingly large number will require them in the coming decade. This is because many mid-century buildings have systems that are reaching the end of their useful life and require replacement. There are also many office buildings undergoing changes in tenancy which will require office fit-outs or conversions to other uses, which will enable extensive renovations. This large number of buildings ready for renovation provides the opportunity for a coordinated, systematic response to the renewal of these systems in which energy efficiency is the overarching goal.

If these major renovations are energy-conscious, a 60% average carbon reduction goal can be realized for many large buildings. Based on data modes from the Chicago Study, 90% of the Chicago Loop square footage was designed and constructed before the 1975 energy crisis. These buildings have a great opportunity to partner with the city on their planned renovation programs to reach the aggressive energy targets.

Solutions for retrofitting buildings include:

- Electrification of heating and hot water systems
- Require buildings to track usage and energy intensity, making the data publicly available.
- Expand Energy Performance Contract (EPC) incentives or require, simple prescriptive upgrades such as LED lighting and digital, variable speed pumps and fans, regardless of whether a building

is undergoing a renovation project.

- Upgrade of building envelope (major retrofit)
- Upgrade Mechanical (heating, cooling and domestic hot water systems (major retrofit)
- Upgrade building lighting and shading systems with LED lamps and daylight controls
- Integration of intelligent and adaptive building management systems
- Require ongoing commissioning of mechanical plant
- Incentivize tenant and building occupant programs that encourage behavioral change.

An effective combination of requirements and incentives is critical for total participation. In some cases, the requirements may be a feature of the incentives.

Referencing the Chicago Decarbonization Study, the total potential savings of energy possible would mean that the Chicago Loop alone could achieve about half of the overall CCAP citywide savings goal for buildings.[106]

The advantage of using low cost, lower-savings measures is that virtually all buildings can participate. However, undertaking these programs requires dedication on the part of building management and owners and the availability of loans or allocation of existing capital budgets to energy upgrades, since the existing energy provider incentives do not cover all expenses. Reduction requirements along with increased incentives would be necessary using this method, because all buildings would need to participate.

The table below (Table 2) shows the comparison on how investment on these retrofits fare against the savings return for the commercial markets. At the beginning, the cost is higher than the return, but as the technologies get adapted and we start seeing savings in energy go up, we see large savings overall.

Table 2 Commercial retrofit investment VS energy cost savings calculations

	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050	30-YEAR TOTAL
COMMERCIAL INVESTMENT	-$4,075,830,480,000	-$4,075,830,480,000	-$412,374,851,630	-$48,715,648,057	-$50,338,644,038	-$52,001,279,142	-$8,715,091,382,867
COMMERCIAL ENERGY COST SAVING	$577,969,413,029	$1,494,031,929,337	$1,885,735,878,714	$1,886,910,073,666	$1,912,559,279,368	$1,978,349,010,027	$9,735,555,584,141
BALANCE	-$3,497,861,066,971	-$2,581,798,550,663	$1,473,361,027,084	$1,838,194,425,609	$1,862,220,635,330	$1,926,347,730,885	$1,020,464,201,274

4-3 Carbon reduction Goals

To be able to swiftly move into America 3.0, as well as follow the lead of other nations at the forefront of this effort, we need a firm goal of a 50% reduction in building emissions - commercial, residential, industrial, etc - by 2030, and a near zero-emission goal for the building stock by 2040.

Based on the proposed retrofit plans, this should be achieved: the average existing building has an EUI

[106] Adrian Smith + Gordon Gill Architecture, “Toward Zero Carbon: The Chicago Central Area Decarbonization Plan” (2010), 63.

(energy use intensity) of 100.2 kBTu/SF. Our aim is for all new buildings to be built to, and all existing buildings to be retrofitted to, achieve an EUI of 42 kBTu/SF. On top of that, the intent is that buildings will have PV installed such that they produce 10% of the average power of a 2020 benchmark building. The total energy saving is 250 Quad BTus against a 558 Quad BTU baseline, achieving a 45% energy reduction average. Due to transmission losses in the grid, carbon will be higher than that - excluding grid improvements, with PV and electrification it should be at least 55%.

This is also a realistic target for our residential building stock, as retrofit only should help achieve a 42.4% reduction in energy, which will translate to higher reductions in carbon.

5 THE RESIDENTIAL BUILDING STOCK

In 2019 69% of US families lived in single-family homes, with 26% living in multi-family buildings and 5% living in mobile homes.[107] The total number of homes was 121 million homes and total square footage was over 216 trillion square feet. The square footage is set to increase by 1% per year in 2020 falling annually to 0.86% by 2040.

Average single-family home sizes are also increasing and if the current trajectory in size continues, can be expected to be larger than 3,200 sqft by 2040 (see Figure 4).

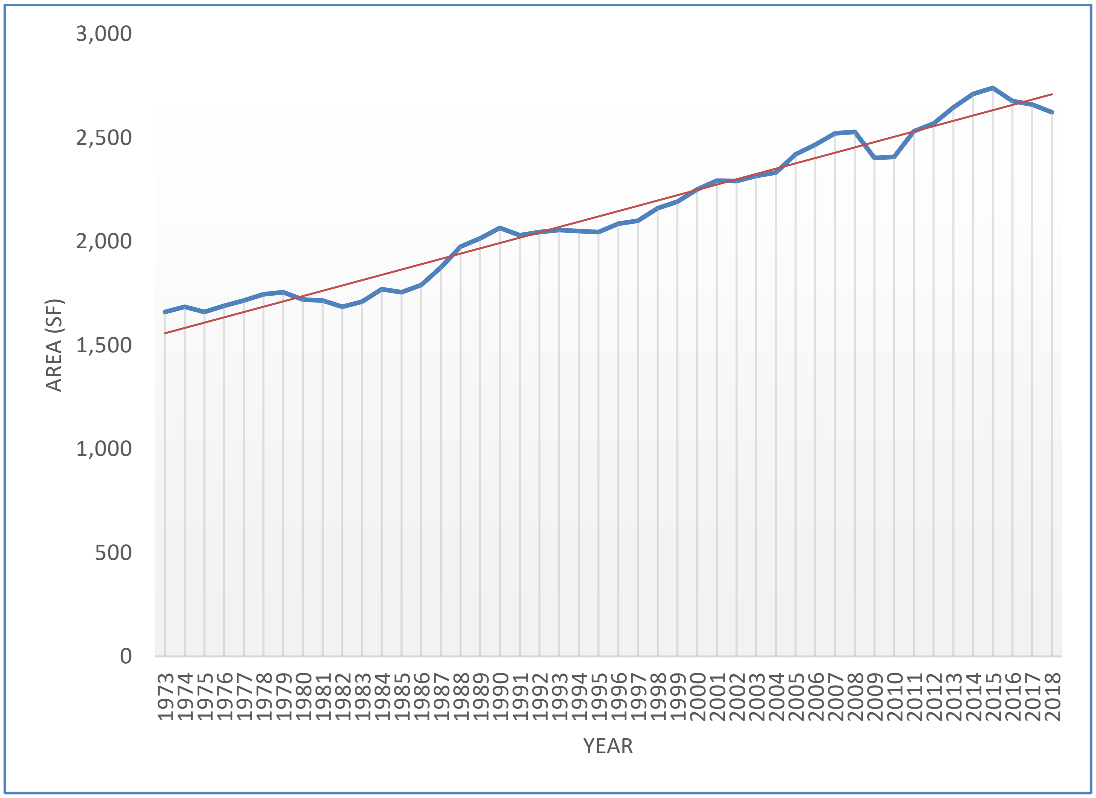

Figure 4 Average size of single-family homes in the US. Red line represents trend line (US Census data)[108]

With so much variation in residential housing stock, and a general lack of energy performance data, we must turn to macro-level data from AEO 2020 to understand the potential of America 3.0.

AEO 2020 provides a projected estimate of the growth of the residential sector. Using this data we can forecast energy usage to 2040 (see Figure 5). Clearly transmission losses are highly significant and as articulated in the infrastructure section America 3.0 seeks to address this through the deployment of a High Voltage Direct Current (HVDC) Continental Electricity Internet and local microgrids. Coupling this

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[107] United States Energy Information Administration, "Annual Energy Outlook 2020", January 29, 2020 (accessed June 6, 2020) https://www.eia.gov/outlooks/aeo/

[108] United States Census Bureau, "Median and Average Square Feet of Floor Area in New Single-Family Houses Completed by Location" (accessed June 6, 2020) https://www.census.gov/const/C25Ann/sftotalmedavgsqft.pdf

with efficiency improvements (we've assumed 2.0% per year) and conversion of all building services to all electric (air / geothermal heat pumps, tankless electric water heating etc.) we can significantly reduce grid electrical energy usage. We assumed an exponential rate of micro-grid connected roof mounted PV installation between 2023 and 2040 to provide resiliency and decentralized renewable power. Figure 6 and Figure 7 illustrate the potential of this scenario.

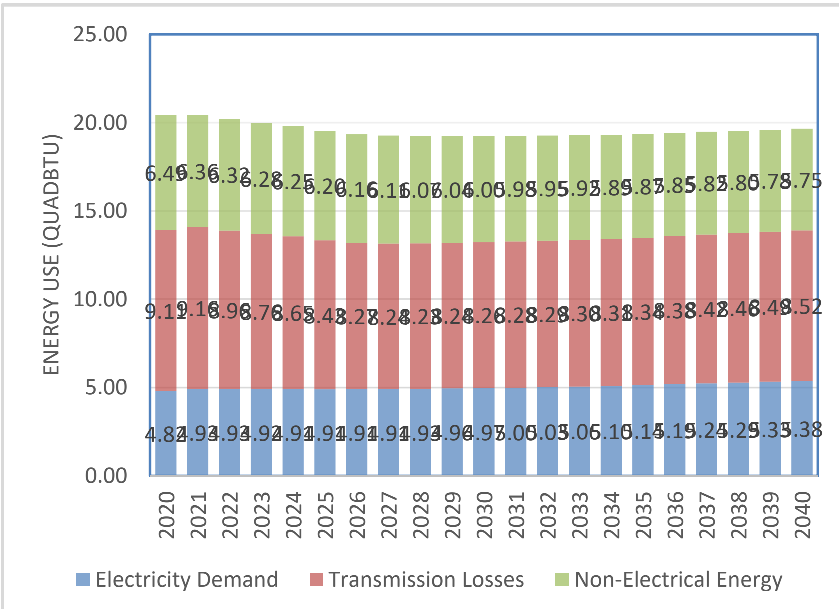

Figure 5 Projected energy consumption by the residential sector (based on AEO 2020 data)

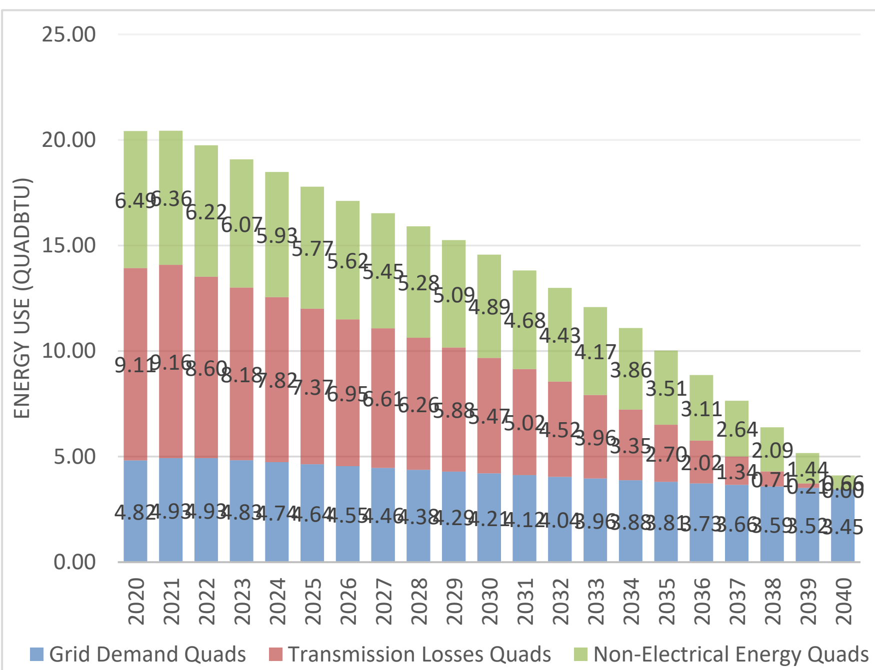

Figure 6 Projected energy consumption by the residential sector under an America 3.0 scenario

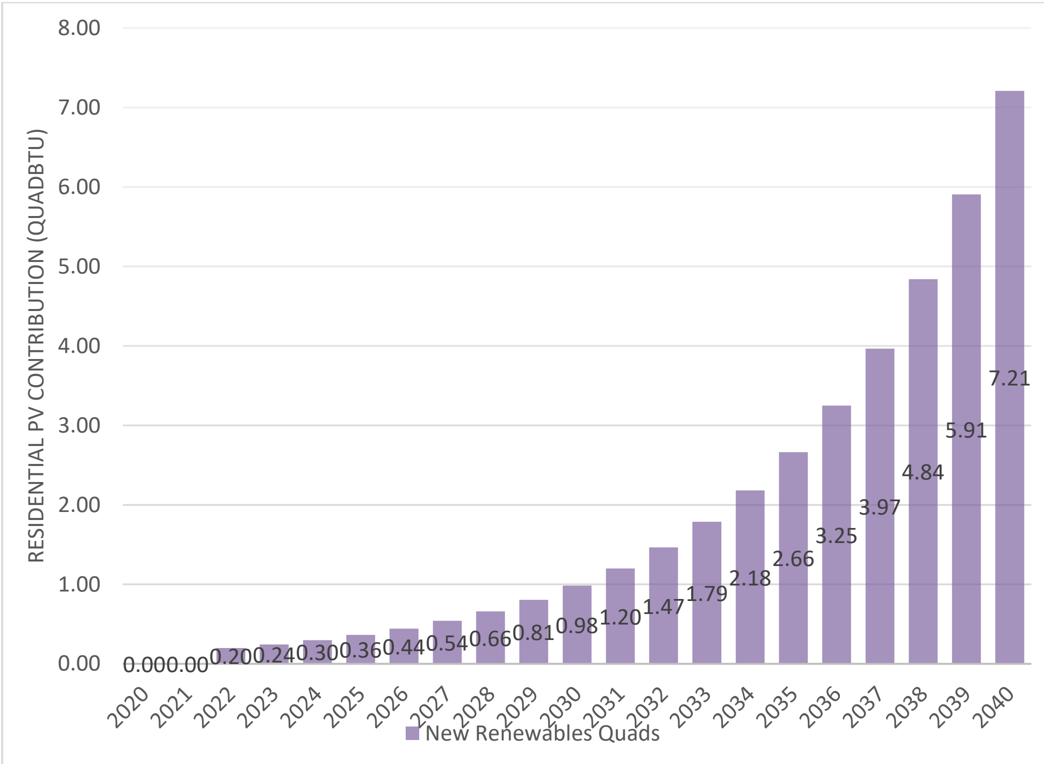

Figure 7 Projected residential renewable energy contribution under an America 3.0 scenario

Projected grid electricity savings amount to 84.28 Quad Btu by 2040, which at the current benchmark rate for electricity amounts to an annual saving of $3.29 trillion. The model is based on a 2021 retrofit cost of $45,000 per dwelling, reducing to $34,000 by 2040 (See Figure 8). Simultaneously the number of dwellings being retrofitted starts at 1.0% in 2020 and rises sharply in year 1 to account for government incentives and then exponentially to 2.7% in 2040 as market forces and lower cost of retrofitting come into play (see Figure 9). **The cost of energy performance retrofits up to 2040 is estimated to be $1.81 trillion.** Although the cost of PV, ($/Watt) may decrease slightly, this is likely to be offset by the increased 'soft' cost of installation and of other materials. Therefore, for this model we have assumed that **the total cost of installing PV remains constant over the time period and is estimated to be $1.61 trillion, giving a grand total retrofit cost of $3.42 trillion. Over the same period, cumulative energy savings are estimated to be $21.7 trillion, resulting in a balance of $18.3 trillion saved (see Figure 10)."**

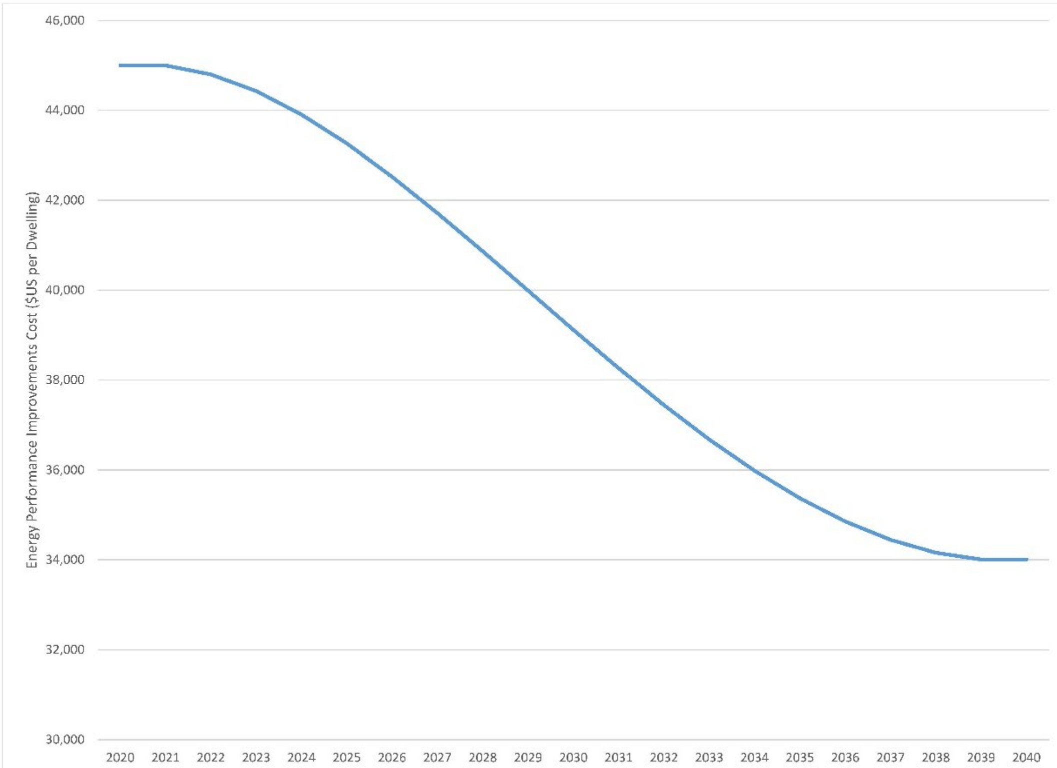

Figure 8 Residential Retrofit Cost

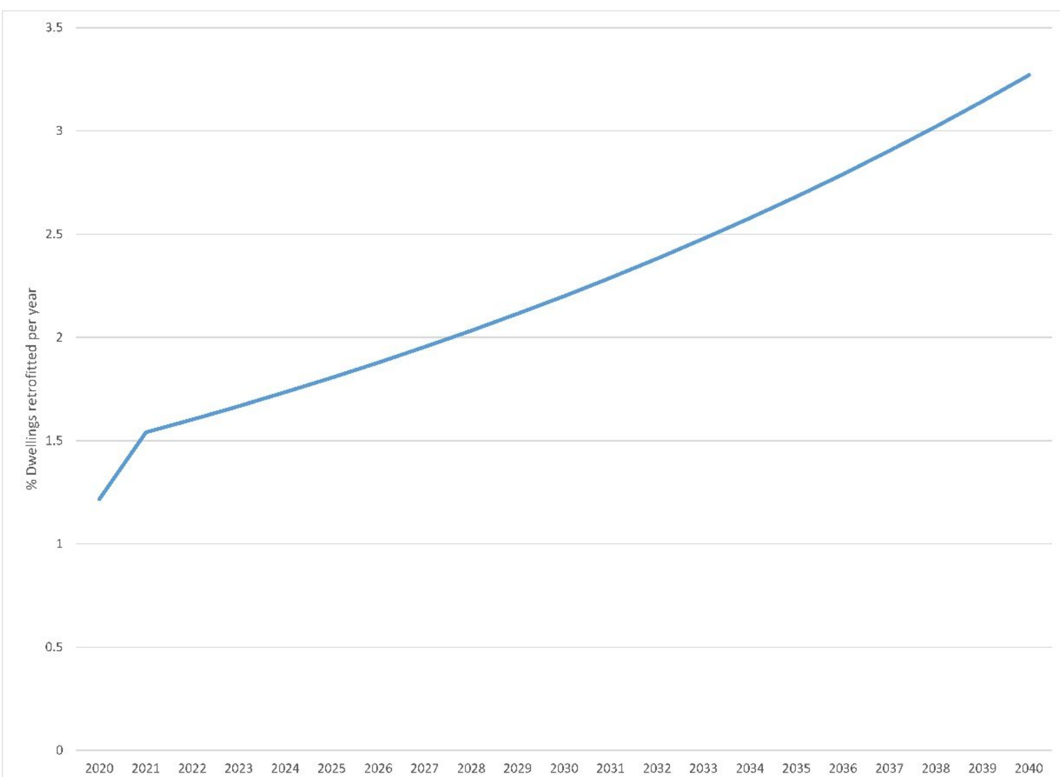

Figure 9 Residential Retrofits per Year

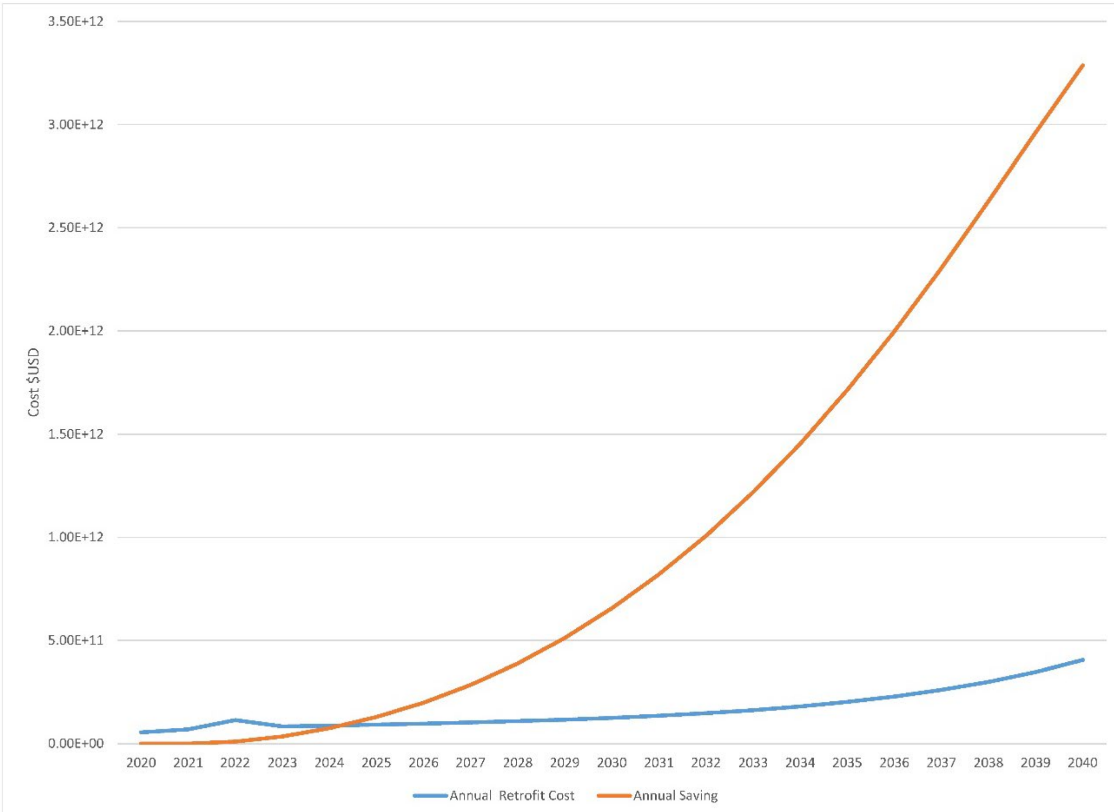

Figure 10 Residential Retrofit Cost vs Savings

Investment VS Savings

The table below (Table) shows the comparison on how investment on these retrofits fare against the savings return for the residential markets. At the beginning, the cost is higher than the return, but as the technologies get adapted and we start seeing savings in energy go up, we see large savings overall.

Table 3 Residential retrofit investment VS energy cost savings calculations

	2021-2025	2026-2030	2031-2035	2036-2040	20-YEAR TOTAL
RESIDENTIAL INVESTMENT	-$502,587,021,954	-$551,374,508,183	-$828,606,459,583	-$1,540,952,608,682	-$3,423,520,598,400
RESIDENTIAL ENERGY COST SAVING	$251,056,905,359	$2,049,505,389,930	$6,246,274,252,280	$13,250,151,357,638	$21,796,987,905,208
BALANCE	**-$251,530,116,594**	**$1,498,130,881,748**	**$5,417,667,792,697**	**$11,709,198,748,957**	**$18,373,467,306,807**

6 THE MANUFACTURING BUILDING STOCK

The most recent comprehensive survey of energy use by the US manufacturing industry was undertaken in 2014 and published in 2017 by the US Energy Information Administration (EIA)[109]. It shows a steady decline in energy consumption (see attached chart). Figure 11 shows that even as real gross output has risen above the 1998 level, both fuel consumption and total employment have fallen.

Much of the emissions reductions in the industrial sector will come from plugging into a smart Third Industrial Revolution infrastructure that will allow them to power their production with renewable energy, and manage their transport and logistics supply chains with short-haul electric vehicles powered by green electricity and with long-haul hydrogen-fuel-cell-powered transport on road, rail, and water routes. Big Data and algorithm governance of supply chains, mobility and logistics operations, and manufacturing and production processes, will also dramatically increase companies' aggregate efficiencies and reduce their carbon footprint in ever more circular business processes.

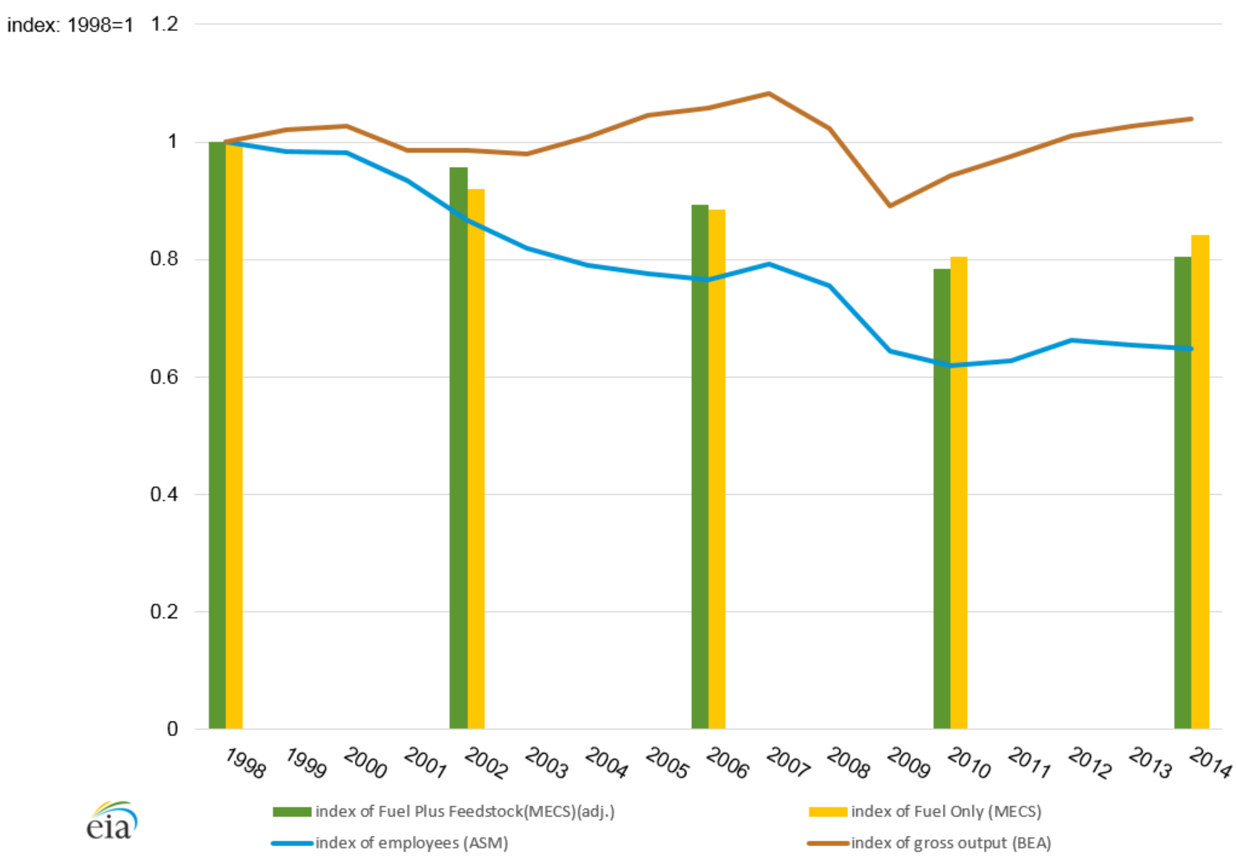

Figure 11 Relation between manufacturing output and resource use

[109] United States Energy Information Administration, "Manufacturing Energy Consumption Survey (MECS)", 2014 (accessed June 6, 2020) https://www.eia.gov/consumption/manufacturing/reports.php

Between 2000 and 2018, grid emissions factor – the average amount of CO_2 emitted in generating 1MWh of electricity fell from 626 kgCO2/MWh to 429 kgCO2/MWh (eGRID data and International Energy Agency, CO2 emissions from fuel combustion report, 2018). Thus, even without improvements in the industry, emissions would decline as a result of a 'cleaner electricity grid'.

Nevertheless, there are significant improvements being implemented at an individual industry scale, which we expect to see strengthening and continuing:

1. Increased automation and deployment of robotic and AI solutions in manufacturing
2. Heliomax solar energy for cement production – the cement industry is responsible for 8% of global CO2 emissions and heliomax can eliminate up to 50% of cO2 emissions at each facility.
3. Constantly falling prices for photovoltaic panel installations have made decentralized power generation a very attractive solution for many factories, reducing manufacturing costs, eliminating risk and reducing their carbon footprint simultaneously. Tesla's Gigafactory in Nevada is set to become one of the world's largest manufacturing facilities that runs entirely on self-generated renewable energy.
4. The Evraz Rocky Mountain Steel Mill in Colorado, one of the largest steel plants in America, announced that its electric arc furnace will be powered by electricity generated at a nearby solar farm, providing the majority of the energy it needs to produce steel twenty-four hours a day, making it the first steel mill in the world powered largely by solar energy.76 Even more dramatic, a new technological breakthrough was announced by the company Heliogen in 2019. The company used AI to manipulate mirrors reflecting the sun to a single point, producing energy with temperatures reaching a quarter of the temperature on the surface of the sun – generating the extreme heat required to produce cement, glass, steel, and other industrial products – all at a cost below the price of fossil fuels and without CO2 emissions.77
5. Energy recovery is becoming more efficient. For example, many steel mills and cement factories are able to generate their own electricity cost effectively and cleanly, using waste heat from manufacturing processes, as plants modernize either through intentional upgrades or through general maintenance. In short, we are seeing step changes in energy efficiency.

7 THE SMART IOT BUILDING STOCK

Advanced sensors distributed throughout and around the residential, commercial, and industrial building stock – the IoT – connect to a high-speed Communication Internet, a Continental Electricity Internet, and a Smart Logistics and Mobility Internet, tying the entire America 3.0 infrastructure together. Energy storage, a smart demand system, and Smart-grid systems integrate hardware, software and services to intelligently manage power demand.

Smart-grid systems allow utilities to turn off the power to certain appliances during peak times so that the utility can produce power more efficiently. Plug-in electric vehicles in homes and businesses can also store energy and send electricity back to the Electricity Internet during peak demand while being compensated, enhancing the ability of the electricity grid to meet demand at any given time of the day.

7-1 Smart Appliances

Smart appliances contain on-board intelligence that “talk” to the grid, sensing grid conditions and automatically turning devices on and off as required.

7-2 Smart Thermostats

Customers can opt to use a smart thermostat, which can communicate with the grid and adjust device settings to help optimize load management. Other smart devices could control air conditioners and pool pumps.

7-3 IoT

The communication of the smart appliances & thermostats occurs through the internet of things (IOT) that connects everything to the high speed communication network, electricity internet, and the mobility and logistics internet.

7-4 Customer Choice

Customers could be offered an opportunity to choose the type and amount of energy they would like to receive with the click of a mouse on their computers.

7-5 Intelligent Demand Management

For the Utility[110]:

- Reduce peak demand through a two-way wireless thermostat
- Events can be scheduled in advance or conducted in real time (less than 5 minutes)
- Verification of demand reduction and participation
- Leverage network operation center statistics, master data management integration and back-

[110] Adrian Smith + Gordon Gill Architecture, “Toward Zero Carbon: The Chicago Central Area Decarbonization Plan” (2010), 143.

office systems

For the Customer[110]:

- View general energy use and costs
- Receive pending notification of demand response events with opt-out option

7-6 Load Measurement and Control

For the Utility[110]:

- Measure power consumption by circuit
- Predict, control and verify load curtailment
- Real time scheduling of events
- Typical sustainable load curtailment of 1 kW-3 kW per household

For the Customer[110]:

- Savings: 10%-15% reduction on household electric bill
- Visibility: detailed circuit-level consumption data
- Control: personal energy profile

7-7 Energy Storage Per Household

For the Utility[110]:

- Stored energy at point of consumption can be discharged to provide peak power
- Currently 10 kWh of stored energy with a 3.3 kW maximum discharge rate

For the Customer[110]:

- Instant, clean, silent backup power with remote monitoring
- Protect critical and sensitive loads such as computers, refrigerators and heating systems
- Optional generator interface provides long-term outage protection
- For light commercial applications, stored energy

8 SMART GRID APPLICATIONS

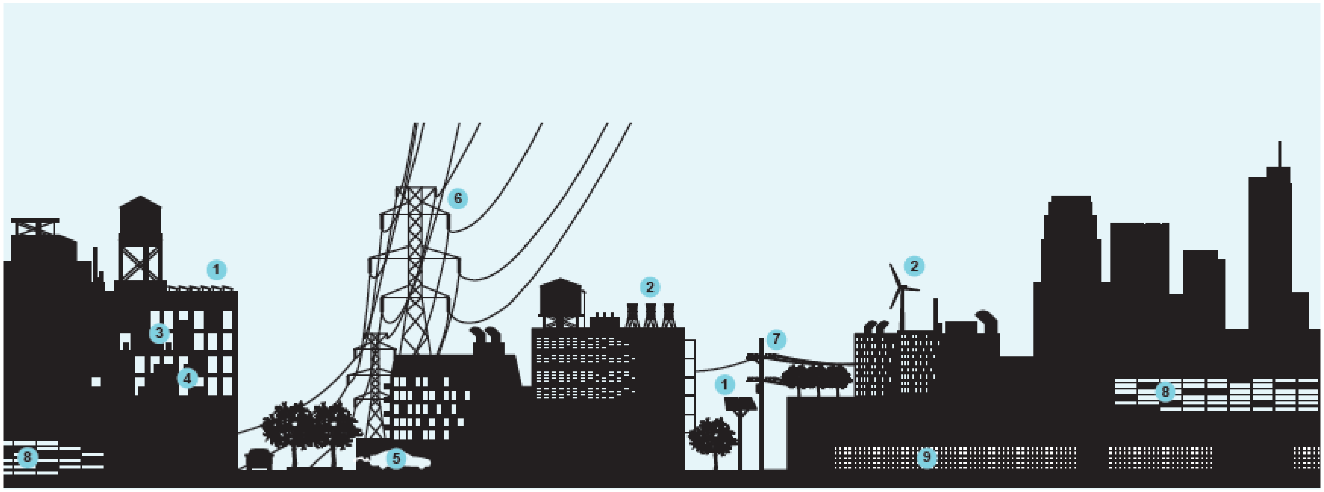

Figure 12 Smart Grid elements diagram (from Decarbonization study)

Smart-grid systems integrate hardware, software and services to intelligently manage power demand. They allow users to communicate on-the-fly information about the current price and use of electricity.

1. **Solar panels** mounted on buildings generate power during the day. If a building is generating surplus power, it can be fed back to the utility company and be reimbursed.
2. **Wind turbines** spin and generate power from air movement and are generally more active during nighttime hours. Like solar panels, wind turbines also have the potential to generate a power surplus.
3. **Smart appliances** monitor how much electricity they're using and shut down when power is too expensive.
4. **Remote control** consumers can permit utilities to control their non-essential appliances such as pool pumps, turning them on and off to fine-tune the grid for maximum efficiency.
5. **Plug-in hybrid cars** refuel using clean electricity generated locally.
6. **Locally generated power** avoids the 15%(+) power loss that occurs when electricity is sent over long distance power lines. "Superconducting" power lines route extra electricity from out-of-state utilities when demand spikes. Micro-grid systems are innovative solutions to this.
7. **Wireless chips** let individual houses communicate with utilities, swapping on-the-fly information about the current price and use of electricity.
8. **Web and mobile-phone interfaces** allow consumers to see how much power their appliances are using when they're not at home, and even to turn them on or off remotely to reduce costs.
9. **Energy storage.** When solar panels produce excess energy, it can be stored in batteries so that houses can use clean energy at night when the sun isn't shining.

9 MOBILITY

An Interconnected Low-Carbon Transit Network is critical to the overall success of a connected energy platform. While many transit routes in cities exist to bring commuters into and out of the cores, many systems lack interconnectivity and some are outdated. To steer more of the population toward taking sustainable modes of transit, Cities need to augment existing transit and incorporate new systems to accommodate commuter needs.

All systems of movement should be interconnected with the nodal IoT building infrastructure, including:

- Rail
- Bicycle Paths and Bicycle Sharing
- Car Sharing, Taxis and Smart Transit
- Underground Pedway
- Pedestrian Initiatives
- Intermodal Transit
- One-Way Car and Bicycle Sharing
- Green Corridor – infrastructure connectivity

While it may seem obvious that all mobility networks are connected, they are often siloed and not physically conducive to efficient pedestrian movement. On the larger scale of mobility, the relationships between cities, towns and rural areas across the Unites States can and should be connected utilizing existing infrastructure for multiple modes of connectivity.

The South Bend, Indiana Renaissance District Project is creating a node, connecting mobility (an existing Train Station and Rail line), data (data centers which create waste heat to energy), warehouses (to establish a seamless logistics and supply chain), fiber (a hub stretching across Indiana, Michigan and Illinois), energy (producing its own off the grid energy through photovoltaics), and education (creating start-up flexible environments for incubating smart TIR businesses).

This is the next expansion of the Building network: utilizing data centers, warehouses, and existing building stock as connective tissue across the United States to complete the smart continental network of nodal buildings, energy, communications, and mobility. Data Centers and Storage Facilities provide a logistical advantage by nature of their ability to be located in remote areas and to physically reach second and third tier communities.

By investing in distributed and decentralized energy production and storage in these remote locations, these projects provide a much-needed infill between major cities, allowing smaller towns and rural communities to plug in to the America 3.0 infrastructure. Creating a spine across the country that is connected in this way, formalizes the ability to shift resources, data and skill sets seamlessly to the benefit of every community.

10 SMART GRID INFRASTRUCTURE

10-1 Our Current Grid

The U.S. electricity grid is a remarkable infrastructure worth over $1 trillion. It includes more than 200,000 miles of high-voltage transmission lines and 5.5 million miles of distribution lines servicing hundreds of millions of end users.[111] The current technology being used to operate the US electricity grid is highly uneconomical as it is unable to store a significant amount of energy. As a result, the grid must be constantly monitored and balanced in real time throughout the day. The resulting inefficiencies lead to increased carbon emissions, as power plants run on part load conditions or lose significant amounts of energy in distribution.

Fortunately, these characteristics can be minimized with intelligent control systems. Intelligent infrastructure can also have broader implications with synergies in a number of areas such as:

- Continuous commissioning of buildings
- Reduced transmission and distribution (T&D) line losses
- Direct feedback to customers
- More effective and reliable demand response and load control
- Enhanced measurement and verification (M&V) capabilities

Energy production (and therefore carbon emissions) has accelerated over the past half century, corresponding to increased demands due to the widespread use of the personal electronics that typify our information age. Taking into account pending federal legislation to curb greenhouse gas emissions and increase the energy efficiency of systems, we will soon rely more heavily on renewable energy technologies. The reliance on these technologies will necessitate new means of managing energy supply and demand.

10-2 Grid Emissions Factors

As previously discussed, it is not unrealistic to achieve a 50% reduction in building emissions by 2030. By 2040, this goal expands to be near-zero. An important change needed to be able to achieve this goal lies in the retrofit of buildings, and having an overall more efficient building stock that consumes less energy. But the whole vision can only be complete if our electric grid emissions factors reduce significantly as well, as the building stock emission savings are dependent on the grid emissions factors.

A grid emission factor is a value that compares the amount of carbon emissions required to be released into the atmosphere to generate a useful unit of power. This number accounts for fossil fuels burned, as well as transmission losses, to deliver a unit of power to the site. Therefore, the grid emissions factor of a kWh from a coal power plant is a lot higher that the grid emissions factor from a solar panel farm. Usually these numbers are given by the US EPA (Environmental Protection Agency) and vary by

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[111] United States Energy Information Administration, “U.S. electric system is made up of interconnections and balancing authorities" July 20, 2016 (accessed June 6, 2020) https://www.eia.gov/todayinenergy/detail.php?id=27152

geographic location, based on the composition and quality of the grid mix.
Some jurisdictions have cleaner grids then others, and therefore their grid emissions factor is much lower. Figure 13 maps out the various energy grid sub-regions of the United States and shows their emissions factor. Darker red means a higher emissions factor, while a lighter color (yellow) represents cleaner grids.

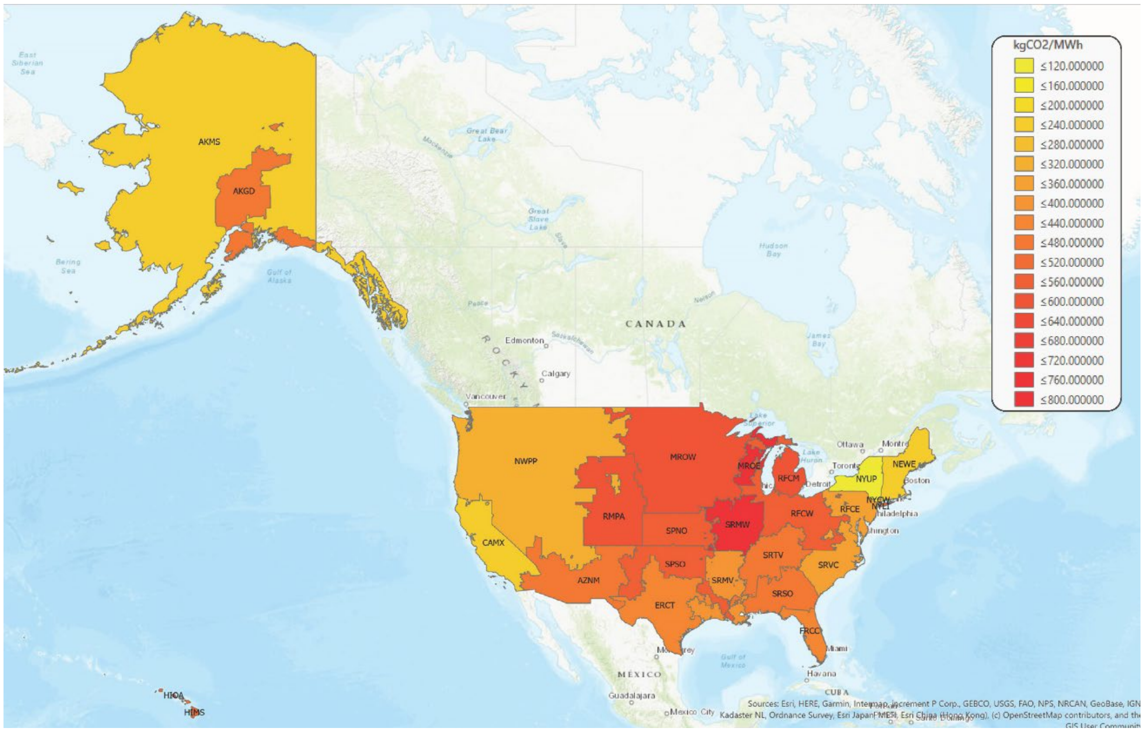

Figure 13 Emissions factors of US sub-regional energy grid (data from eGRID 2018)[112]

The plan for America 3.0 targets energy use reduction for buildings, which means buildings need less energy to operate. But we also need to focus on meeting these energy needs sustainably, with a grid that relies heavily on renewable sources.

10-3 Smart Grid

If our building stock were fully intelligent, as well as our energy supply, the whole social infrastructure of our country could be enabled through information technology. Every year, consumers purchase millions of televisions, computers, mobile phones, and iPads to enhance their daily lives. These technologies present new opportunities to improve the intelligence and distribution efficiency of energy and information, engendering new infrastructure intelligence.

Regional trends in energy supply for the state of Illinois, for example, and the city of Chicago exemplify

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[112] United States Environmental Protection Agency, "Emissions & Generation Resource Integrated Database (eGRID) Questions and Answers: What do the eGRID subregion and NERC region maps look like?", December 5, 2016 (accessed June 6, 2020) https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid-questions-and-answers#egrid6

an aggregate of energy sources including solar, wind, hydroelectric, and other renewable sources[113]. These renewable sources are projected to contribute an increasing percentage of the city's energy supply in the years to come. Increased reliance on near-zero carbon technologies will come with additional demands on our energy distribution infrastructure, requiring deployment of smart-grid technologies.

Expanding the concept of the smart grid to encompass the broader scope of a Continental Electricity Internet infrastructure, which goes beyond supply-and-demand management strategies using algorithmic governance to enable the additional amenities mentioned above, will transform the way America uses electricity in the twenty first century.

Strategies for the intelligent growth of a National Network include:

- Smart Infrastructure Overview
- Smart Grid Applications
- Smart Grid Elements
- eFleet Power and Telecommunications Infrastructure

[113] United States Energy Information Administration, "Illinois State Profile ad Energy Estimates" May 21, 2020 (accessed June 6, 2020) https://www.eia.gov/state/?sid=IL

11 FORWARD-THINKING CITIES

Microgrids, basically mini power grids, use technologies such as energy storage to provide power to specific communities/neighborhoods if an outage occurs on the larger grid. There are already many projects either functioning or underway where the private building owners and the utility companies have work together to implement microscale energy grids. They are described below[114].

11-1 Borrego Springs MicroGrid by San Diego Gas & Electric

As its name implies, a micro-grid resembles our current grid, although on a much smaller scale. It has the unique ability, during a major grid disturbance, to isolate from the utility seamlessly with little or no disruption to the loads within it and reconnect later, also seamlessly.

San Diego Gas and Electric Company's (SDG&E) utility microgrid in the 2,800 customer residential community of Borrego Springs, California (145 kilometers northeast of San Diego) is an example of an "unbundled utility microgrid", where the distribution assets are owned by the utility, but some or all of the distributed energy resources are owned by customers. The goal of the project is to provide a proof-of-concept test as how information technologies and distributed energy resources (solar PV and batteries primarily) can increase utility asset utilization and reliability.

The first of its kind in the area, the Borrego Springs microgrid uses Smart Grid technology—including local power generation, local energy storage, and automated switching—to create a more robust, resilient grid that can dynamically react to changing environmental and system conditions. Borrego Spring's microgrid is connected to the Smart Grid, but can disconnect and function independently during emergencies, supplying vital electricity to the local community through its onsite resources[115].

The community is a somewhat isolated area fed only by a single sub-transmission line. Islanding of the entire substation area is being demonstrated for reliability reasons as well as a potential alternative to building additional transmission capacity. SDG&E is exploring the possibilities of price driven demand response, via interaction with in-home storage, electric vehicles, and smart appliances using the areas installed smart meters and home area network devices[116].

The total microgrid installed capacity will be about 4 MW, with the main technologies being two 1.8 MW diesel generators, a large 500 kW/1500 kWh battery at the substation (which will be instrumental in achieving peak load reduction), three smaller 50 kWh batteries, six 4 kW/8 kWh home energy storage units, about 700 kW of rooftop solar PV, and 125 residential home area network systems[117].

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[114] San Diego Gas & Electric, "Microgrids Help Integrate Renewable Energy and Improve Community Resiliency" (accessed June 6, 2020) https://www.sdge.com/more-information/environment/smart-grid/microgrids
[115] San Diego Gas & Electric, "Microgrids Help Integrate Renewable Energy and Improve Community Resiliency" (accessed June 6, 2020) https://www.sdge.com/more-information/environment/smart-grid/microgrids
[116] Berkeley Lab, "Borrego Springs" (accessed June 6, 2020) https://building-microgrid.lbl.gov/borrego-springs
[117] Berkeley Lab, "Borrego Springs" (accessed June 6, 2020) https://building-microgrid.lbl.gov/borrego-springs

The project's partners include Lockheed Martin, IBM, Advanced Energy Storage, Horizon Energy, Oracle, Motorola, Pacific Northwest National Laboratories, and University of California San Diego. The U.S. DOE supported the project with $7.5 million of federal funding, with additional funding coming from SDG&E ($4.1 million), CEC ($2.8 million), and other partners ($0.8 million)[118].

SDG&E submitted a plan to the California Public Utilities Commission in 2018 to expand energy storage and microgrids throughout the San Diego region. If approved by the CPUC, up to 166 megawatts of energy storage would be built to enhance power reliability for public facilities such as police and fire stations throughout the region. The plan also includes an Energy Storage Customer Program, which helps bridge the financial gap for low-income care facilities to purchase their own energy storage system. Pending approval, these projects could be implemented in the coming years[119].

11-2 High Penetration of Clean Energy Technologies by the City of Fort Collins

The Fort Collins Microgrid in Colorado is part of a larger project known as the Fort Collins Zero Energy District (known as FortZED)[120], where the district plans to create as much thermal and electrical energy locally as it uses.

As described by the Lawrence Berkeley National Lab (LBNL) The main goals are to develop and demonstrate a coordinated and integrated system of mixed distributed resources for the City of Fort Collins, reduce peak loads by 20%-30% on two distribution feeders, increase the penetration of renewables, and deliver improved efficiency and reliability to the grid and resource asset owners[121]. The microgrid project involves multiple customers including the New Belgium Brewery, InteGrid laboratory, City of Fort Collins facilities, Larimer County facilities, and Colorado State University main campus facilities as well as a variety of distributed energy generation technologies. It has received $6.3 million in funding from the U.S. Department of Energy and $4.7 million from the various industry partners, including Eaton, Advanced Energy, and Brendle[122].

Technologies in the project include solar PV, CHP, microturbines, fuel cells, plug-in hybrid electric vehicles, thermal storage, load shedding, and demand side management. The combined distributed generation and load shedding capabilities is 5 MW spread across five customer locations, notes the LBNL.

The larger FortZED project represents about 10-15% of Fort Collins Utilities's entire distribution system, with a peak load of 45.6 MW across 7,257 customers. There will be a total of 345 kW of solar PV, as well

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[118] Berkeley Lab, "Borrego Springs" (accessed June 6, 2020) https://building-microgrid.lbl.gov/borrego-springs
[119] San Diego Gas & Electric, "Microgrids Help Integrate Renewable Energy and Improve Community Resiliency" (accessed June 6, 2020) https://www.sdge.com/more-information/environment/smart-grid/microgrids
[120] FortZED, https://www.fcgov.com/fortzed/
[121] Berkeley Lab, "Fort Collins" (accessed June 6, 2020) https://building-microgrid.lbl.gov/fort-collins
[122] Berkeley Lab, "Fort Collins" (accessed June 6, 2020) https://building-microgrid.lbl.gov/fort-collins

as 700 kW of combined heat and power, 60 kW of microturbines, and 5 kW of fuel cells. The brewery in particular can produce over half of the power it consumes, when its own distributed generation facilities (790 kW biogas power, 200 kW solar PV) are running at peak power. Additionally, the various facilities have diesel-based backup generators totaling 2,720 kW in capacity, which are typically used for emergency power[123].

Demand response will occur through various heating, cooling, and ventilation rescheduling using building automation systems. These and other distributed resources will be fully integrated into the electrical distribution system to support the Zero Energy District. Overall, the project is considered to be very innovative for a small municipally-owned utility and will offer interesting lessons for other milligrids under development.

11-3 Perfect Power by Illinois Institute of Technology (IIT)

A “Perfect Power” system is defined as an electric system that cannot fail to meet the electric needs of the individual end-user. A Perfect Power system has the flexibility to supply the power required by various types of end-users and their needs without fail. The functionalities of such a system will be enabled by the smart grid.

The Nation’s first Perfect Power System, Perfect Power at IIT, is an example of how government, utilities, businesses and municipalities can collaborate in the development and implementation of advanced power systems that are required to meet rising 21st century power demands. The project, developed by IIT, is the result of an uncommon partnership among the U.S. Department of Energy (DOE), local utility Exelon/ComEd, the entrepreneurial electricity distribution developer Intelligent Power Solutions, the Chicago-based global provider of electric power delivery solutions for the intelligent grid, S&C Electric Company, and the Galvin Electricity Initiative[124].

[123] Berkeley Lab, “Fort Collins” (accessed June 6, 2020) https://building-microgrid.lbl.gov/fort-collins
[124] Ilinois Tech, “Perfect Power at IIT Celebrates Phase I Completion of Five Year Project”, February 16, 2010 (accessed June 6, 2020)
https://www.iit.edu/news/perfect-power-iit-celebrates-phase-i-completion-five-year-project

The $14 million project has equipped IIT's microgrid with a high-reliability distribution system for enhancing reliability, new sustainable energy sources (roof-top solar panels, wind generation units, flow batteries and charging stations for electric vehicles), and smart building automation technology (building controllers, Zigbee sensors, controllable loads) for energy efficiency and demand response.[125] The model is designed to be replicable in any municipality-sized system where customers can participate in electric market opportunities.[126]

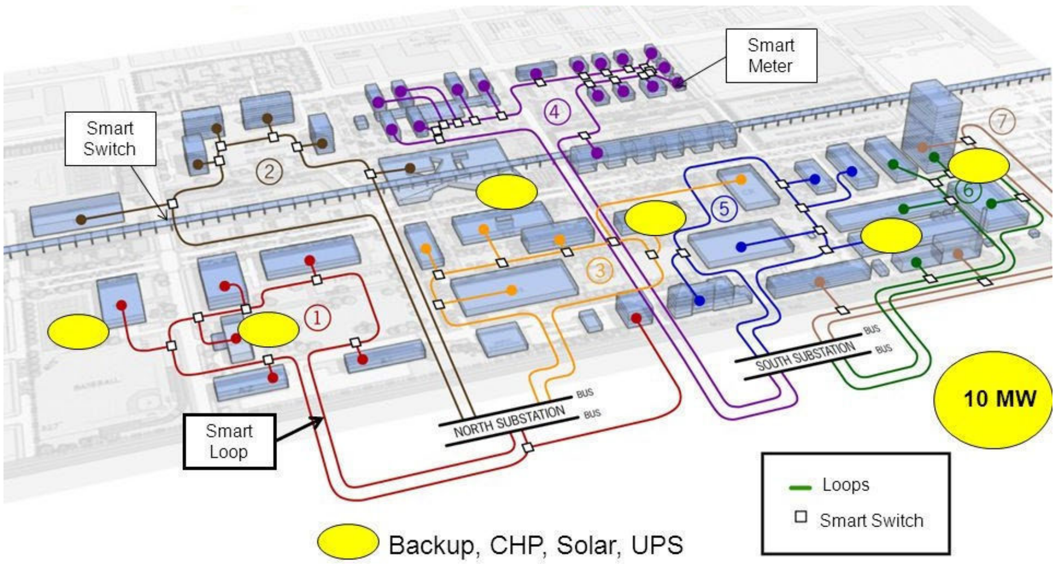

Figure 14 IIT Microgrid diagram (Perfect Power Institute)

All of these microgrid installations are designed to provide a backup distributed and, when necessary, decentralized power system that can allow homeowners, local businesses, neighborhoods, and communities to switch off the main electricity grid were it to suffer a catastrophic power outage brought on by a climate disaster or cyberterrorist attack. Millions of detachable microgrids that connect to the national power grid but can detach at a moment's notice and re-aggregate with other microgrids across the community provide the assurance that the lights will stay on and the power be available in the wake of catastrophic events, making these versatile energy delivery systems the cornerstone of an emerging adaptive and resilient society.

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[125] Robert W. Galvin Center for Electricity Innovation "Microgrid Project at IIT", 2016 (accessed June 6, 2020) http://www.iitmicrogrid.net/microgrid.aspx

[126] Robert W. Galvin Center for Electricity Innovation "Microgrid Project at IIT", 2016 (accessed June 6, 2020) http://www.iitmicrogrid.net/microgrid.aspx

11-4 Green Buildings / Smart Buildings

Every building has unique challenges and opportunities. Therefore, it makes sense to address and optimize buildings on an individual basis prior to integration with a smart grid network—the "smart nodes on a smart grid" concept. Information technology can be used beyond traditional building management systems to provide services to enhance tenant experience, such as high-speed communication and data management, carbon-emission accounting and other potential performance objectives of corporations today.

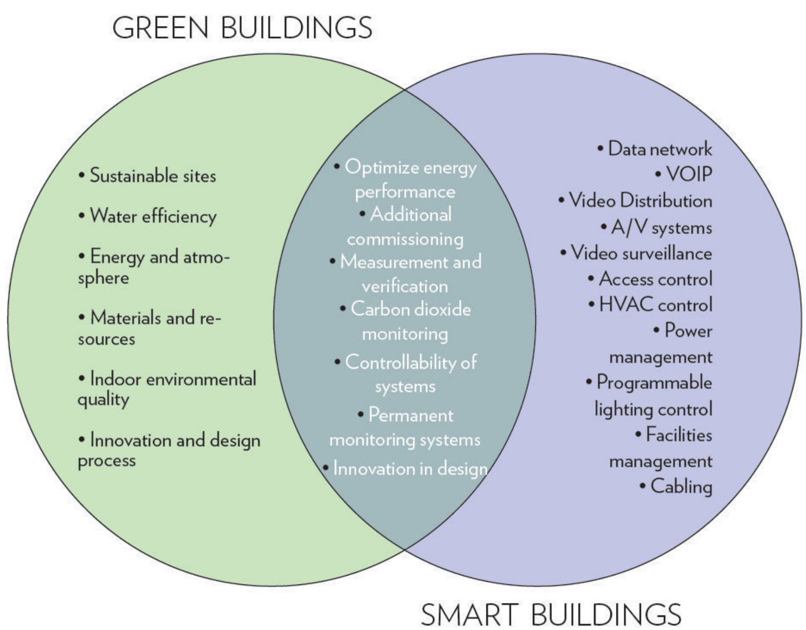

Figure 15 Smart Real Estate diagram: green buildings VS smart buildings (from Decarbonization study)

12 DATA CENTERS

A data center/thin client solution can improve flexibility and reduce power demands by over 200 watts per workstation[127]. This system is purpose-built for server-based desktop virtualization. It moves all software off the desktop to the server, so the device has no CPU, no persistent memory, no operating system and no drivers. Using functionality enabled by server virtualization, this solution delivers not only a complete experience, including native USB support, but also a new set of high-value features not available with current desktop and thin client architectures.

Technologies

- By moving all software off the desktop and onto the server, this system reduces desktop TCO by 70%, saving as much as $3,200 per desktop over three years.
- Physical visits to the desktop endpoint by IT personnel are eliminated.
- Software installations and upgrades are performed centrally.
- These devices consume less than 5W—3% of the power used by a typical PC—making them the ultimate green alternative.
- Environmental controls and next generation facilities solutions

Thanks in part to Internet protocol-based networks, new digital technologies are ready to make dramatic contributions to how buildings function, particularly in reducing their energy consumption. A smart building can be almost any structure, from a shopping mall or home to a hospital or an office high-rise. They all share the common ability of “knowing” what’s going on inside their walls and being able to respond accordingly. Smart buildings control the building automation systems for monitoring and regulating heating, air conditioning, lighting and other environmental variables. They can also oversee other building functions such as security, fire suppression and elevator operations.

Beyond integration, smart building technologies focus on bringing more detailed monitoring and sensing “awareness” to buildings. Typically, heating and cooling systems have one thermostat for an entire office floor. But new smart building networks can now cost-effectively provide far more detailed monitoring of the conditions inside a building, helping a structure’s environmental systems deliver just enough heat, air or cooling when and where it’s needed. Smart buildings equipped with an integrated array of sensors can also monitor such things as the amount of sunlight coming into a room and adjust indoor lighting accordingly.

Advanced smart buildings can know who is visiting a building after hours (based on key swipes from the

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[127] Adrian Smith + Gordon Gill Architecture, “Toward Zero Carbon: The Chicago Central Area Decarbonization Plan” (2010), 147.

security system) and turn on the appropriate lights, equipment and environmental controls.

The bottom-line result of this intelligence and coordination is much lower operational costs for commercial buildings. Industry research suggests that such overhead can account for as much as 80% of the cost of a building during its lifetime, including construction. Much of that expense is from energy use.

Power over ethernet thin-client solution:

- Ultra-low energy/cooling
- Flexible and secure

Bespoke environmental controls:

- Natural light spectrum LEDs
- Demand response ventilation
- Self-powered sensors and controls

Intelligent facilities management:

- Continuous commissioning
- Carbon management ISO 14001 ready

13 SMART GRID UTILITIES

13-1 Renewables Integration

For the Utility[128]:

- Utility control over distributed renewable energy sources
- Measure and verify production to predict supply
- Accumulate renewable energy certificates (REC) and meet return on sales (ROS) mandates
- Ability to stabilize intermittency by automatically dispatching distributed stored energy
- Sell or lease renewable energy systems to customers or co-market with third-party providers

For the Customer[128]:

- Purchase utility-grade renewable energy system from a trusted provider—their power company
- 40%-60% savings on electricity bill
- Plug-in hybrid vehicles
- Reduce cost of electricity used by PHEV
- Utilize PHEV to participate in demand response programs
- Grid point customer portal provides comprehensive production and environmental impact data
- Distributed generation
- Utilize standby generators to participate in demand response programs in combination with load curtailment activity
- Utilize standby generators to mitigate peak demand charges

13-2 Renewables Integration Of Hybrid Vehicles

For the Utility[128]:

- New source of revenue (smart-charging)
- Optimize base load generation
- Value-based pricing to control when and how fast
- PHEVs will recharge
- Stored energy in PHEVs can be discharged to provide peak power (future)
- Measure and verify discharged power for billing reconciliation with customer
- Remotely dispatch power from commercial generators into the grid during demand response events
- Events can be scheduled or on-demand
- Measure and verify dispatched power for billing reconciliation with customers

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[128] Adrian Smith + Gordon Gill Architecture, “Toward Zero Carbon: The Chicago Central Area Decarbonization Plan” (2010), 151.

14 TRENDS IN COSTS RELATED TO DEMAND

In terms of emissions as it relates to economics, the United States has recognized certain shifts, or trends in technology costs as well as demand: as demand increases, cost decreases. The following trends suggest that the future of retrofits and building/city emissions are becoming more and more attainable and beneficial within the United States.

14-1 Solar Energy Industry

Over the past decade there is strong data to support trends related to retrofits. As demand increases, cost decreases for many of the components of retrofits and therefore those trends promise to continue making adaptability more and more affordable. This information is critical to the overall thinking for the future as it should not be considered only for commercial buildings but also for residential buildings including single family and affordable homes.

Components such as solar, integrated wind turbines, battery storage, high-performance building envelopes, sensors, smart appliances and electric vehicles are all components of the connected grid.

For example, the following statistics have been documented and identified by the Solar Energies Industry Association (SEIA) with Wood Mackenzie in their 'U.S. Solar Market Insight 2019 Report'[129]:

- Solar accounted for nearly 40% of all new electricity generating capacity added in the U.S. in 2019, the largest annual share in the industry's history.
- In 2019, the U.S. solar market installed 13.3 GWdc of solar PV, a 23% increase from 2018.
- Cumulative operating photovoltaic capacity in the U.S. now exceeds 76 GWdc, up from just 1 GWdc at the end of 2009.
- The U.S. saw record-setting residential solar capacity added in 2019, with more than2.8 GWdc installed.
- A total of 30.4 GWdc of new utility PV projects were announced in 2019, bringing the contracted utility PV pipeline to a record high of 48.1 GWdc.
- Non-residential PV declined slightly in 2019 with 2 GWdc installed, as policy shifts in states including California, Massachusetts and Minnesota continue to impact growth.
- Community solar continues to expand its geographic diversification, and it experienced a third consecutive year of more than 500 MW installed.
- Wood Mackenzie forecasts 47% annual growth in 2020, with nearly 20 GWdc of installations expected. In total, more than 9 GW were added to the five-year forecast since last quarter to

[129] Wood Mackenzie/SEIA U.S. Solar Market Insight, "U.S. Solar Market Insight: Executive Summary 2019 Year in review" (March 2020), 5.

account for new utility-scale procurement.

- Total installed U.S. PV capacity will more than double over the next five years, with annual installations reaching 20.4 GWdc in 2021 prior to the expiration of the federal Investment Tax Credit for residential systems and a drop in the commercial credit to10% (under the current version of the law).
- By 2025, one in every three residential solar systems and one in every four non-residential solar systems will be paired with energy storage.

The report's 2019 recap[130] identified that the U.S. solar market installed 13.3 gigawatts-direct current (GWdc) of solar photovoltaic (PV) capacity, a 23% increase year-over-year. Residential solar continues to see healthy installation volumes, growing 15% over 2018 levels – the highest annual growth rate since 2016.

Conversely, total non-residential PV (which includes commercial, government, nonprofit and community solar) declined relative to 2018 due to policy transitions and persistent interconnection issues in key commercial markets.

More than 8.4 GWdc of utility-scale PV capacity came online in 2019, up 37% from 2018, with new procurement growing the contracted pipeline to 48.1 GWdc. Across all market segments, solar PV accounted for nearly 40% of all new electricity-generating capacity additions in 2019 (see Figure 16) – its highest-ever share of new generating capacity, the summary concludes.

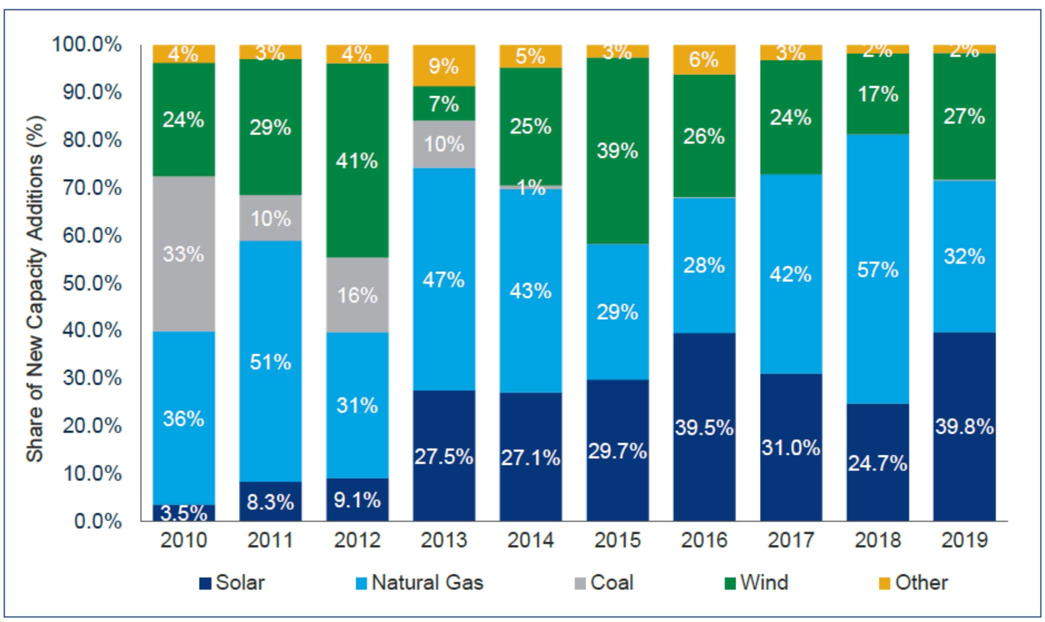

Figure 16 New U.S. electricity-generating capacity additions, 2010-2019 Source: Wood Mackenzie, Federal Energy Regulatory Commission (for category "All other technologies")

[130] Wood Mackenzie/SEIA U.S. Solar Market Insight, "U.S. Solar Market Insight: Executive Summary 2019 Year in review" (March 2020), 6.

14-2 Residential Photovoltaics

The market segment outlooks chapter of the Solar Energies Industry Association (SEIA) / Wood Mackenzie report identified the impactful growth that the residential solar market is having.

Key Figures[131]

- 2.8 GWdc installed in 2019
- Up 15% from 2018

The report describes that 2019 was significant for residential solar for several reasons. Beyond seeing the highest number of total solar installations ever recorded, 2019 also brought a shakeup at the top of the residential solar rankings, reflecting the increased geographic diversity of residential solar adoption. For a national market that has long seen several Northeast states at the top of the rankings (that is, established residential PV markets that historically have benefited from high retail electricity rates and robust incentives), 2019 was the first year in which only one Northeast market (New Jersey) cracked the top five rankings. Instead, the top five state markets are a mixture of mature and emerging markets, with solid installation totals coming from established markets such as California and Arizona but also from newcomers Florida (No. 2) and Texas (No. 5), illustrated in Figure 17 .

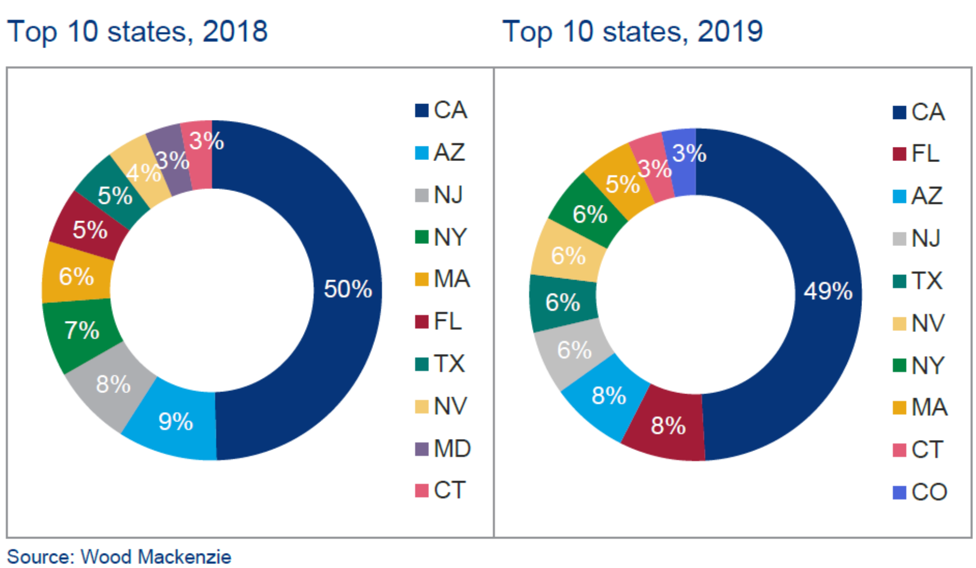

Figure 17 Solar residential rankings

While growth in these emerging markets is driven by increasingly attractive project economics, the report also explains that geographic diversification has also resulted in part from a slowdown in Northeast markets. In this region, higher levels of solar penetration and resulting steep customer-acquisition costs have slowed installation volumes since the peak installation years as the markets have grown past the segment of early-adopter consumers. These higher soft costs remain a long-term risk to the national market over the next few years, especially if the federal solar Investment Tax Credit steps down as scheduled under current law and so long as cost continues to be the foremost criterion in

[131] Wood Mackenzie/SEIA U.S. Solar Market Insight, "U.S. Solar Market Insight: Executive Summary 2019 Year in review" (March 2020), 12.

consumers' decision whether to adopt solar.

In 2019, California also demonstrated that residential solar adoption across the U.S. can be driven by other factors such as resiliency and concerns about climate change. In California, the combination of new-build home solar adoption (which began to gain steam in 2019 and is legally required for most single-family homes starting in 2020) and increasing disaffection with utilities due to public-safety power shutoffs (PSPS) is beginning to drive solar installations, increasingly paired with storage. While some of these drivers are now specific to California, national press coverage of PSPS and wildfires in the state, along with increased international emphasis on climate solutions, may encourage residential solar adoption across the country.

From 2020-2021, residential growth will range from 9% to 17% due to both emerging markets with strong resource fundamentals like Florida and Texas and markets where recent policy developments have increased our near-term forecasts. For example, Maryland's recent renewable portfolio standard increase, the removal of South Carolina's net metering cap and new incentive programs such as Illinois' Adjustable Block Program all provide upside potential to our residential forecasts over the next few years.

In the long term, the ITC step-down is expected to pull in demand across all markets before expiring in 2022 for customer-owned systems. After a soft 2022, modest growth will resume in 2023 and continue into 2024, based on economic fundamentals as the market adjusts to post-ITC market conditions. Long-term growth in a post-ITC world will be contingent on continued geographic diversification outside of established state markets (with markets including Pennsylvania and Colorado beginning to take off) as well as regulatory, technological and business-model innovation to improve product offerings in the solar-plus-storage space. Assuming modest growth on these fronts, the report concludes on this topic that residential solar growth is expected to reach high-single-digit percentages by the mid-2020s.

14-3 Growth in Solar is Led by Falling Prices

The cost to install solar has dropped by more than 70% over the last decade (Figure 18), leading the industry to expand into new markets and deploy thousands of systems nationwide[132]. SEIA also identified prices as of Q4 2019 are at their lowest levels in history across all market segments. An average-sized residential system has dropped from a pre-incentive price of $40,000 in 2010 to roughly $18,000 today, while recent utility-scale prices range from $16/MWh - $35/MWh, competitive with all other forms of generation.

[132] Solar Energy Industries Association, "Solar Industry Research Data", 2019 (accessed June 6, 2020) https://www.seia.org/solar-industry-research-data

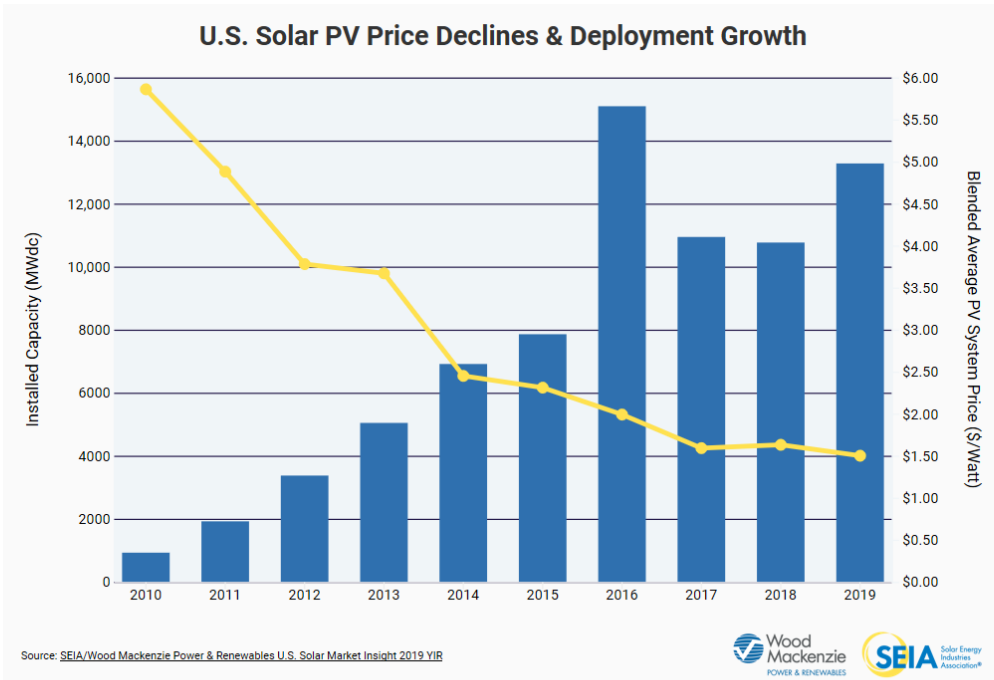

Figure 18 Cost of Solar Installation

In combination with systems costs for solar and wind, retrofit building envelope costs are also important to understand as they relate to updating commercial and residential buildings.

14-4 Building Battery Storage

Over the last decade, the cost of photovoltaic cells plummeted while their efficiency skyrocketed, driving an unprecedented boom in solar farms and rooftop installations[133]. Now, the focus has shifted onto batteries as ways to capture this collected renewable power and help reduce energy demand and peak loads.

Incremental advances have rendered existing technologies less expensive and more efficient. In an echo of the solar market, the cost of lithium-ion batteries has dropped by 80 percent over the last 10 years, according to one estimate.[134]

The result: More solar-plus-storage was installed worldwide in 2018 than in any previous year. Forecasters say the U.S. market is particularly set for spectacular growth in 2019. Ravi Manghani of Wood Mackenzie Power & Renewables projects that American installers will deploy around 1.6 gigawatt hours of energy storage this year — more than double the 2018 total.[135]

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[133] Ken Edelstein, "5 green building trends: Energy storage a bigger piece in renewable energy puzzle", *The Kendeda Fund Living Building Chronicle,* March 14, 2019 (accessed June 6, 2020) https://livingbuilding.kendedafund.org/2019/03/14/energy-storage-bigger-piece-in-renewable-energy-puzzle/

[134] Mark Kane, "Bloomberg's Latest Forecast Predicts Rapidly Falling Battery Prices", *InsideEVs,* June 21, 2018 (accessed June 6, 2020) https://insideevs.com/news/338671/bloombergs-latest-forecast-predicts-rapidly-falling-battery-prices/

[135] Jeff St. John, "5 Predictions for the Global Energy Storage Market in 2019", *Green Tech Media*, December 11, 2018 (accessed June 6, 2020) https://www.greentechmedia.com/articles/read/five-predictions-for-the-global-energy-storage-market-in-2019#gs.VpeapDFx

Over the last two years, battery plant openings have dramatically increased manufacturing capacity[136]. And some states are finally adjusting their clean energy incentives to make storage eligible[137]. Another reason for the anticipated growth: Owners, engineers and contractors increasingly view storage as a standard for renewable energy installations — whether at the residential, commercial or utility scale[138]. By Manghani's measure, solar-plus-storage now competes with the least expensive electricity generated by fossil fuels.

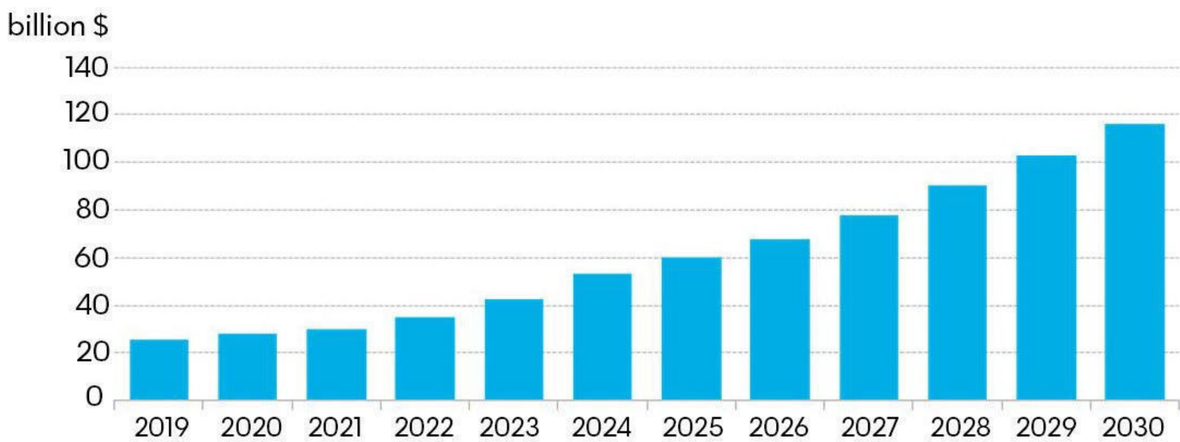

Figure 19 Annual lithium-ion battery market size (Source: BloombergNEF)

BNEF (BloombergNEF) predicts that by 2050, 50% of electricity is to be generated by wind and solar[139]. Batteries will be key to solve issues of variable power output from renewables and will open the way for broader adoption. Power will be more often produced closer to where there's demand (like solar on the roofs of factories or homes). The report predicts up to $548 billion will be invested in battery energy storage systems by 2050 - two thirds at the grid level and the rest by households and businesses.

It's also important to note that there is a fundamental synergy between plug-ins, ESS and renewable electricity. EVs needs to be powered from renewable electricity to unleash full environmental potential, renewables need energy storage and local consumption.

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[136] Ken Edelstein, "5 green building trends: Energy storage a bigger piece in renewable energy puzzle", *The Kendeda Fund Living Building Chronicle,* March 14, 2019 (accessed June 6, 2020) https://livingbuilding.kendedafund.org/2019/03/14/energy-storage-bigger-piece-in-renewable-energy-puzzle/

[137] Renewable Energy World, "Massachusetts Is First State To Make Battery Storage Eligible for Energy Efficiency Incentives", February 4, 2019 (accessed June 6, 2020) https://www.renewableenergyworld.com/2019/02/04/massachusetts-becomes-first-in-the-nation-to-make-battery-storage-eligible-for-energy-efficiency-inc/

[138] Ken Edelstein, "5 green building trends: Energy storage a bigger piece in renewable energy puzzle", *The Kendeda Fund Living Building Chronicle,* March 14, 2019 (accessed June 6, 2020) https://livingbuilding.kendedafund.org/2019/03/14/energy-storage-bigger-piece-in-renewable-energy-puzzle/

[139] BloombergNEF "New Energy Outlook 2019", 2019 (accessed June 6, 2020) https://about.bnef.com/new-energy-outlook/

According to BNEF research, this year the average EV battery pack prices decreased to around $156/kWh, which is some 87% less than it was in 2010 (over $1,100/kWh).The report forecasts that the cost should be around $100/kWh by 2023 (Figure 20)[140].

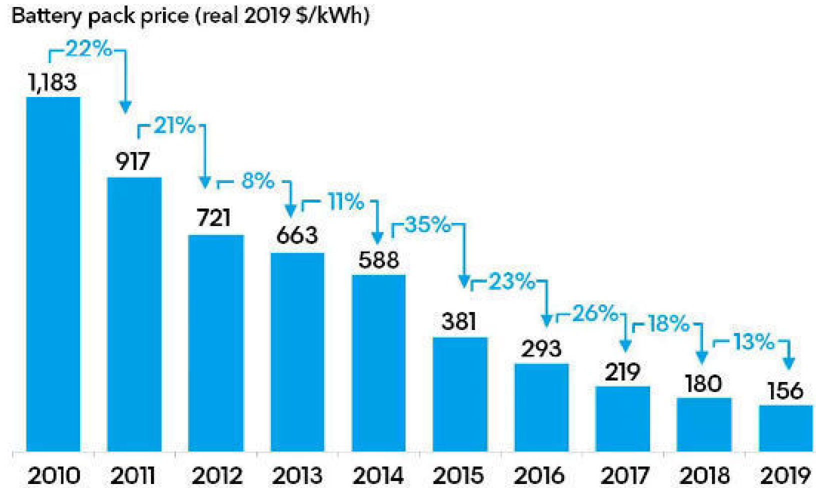

Figure 20 Lithium-ion battery price: volume weighted average (Source: BloombergNEF)

BloombergNEF explains that the main reason behind the most recent decrease are:

- increasing order size
- growth in battery electric vehicle sales
- the continued penetration of high energy density cathodes

14-5 Envelope Retrofits

In Europe, envelope retrofits are, in some cases, packaged as single energy systems that can be applied to an entire home. One such example is the Energiesprong[141] system in the Netherlands where cost reductions have already been recognized due to demand.

This is described in a report funded by the Green Alliance, which looks at successful retrofit examples and their applicability to the UK market. Innovation and economies of scale in the Netherlands have nearly halved the cost of Energiesprong retrofits over seven years. Some of this reduction has already translated to the UK: the first Energiesprong installations in Nottingham cost around £75,000 per home, compared to around £110,000 per home in the Netherlands in 2010.[142]

The study notes that there is potential to bring costs down further. A more robust and competitive domestic supply chain, underpinned by a commitment to Energiesprong retrofits in the UK, would continue to cut costs by raising the productivity of UK construction. By 2025, a total retrofit could cost

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[140] Mark Kane, "BloombergNEF: Average Battery Prices Fell To $156 Per kWh In 2019", *InsideEVs*, December 4, 2019 (accessed June 6, 2020) https://insideevs.com/news/386024/bloombergnef-battery-prices-156-kwh-2019/

[141] Energiesprong, https://energiesprong.org/about/

[142] Chris Friedler and Chaitanya Kumar, "Reinventing Retrofit: how to scale up home energy efficiency in the UK" (Green Alliance, February 2019), 15.

£35,000 per home, on the basis of 5,000 homes being retrofitted every year. This reduction is illustrated in Figure 21 .

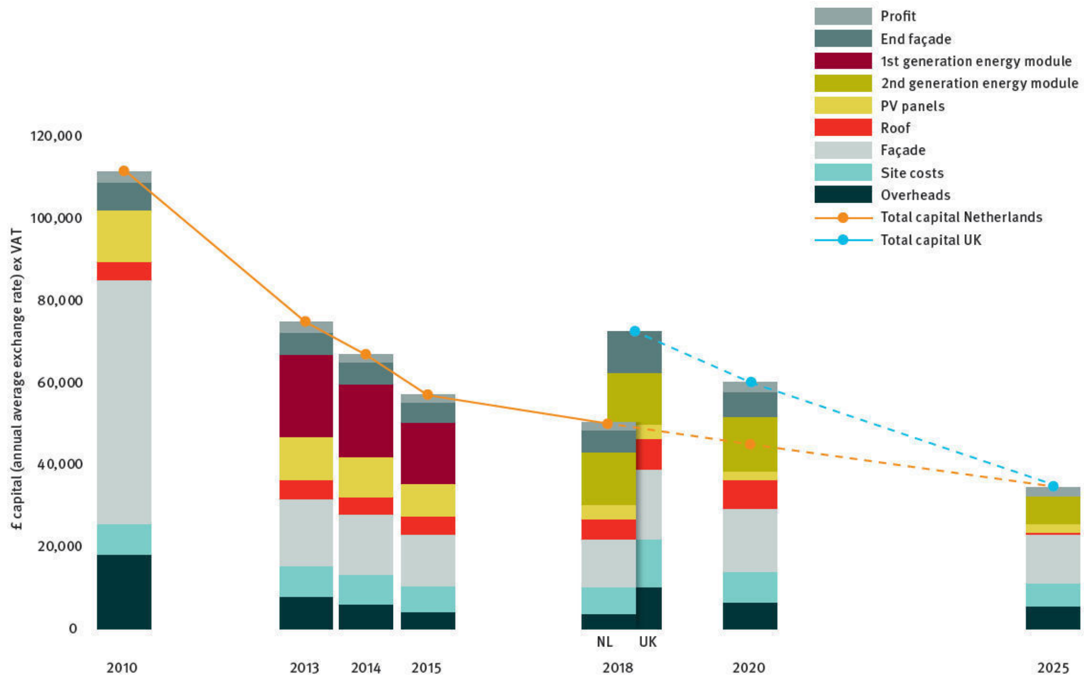

Figure 21 Total home retrofit cost projections [142]

14-6 Sensors

In their 2019 Manufacturing Trends Report[143], Microsoft describes the importance of machinery and sensor integration to achieve the next level of industrialization:

'Since the start of the First Industrial Revolution, manufacturing has been the force pushing industrial and societal transformation forward. Today, we're in the midst of another industrial revolution, as a new generation of sophisticated technologies is transforming manufacturing into a highly connected, intelligent, and ultimately, more productive industry. The manpowered shop floor of the past is being replaced by smart manufacturing facilities where tech-savvy workers, aided by intelligent robots, are creating the products of the future.

In this America 3.0 infrastructure revolution, machinery is outfitted with smart sensors to collect comprehensive, real-time data; artificial intelligence enables superhuman production efficiency and seamless quality assurance; blockchain transactions significantly expand transparency and security; edge computing assures nearly uninterrupted connectivity; and impending high-speed broadband allow for ever-larger volumes of data processing from anywhere.

Modern manufacturers are no longer just makers, they are the thread that connects the entire lifecycle of a product, and to thrive in this modern environment, they must increasingly rely upon technology to

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[143] Microsoft Dynamics 365, "2019 Manufacturing Trends Report", 2019 (accessed June 6, 2020) https://info.microsoft.com/rs/157-GQE-382/images/EN-US-CNTNT-Report-2019-Manufacturing-Trends.pdf, 2.

power breakthrough innovations and drive more intelligent operations.'

The report further describes six emerging trends in manufacturing that Microsoft believes will help Empower manufacturers to design more intelligent operations and increase the speed of doing business.

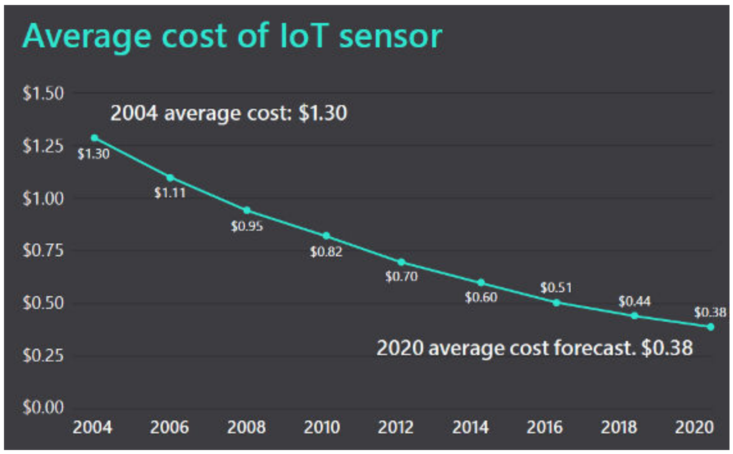

Figure 22 Average cost of IoT sensor [144]

The report continues to explain that, as more manufacturers seek to make their legacy systems more intelligent, the market size for sensors and controllers has grown substantially and is projected to grow to $6.1 billion by 2020, up from $5.1 billion in 2016.[145] The increased availability has also driven down cost for IoT sensors. Between 2004 and 2018, the average cost of a sensor dropped nearly 200% to an average cost of $0.44,[146] (see Figure 22) making intelligent manufacturing more affordable and accessible for manufacturers of all sizes[147].

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[144] Microsoft Dynamics 365, "2019 Manufacturing Trends Report", 2019 (accessed June 6, 2020) https://info.microsoft.com/rs/157-GQE-382/images/EN-US-CNTNT-Report-2019-Manufacturing-Trends.pdf, 16.
[145] MarketsandMarkets, POSRI, "China is Shifting to the 'Smart Factory of the World'" (October 2016)
[146] Goldman Sachs, BI Intelligence Estimates, "The average cost of IoT sensors is falling" (2016)
[147] Microsoft Dynamics 365, "2019 Manufacturing Trends Report", 2019 (accessed June 6, 2020) https://info.microsoft.com/rs/157-GQE-382/images/EN-US-CNTNT-Report-2019-Manufacturing-Trends.pdf, 7.

14-7 New Skills

The Microsoft Report estimates that over the next decade, employers will seek to place talent in nearly 3.4 million manufacturing jobs (2.7 million to replace the existing workforce as Baby Boomers retire and the remaining 700,000 new jobs due to anticipated economic expansion). However, because of the skills gap, it is likely that 2 million of these jobs will remain unfilled. At present, fully 60% of open production positions are unfilled because of a talent shortage. The number of positions left open due to the skills gap is growing; over the next decade, nearly 2 million manufacturing jobs will go unfilled[148] (Figure 23).

Summary

As technology advances and the IoT network becomes distributed and de-centralized in order to connect the country, America will have to grapple with a shortage of skills as potential workers seek the new opportunities that come with the America 3.0 buildout and deployment. Where and how will the 21st century American workforce live and work in the coming era?

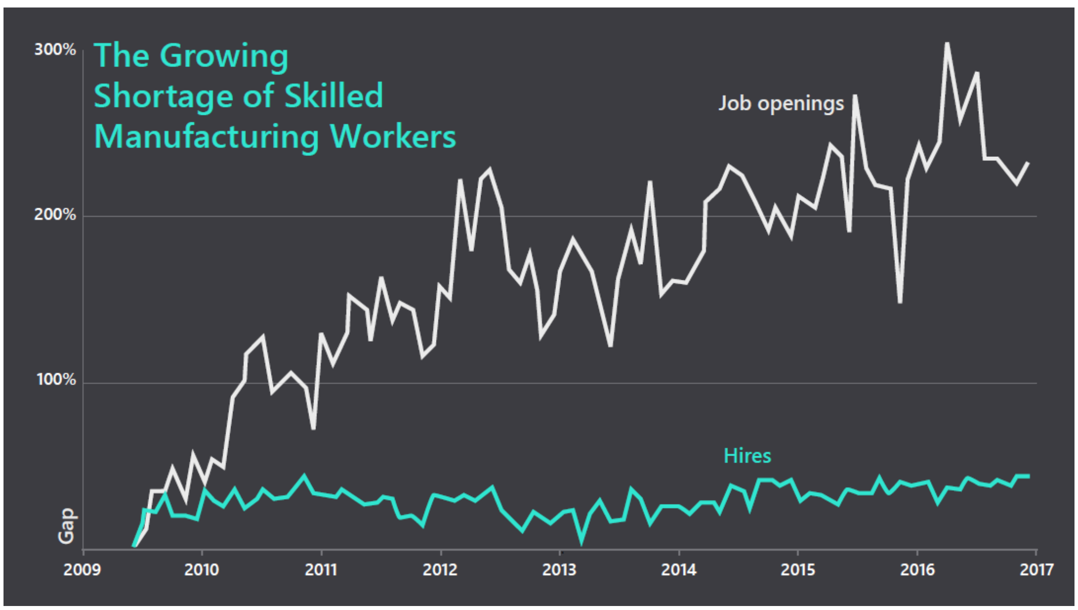

Figure 23 The Growing Shortage of Skilled Manufacturing Workers [148]

[148] Microsoft Dynamics 365, "2019 Manufacturing Trends Report", 2019 (accessed June 6, 2020) https://info.microsoft.com/rs/157-GQE-382/images/EN-US-CNTNT-Report-2019-Manufacturing-Trends.pdf, 45.

14-8 Affordable and Middle-Income Housing

When considering that 80% of the US residences are single family homes[149] located in urban, suburban and rural areas, housing must be considered as a significant contributor to any energy and carbon reduction strategy. This relates directly to the concept of geographically and physically creating a spine of development throughout the country that links the IoT through a variety of building types and communities.

The affordable and middle-income housing crisis in the United States is well documented.

An article by the Monroe group lists a series of eye-opening facts about the affordable housing crisis in the United States[150]:

- Communities across the country are facing low-income housing shortages – there is not a single county in the United States that can fill 100% of its low-income population's need for safe, affordable housing.
- 46 million people live in poverty in the United States. This number has increased 38% over the last 13 years – the highest rate in almost 60 years.
- More than 11 million Americans now pay more than half their salaries for their monthly income for rent. This rate has increased more than 30% over the last five years, which is also a record high.
- One in four housing markets is not affordable by historic standards; new 2016 data from ATTOM Data Solutions shows 24% of US counties are now less affordable now than last year at 19%.
- 15 million children (or 21% of all children) live in families with incomes below the federal poverty level.
- On average, there are only 28 adequate and affordable housing options for every 100 extremely low-income households.

The National Low Income Housing Coalition's report on the shortage of affordable homes in the U.S notes that over 10.9 million of the nation's 43.7 million renter households have extremely low incomes[151]. Only 7.3 million rental homes are affordable to extremely low-income renters, assuming households should spend no more than 30% of their incomes on housing. This supply leaves an absolute shortage of 3.6 million affordable rental homes. Extremely low income renters are the only income group facing this absolute shortage of affordable homes. The shortage does not account for the 568,000 people who are experiencing homelessness, as the ACS includes only households with an address. The study estimates that, taking into account the number of people experiencing homelessness in families, another 449,737 homes are needed. The real shortage of rental homes affordable to extremely low-

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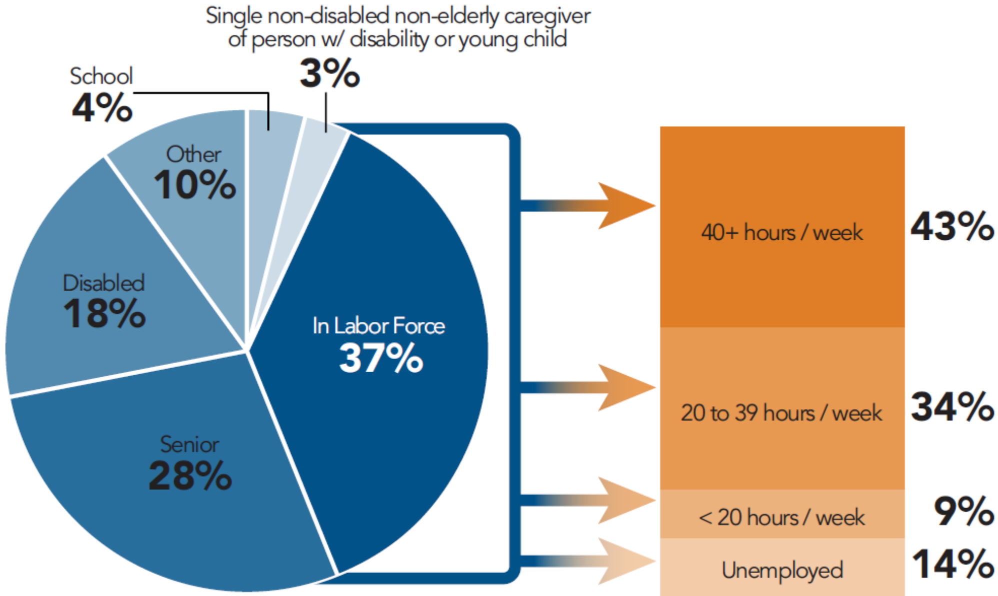
[149] Jennifer Rudden, "Single-family vs multifamily homes in the U.S. 2020", *Statista*, March 12, 2020 (accessed June 6, 2020) https://www.statista.com/statistics/1042111/single-family-vs-multifamily-homes-usa/

[150] The Monroe Group, "Affordable Housing Statistics", (accessed May 26, 2020) https://www.monroegroup.com/about-us/affordable-housing-statistics/

[151] National Low Income Housing Coalition, "The Gap: A Shortage of Affordable Homes", March 2020 (accessed June 6, 2020) https://reports.nlihc.org/sites/default/files/gap/Gap-Report_2020.pdf, 2-3.

income households, therefore, is closer to 4.1 million. Even this estimate is conservative, as it does not account for doubled-up households.



Note: Mutually exclusive categories applied in the following order: senior, disabled, in labor force, enrolled in school, single adult caregiver of a child under 7 or of a household member with a disability, and other. Senior means householder or householder's spouse (if applicable) is at least 62 years of age. Disabled means householder and householder's spouse (if applicable) are younger than 62 and at least one of them has a disability. Working hours is usual number of hours worked by householder and householder's spouse (if applicable). School means householder and householder's spouse (if applicable) are enrolled in school. Fifteen percent of extremely low-income renter households include a single adult caregiver, more than half of whom usually work more than 20 hours per week. Eleven percent of extremely low-income renter households are enrolled in school, 48% of whom usually work more than 20 hours per week. Source: 2018 ACS PUMS.

Figure 24 Extremely Low Income Renter Households

The report then tries to describe 'who are extremely low-income renters?' [152] (Figure 24) Of these, eventy-seven percent of extremely low-income households in the labor force work more than 20 hours per week, but low-wage employment does not provide them adequate income to afford housing. The national average of what a full-time worker, working 40 hours per week for 52 weeks of the year, needs to earn to afford a modest one-bedroom or two-bedroom apartment is $18.65 or $22.96 per hour, respectively.[153] A recent report from Brookings finds that 53 million people are "low-wage workers," with a median hourly wage of $10.22. Nearly half of this group works in retail sales, food preparation, building cleaning, personal care, construction, or driving.[154] Low-wage employment will continue to grow. Seven of the ten occupations projected to add the most jobs over the next decade, including medical assistants, home health aides, janitors, and food servers, provide a median wage that is lower than what is needed for a full-time worker to afford modest rental housing.[153]

Recognizing the large gap between the need for affordable housing and the supply and given the

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[152] National Low Income Housing Coalition, "The Gap: A Shortage of Affordable Homes", March 2020 (accessed June 6, 2020) https://reports.nlihc.org/sites/default/files/gap/Gap-Report_2020.pdf, 12.

[153] National Low Income Housing Coalition, "Out of reach: The high cost of housing" (Washington, DC 2019), (accessed June 6, 2020) https://reports.nlihc.org/sites/default/ files/oor/OOR_2019.pdf

[154] Ross, M. & Bateman, N. "Meet the low-wage workforce" (Washington, DC 2019)

understanding that this gap will continue to grow, the approach to solving this problem has to reach beyond the private sector. If there were a larger unified approach to the problem that included Federal lands as a means to support housing, this may alleviate a large percentage of the current housing cost burden. It is estimated that up to 50% of affordable housing costs are due to legislated constraints and land costs.

Considering the opportunity to link logistics, services, data and energy through a connected network across the United States, affordable land available for development as well as retrofit and adaptive reuse of existing buildings could contribute to the solution to the housing crisis. In many cases, affordable housing prices are driven up by complicated regulations and high land costs in urban areas. In order to alleviate these, less expensive areas or even Federal Lands could be considered for the housing.

Opportunities for the identification of Right Of Ways or water shed areas across the country may be an option. These tend to be well located with respect to infrastructure, utilities and are often found adjacent to or even within existing communities. These sites should be considered as a decentralized distribution of affordable and middle-income housing and, where possible, should be integrated into existing communities and not isolated as compounds or neighborhoods onto themselves.

In doing so**,** the social, economic, and public health considerations in delivering energy efficient, healthy and low carbon housing at affordable costs and low operation costs would be an essential part of a green energy and zero-carbon future. The housing would serve as the vehicle for connectivity by establishing new live-work and resilient communities across the country.

The lack of affordable housing for millions of low- and moderate-income families is a sleeping giant that threatens the very stability of the Republic. Now, in the midst of the COVID-19 pandemic, with unemployment reaching levels last experienced during the height of the Great Depression during the 1930s, and expected to continue to climb, the question is what will happen to the millions of families threatened with foreclosures and evictions from rental properties and forced onto the streets.

As alluded to in part one, America faced a similar economic crisis after the Civil War and in the 1930s during the Great Depression. In both instances, the federal government intervened with a strong hand, introducing landmark legislation to ensure adequate shelter for millions of Americans. The Federal Homestead Act of 1862 and successive extensions ceded 160 million acres of public lands – 10% of the total land area of the United States – to 1.6 million homesteading families, mostly west of the Mississippi River, providing a vital life support and a firm stake from which to build out an America 1.0 infrastructure in the last third of the 19^{th} century.

The Great Depression in the 1930s once again raised the specter of mass homelessness across America and widespread unemployment and social unrest. American families were forced onto the streets, where they set up makeshift shelters – called Hoovervilles – on public lands. Once again, the federal government responded with the passage of the Federal Housing Administration Act (FHA). The FHA underwrote and insured loans made by banks and private lenders for home building, making possible 34 million home mortgages and 47,000 multi-family project mortgages in ensuing decades. While FHA policies blatantly discriminated against black families in a policy of redlining their neighborhoods, denying millions of African-American families access to affordable housing, working class and middle class white America benefited with being able to secure decent housing and a firm base by which join the ranks of a post World War II largely-suburban middle class.

Now, as the nation reels in the throes of a third economic crisis and mounting social unrest, attention is once again turning to the critical question of securing affordable housing for millions of disenfranchised American families. Although the federal government has yet to enact programs of a similar scale to address the current economic crisis, a new generation of elected officials across the country are beginning to seize the leadership role and are experimenting with initiatives that, if scaled, could usher in the America 3.0 infrastructure and the new businesses and employment opportunities that accompany it.

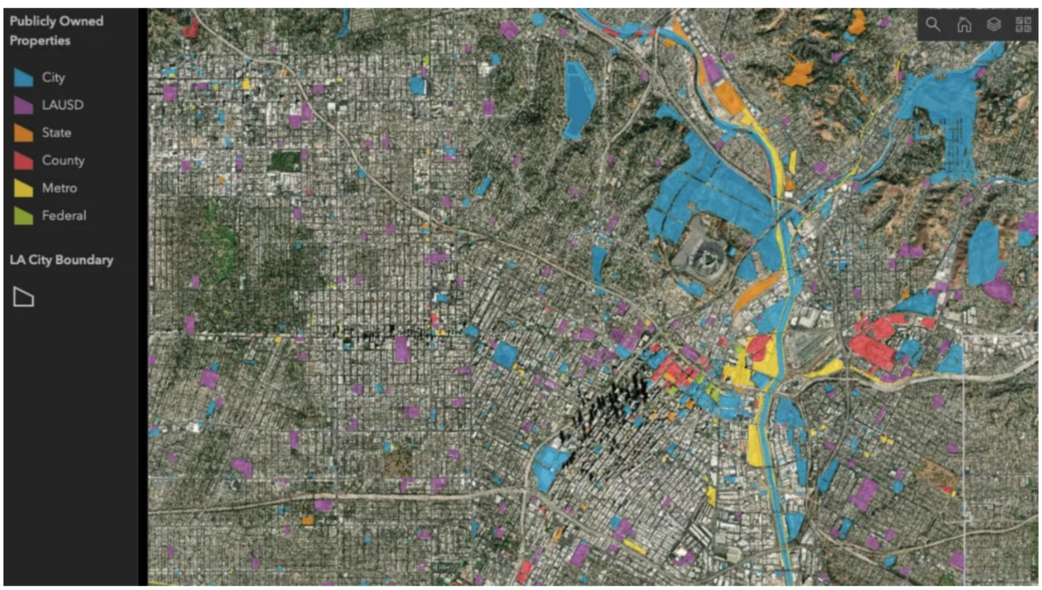

Figure 25 Property Panel View: Properties from six public agencies are displayed on the map (Source: https://la.curbed.com)

Cities, counties, and states have rediscovered public lands and have begun to survey every acre of federal, state, municipal, and county public land parcels in their jurisdictions that could be ceded over to create affordable low and moderate income housing for millions of desperate American families, who are wondering if they will have a roof over their head.

Los Angeles, the nation's second largest metropolitan area, is among the first mover cities in an emerging America 3.0 Homesteading Act. The city has established the Los Angeles Property Panel[155], whose mission is to create an open-source online geo-spatial database that categorizes all available public land – federal, state, municipal, and county – within their jurisdiction, and to determine which

[155] Property Panel, https://lacontroller.org/data-stories-and-maps/propertypanel/

parcels might be appropriate to give over to affordable low and moderate income housing for families in the Los Angeles metropolitan region. An example view of the panel is shown on Figure 25 .

Los Angeles boasts 14,000 public land properties, owned either by the federal government, the government of California, the government of Los Angeles County, and the city of Los Angeles. The city itself owns 7,500 of the 14,000 public land properties in the jurisdiction. The Property Panel is using this online interactive geospatial portal to inform the public and engage local main street businesses, civil society organizations, and neighborhood associations in exploring ways to use the property to create affordable housing, new businesses and employment queued to the most disadvantaged neighborhoods, with the goal of rejuvenating the city and creating a more inclusive and resilient Los Angeles.

Los Angeles Controller, Ron Galperin, who is spearheading the initiative, has proposed the creation of the Los Angeles Municipal development Corporation, a non-profit entity that would oversee the management of these untapped public land parcels and in consultation with local businesses, civic organizations, and neighborhood associations, begin the process of giving over these public land parcels for low and moderate income housing stock and for revitalizing business corridors in low-and-moderate income neighborhoods.

Other cities around the country – Seattle, Oakland, Detroit, New York City, Washington DC, to name just a few – are launching similar initiatives in a budding America 3.0 homesteading movement that is gaining traction across America.

While the notion of ceding public land to develop low and moderate income housing is an increasingly attractive public policy initiative, the reality is that local developers are often reluctant to build low- and moderate-income housing in disadvantaged neighborhoods, arguing that they cannot secure sufficient return on their investment to remain viable. To address the problem, in 2017 the US Congress passed and the President signed into law the US Tax Cuts Jobs Act (TCJA) to encourage revitalization and redevelopment in the poorest communities of the country. To attract developers to invest in low and moderate income housing, the Act included generous tax incentives. Concurrently, the governors of the 50 states were assigned the task of earmarking the poorest at-risk counties for development. There are currently 8,700 “Opportunity Zones” listed in counties across America.[156] Unfortunately, the 2017 Tax Cuts Jobs Act did not sufficiently define the criteria that needed to be met, leaving the door open for some developers to take advantage of the tax incentives while building more expensive housing and gentrifying neighborhoods that bordered wealthier parts of the city.

Still, with thousands of Opportunity Zones already marked off, the US Congress could amend the Act to provide more granular details that would need to be agreed to by developers to ensure that the spirit of the act is not undermined.

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[156] The Internal Revenue Service of the United States, "Designated Qualified Opportunity Zones under Internal Revenue Code § 1400Z–2," July 9th, 2018 (accessed April 30th, 2020), https://www.irs.gov/pub/irs-drop/n-18-48.pdf.

The city of Charleston, South Carolina is among the first to place restrictions on developers to ensure compliance with the intended purpose of the Act. The new provisions provide both incentives and penalties. First, the carrot. If the developer builds affordable housing, the city automatically triggers pathways to expedite city approvals – in other words, “time bonuses” which are much coveted by developers. The city also has a stick. If the developer does not meet all the requirements, says Jacob Lindsay, the city’s Director of Planning, Preservation, and Sustainability, the “developer cannot get their power turned on in their new building until they have met all the criteria”.[157] Other cities are likely to enact their own provisions to encourage developers to follow suit and build low and moderate income housing in Opportunity Zones.

To ensure all 8,700 Opportunity Zones are in compliance, the federal Act will need to be amended to include specific provisions that will encourage the retrofitting of low and moderate income housing and the conversion of buildings to IoT nodes equipped with fiber based broadband connection, solar PV installations, edge data centers, storage batteries, and nearby charging stations for electric vehicles to make their homes and neighborhoods resilient to climate disasters that are already exacting a devasting toll in the poorest communities.

Ceding public land to build smart zero-emission and nodally-connected low and moderate income multi-family housing and new commercial businesses in disadvantaged communities represents a bottom-up and distributed economic development plan and accompanying political movement with long legs that will increasingly become a foundation for the emergence for a new social contract – The Resilient Society. Hopefully, this budding economic and political movement will be in time to provide a new and powerful social mooring for four generations of Americans who find themselves in limbo amidst the carnage wrought by increasingly virulent pandemics and evermore threatening climate disasters.

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[157] Health Ellison, "Charleston initiative aims to incentivize affordable housing development in Opportunity Zones," *The Charleston City Paper*, January 28th, 2020 (accessed May 15th, 2020), https://www.charlestoncitypaper.com/TheBattery/archives/2020/01/28/charleston-initiative-aims-to-incentivize-affordable-housing-development-in-opportunity-zones.

15 CONNECTED NETWORKS

Connected networks across the United States already exist for many systems. While these individual components are there to serve communities, many are siloed and not interconnected. Looking at a small sample of simple networks such as the Interstate system, travel lodges, the largest logistic centers, data centers and fiber, patterns emerge that illuminate the strategies for moving and connecting people, services, goods and information. Following that pattern and filling in the gaps with an Internet system, energy policy and affordable housing needs could realize the full concept.

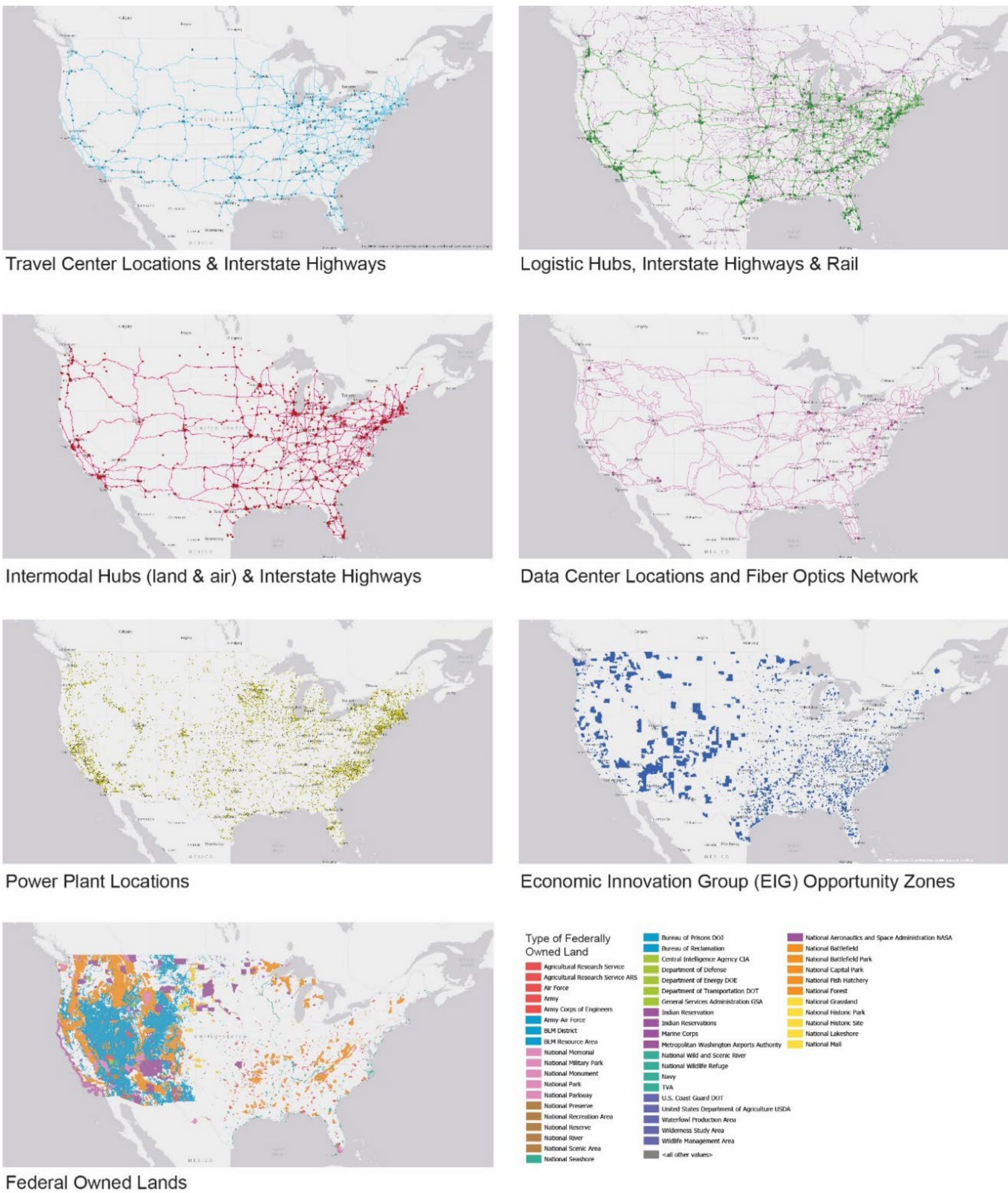

Figure 26 Network Maps of the USA

The maps on Figure 26 show a series of networks that contribute to the connectivity of the US both physically and virtually.

Amongst the maps, there is one of federal owned lands. Federal lands are lands in the United States owned by the citizens of the United States. They are held in public trust and managed by the federal government. 28% of the landmass of the US is owned by the Federal Government. Almost all Federal Land is located in the Western United States and Alaska. It is important to note that many of these lands are natural resources or dedicated to the military, but there are opportunities when identifying federal lands in proximity to urban areas or Opportunity Zones to evaluate their potential as affordable housing locations.

Figure 27 is a combination of all the individual maps, which can be used to identify patterns or areas of focus and concern to move towards a more connected America.

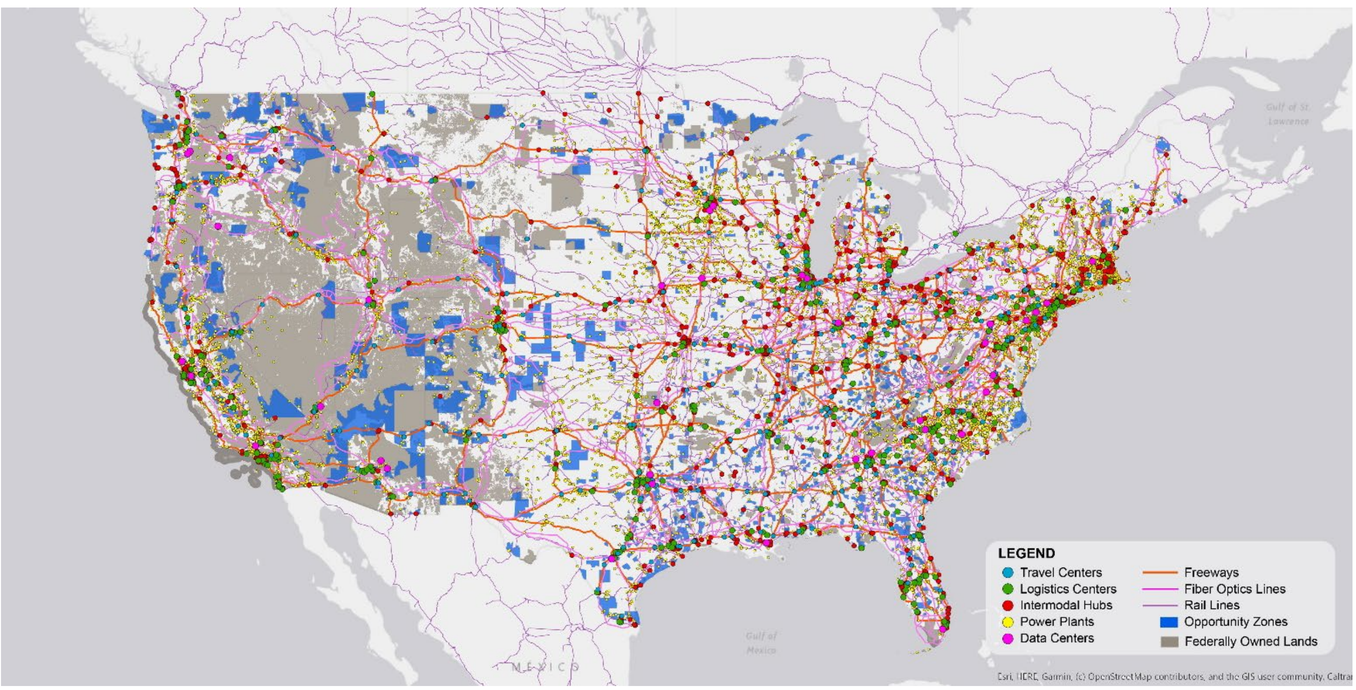

Figure 27 Compound Map of Networks

16 CONCLUSION

The reality of the current state of energy and carbon in the United States cannot ignore the existing building stock as an opportunity to redefine buildings as energy suppliers. Through a connected network, buildings can aid in the supply of energy and data to the entire Country with a decentralized, safe and efficient energy network. Combined with logistics, infrastructure, data networks and housing, the platform exists to connect the United States and advance the Country toward a carbon neutral and highly successful future. What we have therefore is a total democratization of energy for the United States. Every home, every building is a power station and creates on demand energy where needed as needed.

The implementation plan that delivers this National Strategy will require a fully integrated multi-disciplinary approach from the outset. Policy, Land strategy, Master Planning, Infrastructure and Economics surrounding this effort will need an agreed upon set of targets and goals that align with policy and standards. These goals will need to test efficiencies and analytical results against design approaches.

A four or five year delivery plan will need to include Governmental and State approvals as well as National policy as it relates to energy and carbon.

This is power to the people, literally and figuratively:
a publicly accessible energy platform; connected at all scales from the single solar panel on the home to the National Grid.

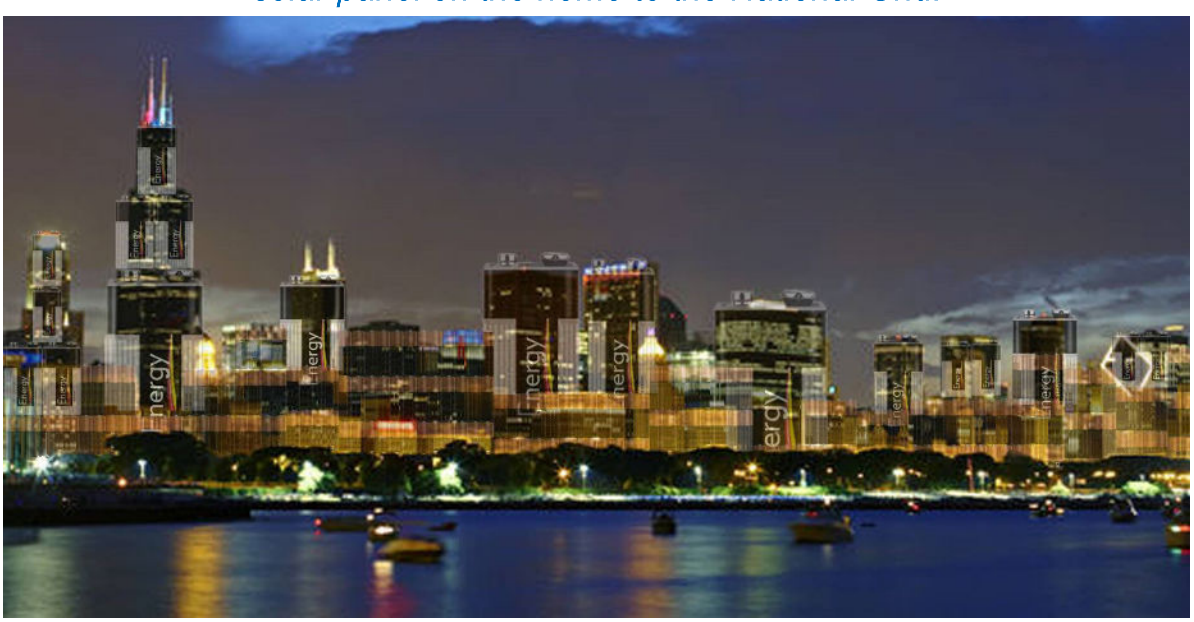

Figure 28 Buildings as batteries

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Gordon Gill – Design Partner
Robert Forest – Managing Partner
Christopher Drew – Director of Sustainability
Katrina Fernandez Nova –Architect

AMERICA 3.0

HYDROGEN AS A CRITICAL ENABLER

THE HYDROGEN COUNCIL

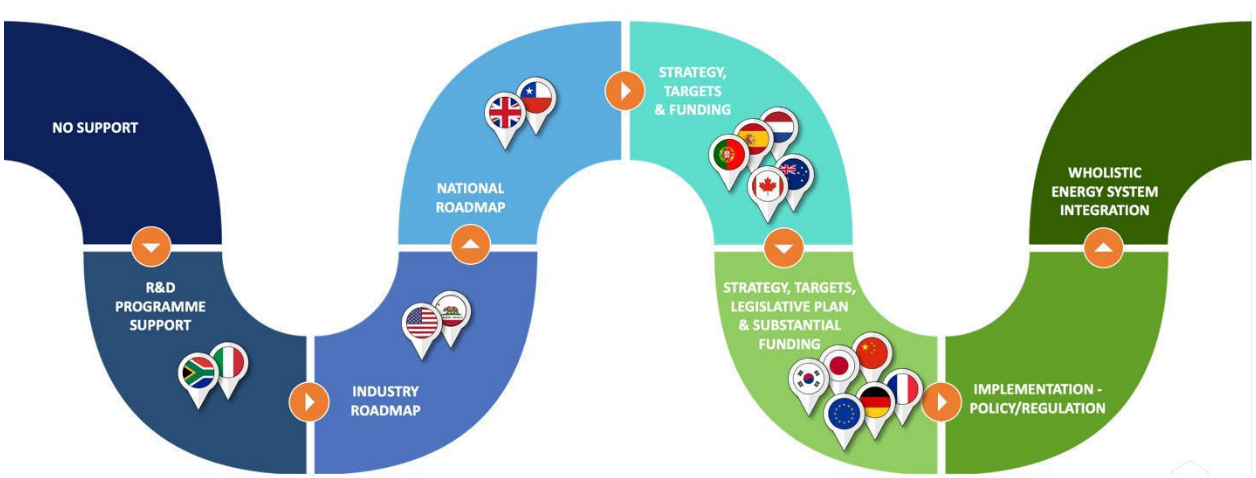
TABLE OF CONTENTS

1 INTRODUCTION

A key component of any strategy to decarbonize the economy and promote US manufacturing and innovation is hydrogen. Hydrogen is a versatile, clean, and safe energy carrier that can be used as fuel for power or in industry as feedstock. It produces zero emissions at point of use. It can be stored and transported at high energy density in liquid or gaseous form. It can be combusted or used in fuel cells to generate heat and electricity.[158] All of these qualities make it a critical enabler of the energy transition as a means to store renewable electricity, as a zero-tailpipe emissions transportation fuel, or as a clean solution for industrial processes. Europe and East Asia are investing heavily in hydrogen and fuel cell technologies, with the European Union pledging to invest hundreds of billions of dollars and publishing a regional hydrogen strategy, South Korea committing to invest $34B, and Japan publishing the first ever national hydrogen plan.[159] Comparable US investment and planning for the hydrogen economy will create economic and competitive benefits commensurate with the decarbonization prospects of the technology. Similarly, the US must invest in scaling up capacity and reducing the cost to produce hydrogen and the infrastructure to deploy it in the applications where it is cost effective and achievable. Finally, policy makers must use available tools to solve the problems the market cannot: infrastructure, development and deployment.

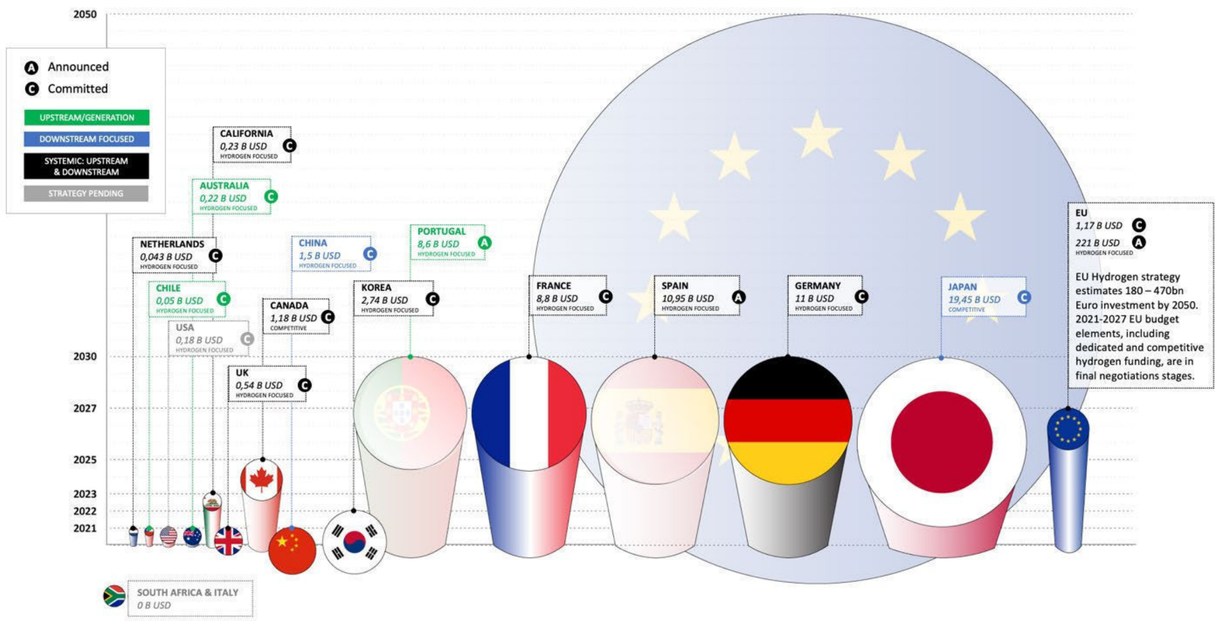
Figure 1 – Many countries are well advanced with national strategies, targets and funding

(Source: Hydrogen Council)



[158] (Hydrogen Council, 2017)
[159] (US Fuel Cell Hydrogen Energy Association, 2020)

Figure 2 – Significant Funding Commitments for Systemic Support (Source: Hydrogen Council)



2 DECARBONIZING HYDROGEN

Generating electricity from intermittent renewable energy sources and increasing electricity demand will create enormous strain on the electricity generation capacity. Grid capability, intermittency, as well as application of low-carbon seasonal storage and back-up generation capacity will be challenges to address. Hydrogen helps optimize the power system for renewables, facilitating further increases in renewable share of generation. One technology that harnesses renewable electricity to produce hydrogen is electrolysis. Electrolysis produces hydrogen by using (excess) power supply and enables its use in other sectors (transportation, industrial processes, residential heat) or to store it for future re-use. Hydrogen has the potential to improve economic efficiency of renewable investments, enhance security of power supply and serve as a carbon-free seasonal storage, supplying energy when renewable energy production is low and energy demand is high, e.g., winter in the Northeastern United States. [160]

Some hard-to-abate sectors cannot be decarbonized via the grid or with batteries, like heavy duty or off-highway transportation. In many of these sectors, direct electrification is and will remain technologically challenging or economically inefficient. Green hydrogen (produced with renewable energy) offers a decarbonized solution for these applications. Investing in these decarbonized hydrogen sources will realize both the economic, climate and air quality benefits detailed in the following section.

[160] (Hydrogen Council, 2017)

3 ECONOMIC AND COMPETITIVENESS BENEFITS

According to the US Fuel Cell Hydrogen Energy Association Roadmap to a US Hydrogen Economy, by 2030, the hydrogen economy in the US could generate an estimated $140 billion per year in revenue and support 700,000 total jobs across the hydrogen value chain. By 2050, it could drive growth by generating about $750 billion per year in revenue and a cumulative 3.4 million jobs.[161] Hydrogen's potential for decarbonizing transportation is discussed elsewhere in this report (Section 6-2 Hydrogen Opportunity), and the building blocks achieved by scaling up use in commercial transportation markets are key to widespread adoption of hydrogen production and decarbonizing tough to abate sectors like logistics, industrial heating and industry feedstock.[162] Because of hydrogen's potential for many industries, effective deployment of the technology will require labor skilled in the manufacturing, automotive, energy, industrial and logistics sectors, and all of the multiplier effects that entails. Revenue and jobs grow along this value chain, as depicted in the US Fuel Cell & Hydrogen Energy Association's Roadmap to a US Hydrogen Economy Report:

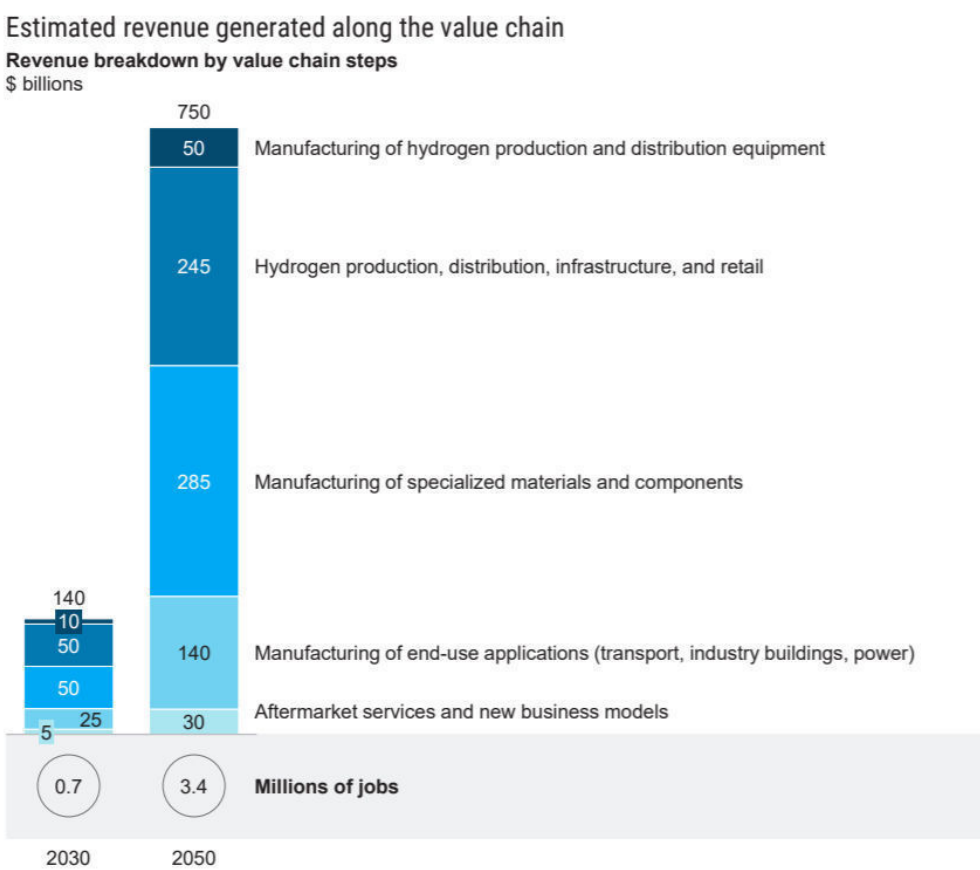


Figure 3[163]

[161] (US Fuel Cell & Hydrogen Energy Association, 2020)
[162] (Hydrogen Council, 2020)
[163] (US Fuel Cell & Hydrogen Energy Association, 2020)

US government investment in the hydrogen economy will also strengthen competitiveness. European and Asian governments have invested hundreds of billions of dollars globally to develop their regional hydrogen industries.[164] The US has a comparative advantage as a domestic producer and global supplier of oil and gas. The existing infrastructure and networks for this industry can be repurposed for US exports of decarbonized hydrogen[165] as countries commit to aggressive emissions reduction goals to meet the objectives of the Paris Climate Agreement.[166] US leadership in this space will be useful not just economically, but diplomatically as well. The US is already a leader in hydrogen and fuel cell technology development. The US Department of Energy's Hydrogen at Scale (H2@Scale) Initiative explores the potential for wide-scale hydrogen production and utilization in the United States to enable resiliency of the power generation and transmission sectors, while also aligning diverse multibillion-dollar domestic industries, domestic competitiveness, and job creation.[167] H2@Scale outlines the role hydrogen and fuel cells can play throughout the US value chain:

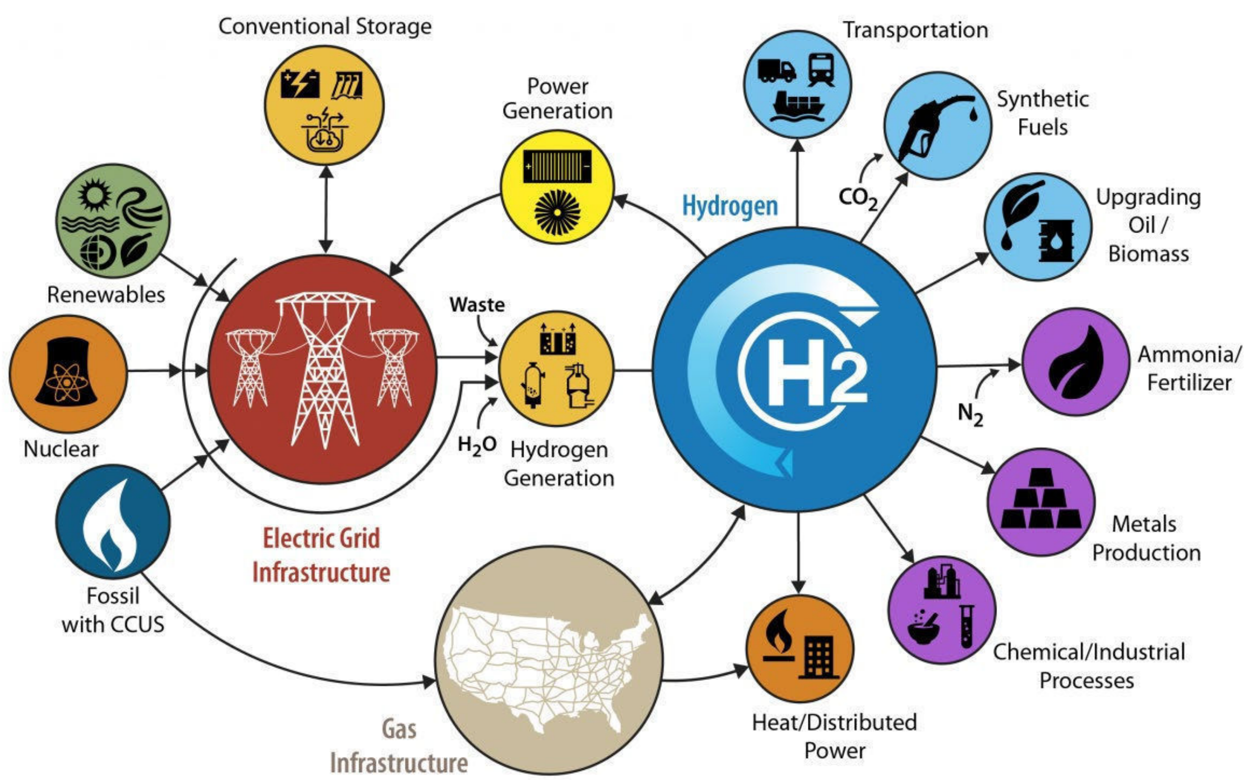


Figure 4[168]

The ability for hydrogen to fill energy and power gaps nationwide presents a tremendous opportunity for US jobs, economic growth and competitiveness over the next 30 years of the energy transition.

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164 (US Fuel Cell Hydrogen Energy Association)
165 (International Renewable Energy Agency (IRENA), 2019)
166 (Hydrogen Council, 2017)
167 (Department of Energy, 2020)
168 (Department of Energy, 2020)

4 VALUE IN SCALE

To achieve this potential, it is critical that the US government set a vision for scaling up. The transition cannot happen overnight, and investments by both public and private sector should be done thoughtfully, with a focus on closed eco-systems that can transition broadly and early, with accompanying air quality benefits, like ports and industrial facilities. The following graphic from the Hydrogen Council's Pathways to Hydrogen Competitiveness Study outlines the 5 complementary levers to encourage thoughtful deployment:

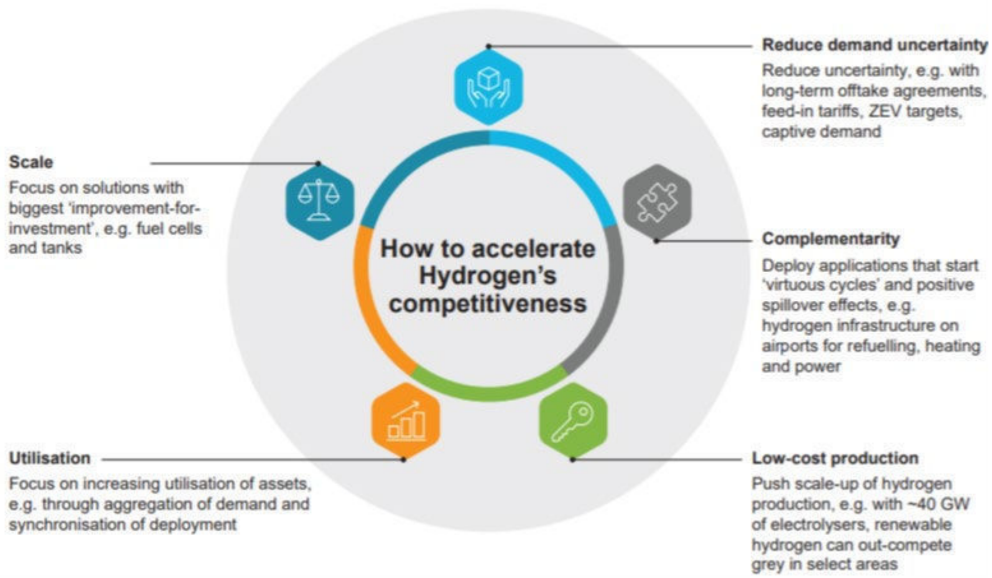


Figure 5[169]

Regulatory policies adopted by Public Utility Commissions, regulators and markets like long-term offtake agreements, feed-in tariffs and transportation emissions reduction targets can ensure investors of continuing demand and reduce uncertainty as a barrier to developing hydrogen projects. Early deployment in complementary applications, like ports, can create virtuous cycles that quickly scale up and reduce cost. A port, for example, could invest in renewable electricity for green hydrogen production through electrolysis to and use the hydrogen produced to power its forklifts, drayage trucks and even facilities power. That initial ecosystem could grow to power the rail and long-haul trucks that move goods inland, and even the ships the ports serve. This, of course, would require low cost production of low carbon or renewable hydrogen, which can be achieved by continued scale from these initial pilot programs. This type of deployment speaks to the utilization potential of hydrogen across the value chain. Another example being industrial processing facilities that already use hydrogen produced by steam-methane reformation (SMR) to refine fuels, among other things. Deployment of large scale electrolyzers in these hard-to-abate sectors will enable efficient utilization of the resources available. Finally, focusing on scaling up complementary technologies with the most room for improvement per investment- like proton exchange membrane (PEM) or alkaline fuel cells that run on hydrogen and

[169] (Hydrogen Council, 2020)

hydrogen storage tanks, can further increase the use-cases for the hydrogen produced. Each piece of this puzzle not only reinforces the use case, but lowers cost for the others, enabling a smart and strategic scale up for US industry.

5 POLICY LEVERS

US policy to accelerate adoption of hydrogen and fuel cell technologies should adopt three goals: promoting infrastructure, development and deployment. There are several levers Congress and the Administration can use to achieve those goals. Congress can enact tax policy and establish development and deployment grant programs throughout government and procurement agencies. The Executive Branch can implement regulations that reduce emissions for current technologies and close the cost delta between conventional and decarbonized technologies. Both branches should promote long-term shared vision strategies to give investors and business visibility to invest in the right technology and project development.

Clean energy technologies like wind and solar were adopted because of technical advancements made in partnerships between industry and national labs, and tax policy that incentivized adoption. Hydrogen, similarly, can solve for the development side of the equation by continued robust funding for DOE's H2@Scale Initiative[170]. Additional research is needed to optimize for weight, cost, efficiency and manufacturing capability of both hydrogen and fuel cell technologies, and to optimize their performance for various applications like long-haul trucking and stationary power generation.

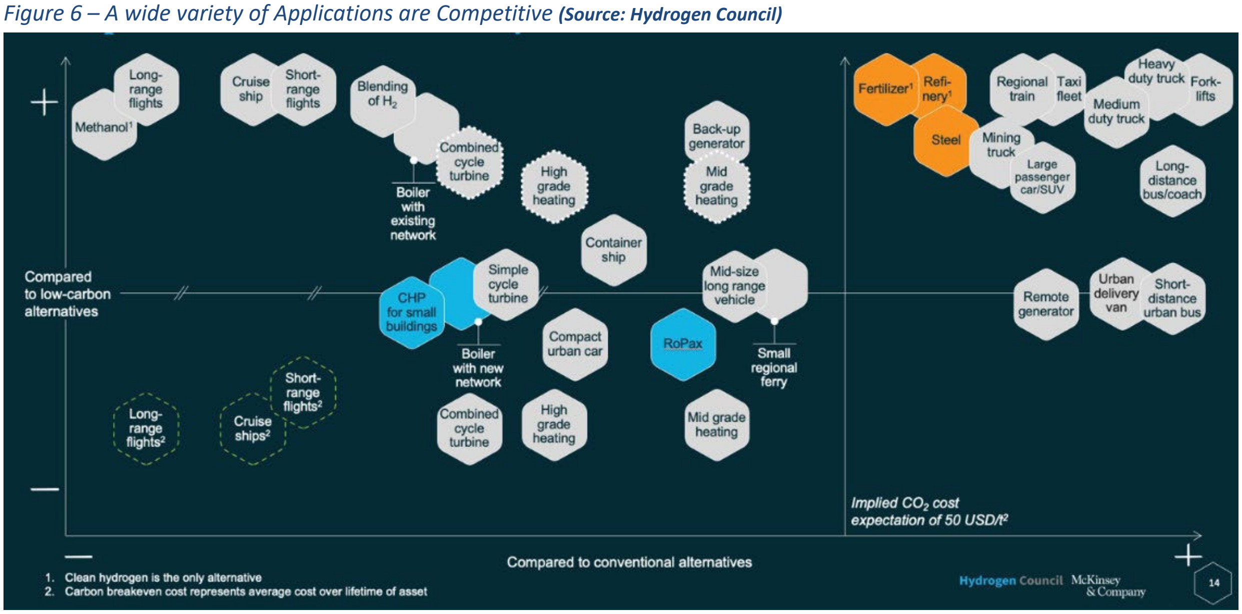
Deployment can be achieved by long-term extension and expansion of tax credits for fuel cell powered vehicles, hydrogen fueling infrastructure and fuel cell stationary power (Secs. 30B, 30C and 48 of the tax code respectively). Additionally, new tax credits should be created to incentivize investment in clean hydrogen production equipment and energy storage with hydrogen as an applicable technology. Complementary technologies like carbon capture, utilization and sequestration (45Q) that can effectively decarbonize hydrogen should also be extended and expanded.[171] Existing or new grant programs for federal procurement of fuel cell powered federal fleets, a federal clean energy standard, and low carbon fuel incentives can also drive adoption. Regulatory policy also has a role to play. More stringent regulations on emissions from stationary and mobile power sources will drive additional technology on incumbent applications. When that equipment becomes more expensive, the delta between incumbent technologies and decarbonized options shrinks, creating more market pull for hydrogen and fuel cells. This clarity and vision from the tax code and federal policy will send a signal to the market to continue robust investment in these technologies and projects to advance the scale up discussed in the previous section.

[170] (Department of Energy, 2020)
[171] (US Fuel Cell & Hydrogen Energy Association, 2020)

Robust investment in infrastructure by the federal government is also needed. Alternative Fuel Corridors as proposed in Senate Bill 2302[172] would enhance a grant program available to state and local governments, private entities and manufacturers to develop alternative fueling and charging stations for designated corridors. This program would create hubs to build out hydrogen fueling infrastructure as another way to achieve the scale discussed in the previous section. Additional grant programs should be created for industries where hydrogen presents a decarbonization opportunity. Existing programs like the Diesel Emissions Reduction Act (DERA), DOE's Clean Cities Program, DOE's State Energy Programs, Department of Transportation's (DOT) Lo-No Emissions Vehicle Program, DOT's Congestion Mitigation and Air Quality (CMAQ) all present opportunities to include robust hydrogen projects as part of their clean air and energy goals.[173] By including robust funding through Congressional authorization and appropriations to build out the infrastructure and capability of hydrogen technology, Congress can send a strong signal to manufacturers, investors and industrial companies that the US is committed to decarbonizing these sectors, and the private investment needed to match these ambitions is worthy.

Hydrogen and fuel cell technologies present a fantastic opportunity to enable widespread renewable energy adoption while also decarbonizing hard-to-abate sectors. Investing in the US hydrogen economy can create jobs, growth and increase American competitiveness. Scaling up the hydrogen capability domestically will reduce costs and accelerate adoption of decarbonized hydrogen more quickly if done strategically and with national leadership. This can be achieved by policies that promote additional development, deployment and infrastructure through tax, grant and regulatory policy. The works sited in this section provide deeply researched roadmaps to scale up the industry, decarbonize the fuel and promote the hydrogen and fuel cell economy in the United States. Realizing the potential of hydrogen can go a long way toward reaching the goals of the Paris Climate Agreement of net-zero emissions by 2050.

Figure 6 – A wide variety of Applications are Competitive ***(Source: Hydrogen Council)***



172 (Senate Environment and Public Works Committee, 2019)
173 (US Fuel Cell & Hydrogen Energy Association, 2020)

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Daryl Wilson - Executive Director

AMERICA 3.0

NEW ECONOMIC OPPORTUNITIES AND MILLIONS OF NEW JOBS

Working Narrative with Indicative Results
for the America 3.0 Transition

ECONOMIC AND HUMAN DIMENSIONS RESEARCH ASSOCIATES

*See Appendix for a description of Economic and Human Dimensions Research Associates's scope of work

TABLE OF CONTENTS

1 THE ROLE OF OPPORTUNITY COST IN AN ECONOMIC FUTURE

Choices have consequences, whether directly or indirectly. For example, the oil and gas industry now supports as many as 10.3 million jobs within the United States.[174] The statistics bear that out. But it is also true that our use of oil and gas resources contributes about two-thirds of the nation's energy-related carbon dioxide emissions.[175] Moreover, one recent study by the International Monetary Fund (IMF) suggests that gasoline usage may create a series of climate, air quality health, and other economic burdens which have a cost of roughly equal to $1.94 per gallon of gasoline. While natural gas is considered a significantly cleaner fuel, that same IMF study indicates that it might have a climate and environmental health burden of 33 to 44 cents per gallon of gasoline equivalent.[176] So natural gas is cleaner but still has a significant cost.

With that backdrop, the question that may naturally arise is whether the trade-off or the benefit of 10.3 million jobs is worth the health and environmental damages driven by the large-scale consumption of oil and gas resources? In other words, what is the "opportunity cost" of continuing any given level or pattern of energy consumption? And might we pose an even better question by asking whether we can get more jobs, with even greater additional economic benefits, by investing in alternative energy strategies other than conventional fuels—in this case a of combination greater energy efficiency and renewable energy resources on the same scale of current oil and gas consumption. If we step back and actually explore the full array of the evidence now available to us, it appears that the same money we now spend for oil, gas, and coal might actually produce substantially more employment opportunities if scale up our investments in both energy productivity improvements and the green energies. More critically, it does appear that if we ask the right questions, we can provide an increase in total jobs, even as the new series of choices allow a significant reduction in greenhouse gases and other air pollutants. This will all, in turn, facilitate the transition to a generally healthier environment. . . and economy.

In this analytical narrative we explore the logic and consequences of investing in two different kinds of energy infrastructures. The first is an infrastructure that depends on the more conventional development of fossil fuels as part of the 20th century buildout. The second is a more complex, vibrant and smart Third Industrial Revolution Infrastructure which our colleague Jeremy Rifkin calls *America 3.0 The Resilient Society*. Among the key factors that will enable this 21st Century transition is the more productive use of clean energy resources as their higher level of aggregate efficiencies allow "ever-larger collectivities of human beings to

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[174] See, for example, "Execs' Open Letter to 2020 Candidates Promotes Oil & Natural Gas 2/24/2020." As explained in subsections 4.2.2 of this narrative, the 10.3 million jobs cited here reflects not simply the direct jobs in the oil and gas industry, but also the indirect and induced jobs also supported by the larger industry's revenues. https://www.westernenergyalliance.org/pressreleases/execs-open-letter-to-2020-candidates-promotes-oil-natural-gas

[175] *Annual Energy Outlook 2020 with projections to 2050* (AEO 2020). Table 18 on Energy-Related Carbon Dioxide Emissions by Sector and Source. Washington, DC: U.S. Energy Information Administration. https://www.eia.gov/outlooks/aeo/tables_ref.php

[176] Parry et al. (2014). This was a book which explored how energy prices might be adjusted to reflect the costs of air pollution, the impacts of climate change, and other economic burdens. The original values for gasoline were listed as $0.43 per liter, and for natural gas as $2.30 per gigajoule and $3.10 per gigajoule—in 2010 U.S. Dollars. Using appropriate heat values and the rate of inflation from 2010 to 2020, the values were adjusted for easier comparison as shown in the text.

engage in more complex, integrated, and inclusive economic, social, and political life as an extended social organism."[177]

We explore these choices in four separate ways. First, we provide an initial backdrop to understand how greater energy and resource productivity—what we call higher levels of aggregate efficiencies—can promote a more robust social and economic well-being. Second, we look at the way jobs might be supported by different patterns of investments and energy expenditures. Next, we explore potential impacts of air pollution and the consequences on the health and economy nationally. And finally, we explore the possibility of severe climate disruption. All of these have very real social, economic, climate and other environmental consequences.

[177] The America 3.0 Framing document.

2 OVERVIEW OF U.S. ENERGY CONSUMPTION

In 2019, the 331 million people living within the United States spent an estimated $1.2 trillion to meet their combined needs for an array of energy services (EIA 2020)[178]. That is equivalent to an economy-wide per capita energy bill of about $3,600 per person per year (with costs expressed in 2019 constant dollars). The many payments that were made each day, or each month, for energy services that enabled U.S. residents to cool and light their homes, drive to work, listen to music, or watch television. For some, the payments simply provided the means to maintain a comfortable home. For others, the disbursements powered their many business enterprises. Purchases of electricity enabled access to the Internet, as well as filtering and purifying the water that was delivered to local homes, schools, and businesses each and every day. In short, the variety of energy services impacted almost every element of our social and economic well-being.

Although the U.S. economy derives important benefits from the use of the many different forms of energy resources, the inefficient use of all forms of energy also creates an array of costs and constraints that burden our economy. As one critical example, the incomplete combustion of fossil fuels releases massive amounts of pollutants into the air. The current mix of energy resources used to support worldwide economic activity will also result in more than $100 billion of health and environmental damages annually within the United States (Harvey 2016). According to the Energy Information Administration, the nation's energy consumption also dumped 5.1 billion tons of energy-related carbon dioxide into the atmosphere in 2019 alone (EIA 2020). This contributes to an acceleration of global climate change. In addition, a 2014 report published by the International Energy Agency (IEA) noted that the inefficient use of energy imposes an array of costs which can weaken or constrain job creation and the development of a more robust economy (Campbell, Ryan et al. 2014).

As detailed in a variety of other recent studies, it turns out that both the U.S. and the global economy may only be 16 percent energy-efficient (Laitner 2019, based on Ayres and Warr 2009, Laitner 2015, and Voudouris and Ayres et al. 2015; see also, Blok et al. 2015). Said differently, of all the high-quality energy resources consumed within both the U.S. and international markets, an estimated 84 percent of that energy is wasted as it is consumed. Research by economist Robert Ayres and his colleague Benjamin Warr (2009) documents that improvements in both the quality and efficiency of delivered energy services may be the critical factor in the well-being of an economy. They further suggest that a greater level of what we might call energy productivity, aggregate energy efficiency, or simply "aggregate efficiency," may be one of the primary drivers that supports meaningful social and technological progress.

So, whether concerns are about energy costs, energy security, lagging job creation or global climate change, there is an increasing emphasis on, and review of, the role that energy plays within any national economy—or even the global economy more generally. And while there are large opportunities to promote the more efficient use of energy and other resources—for example, shifting to a smart, more productive electricity grid which supports 80 percent or more renewables—the mere existence of an opportunity does not guarantee a positive outcome. In a nutshell, the more productive use of energy and resources will not automatically

[178] EIA 2020. Op. Cit. See Table 3. "Energy Prices by Sector and Source."

happen. *It will take purposeful effort, guided by smart policies and programs, to drive the necessary activities and investments to achieve optimal, large-scale benefits* (Laitner et al. 2018, and also Lebot and Weiland 2020).[179]

But how to do things differently? What is needed to accelerate the more productive use of energy and other resources—at sufficient scale—over the next two or three decades? And equally critical, what is needed to achieve the deep reductions in energy-related carbon dioxide emissions over the next decade as suggested by the International Panel on Climate Change in a report released in October 2018 (IPCC 2018)? In the sections that follow, we briefly explore what we call the "economic imperative of much greater aggregate or resource efficiency."

Within this short narrative, especially given the time constraints to respond to a national inquiry, we cannot undertake a full-blown jobs and economic assessment which examines the magnitude of effort, the investments that are essential to elevating the performance of the American economy, and then fully document the likely very positive impacts on future employment and career development opportunities. Rather, as Rifkin highlights in the opening narrative of what we might now call the America's "innovation strategy", or the "America 3.0 roadmap," here we focus especially on *the compelling logic* of how the transformation of America's infrastructure will likely ensure a more robust social well-being and job creation process within the American economy. Equally important will be the large scale of the policies and programs required to support that transition. In this regard we then explore the employment and other economic benefits that will result from the more productive investments in the nation's appliances, equipment, and infrastructure.

[179] As the term is used here, "at scale" generally means a reduction of energy use by 40 percent or more over a projected level of consumption by the year 2040. Examples of international scenarios which achieve that scale of reduction can be found in European Climate Foundation (2010), Laitner et al. (2012), Teske et al. (2017), and Metropolitan Region of Rotterdam and Den Haag (2017). It might be worth noting that, as an update to an earlier study (Laitner et al. 2012), Nadel (2016) found that 13 efficiency specific measures in the United States, if pursued aggressively, would reduce 2050 energy use by 50 percent relative to currently predicted levels. But as he also noted, achieving those energy efficiency savings would require an expansion of energy efficiency efforts and policies well-beyond business-as-usual. And in this case, greater aggregate energy efficiency would also be enabled by a more productive infrastructure.

3 THE IMPERATIVE OF A MORE ENERGY PRODUCTIVE ECONOMY

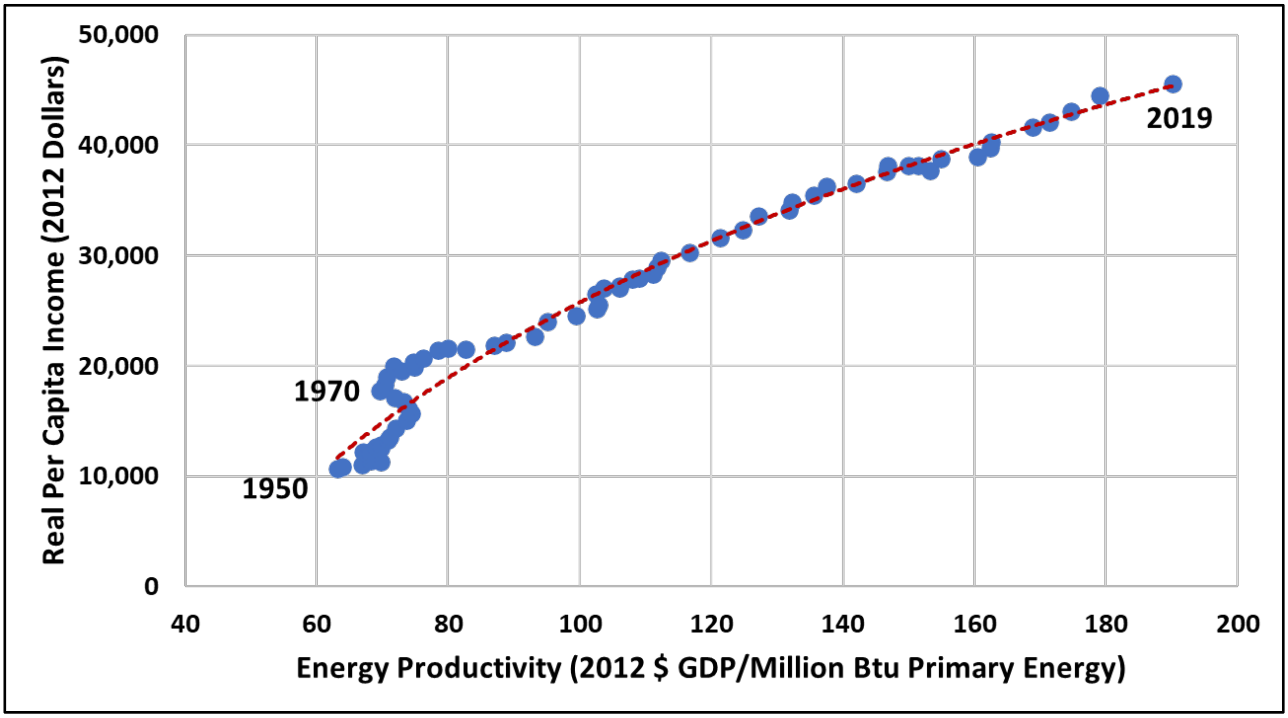
The American economy sits at the crossroads of both challenges and opportunities. On the one hand, the U.S. market shows signs of a lagging performance—among other things, weakened by the inefficient use of resources, whether capital, materials, water and especially energy. The newly released report by the American Society of Civil Engineers (ASCE 2021), for example, indicates that a weakened and outdated infrastructure will cost the average household more than $3,300 per year in disposable income through 2039. If we step back and explore the issue more deeply, we can see a slow erosion of our economic well-being over a longer historical period. Over the period 1970-2007, for instance, the nation's real per capita personal income—a useful proxy of economy-wide productivity—grew at a reasonable rate of 2.1 percent per year. Over the next 12-year period through 2019, however, the growth of per capita income weakened significantly, dropping to 0.9 percent per year (Woods and Poole 2020). Recent projections indicate the growth rate might pick up again, but it will move at perhaps a more sluggish rate of 1.3 percent over the period 2019 through 2050 (Woods and Poole 2020). The difference between a 2.1 percent rate of improvement compared a 1.3 percent implies an economy that may be 25 percent smaller than otherwise expected by the year 2050. A weaker economy means less revenue for education and healthcare, as well as likely fewer investments that can support future infrastructure improvements and upgrades.

Figure 1, below, highlights the central and critical role of energy productivity or aggregate efficiency as it supports or drives greater per capita incomes within the United States. Long-story short: there is a critical link between higher levels of aggregate efficiency as it enables a reasonable improvement in real per capita income over time. As we look at the data in Figure 1, we can see the straightforward positive connection between aggregate efficiency (i.e., energy productivity as it is defined below) and our overall economic well-being. The latter is reflected in the rise of real per capita personal income within the United States.

In 1950 the consumption of one million Btus of total energy supported only $63 of economic activity (Gross Domestic Product, or GDP, expressed in constant 2012 dollars).[180] That scale of productivity enabled an average personal income of about $10,700 per person in 1950 (also expressed in 2012 dollars). While the economic transition that followed World War II displayed an uneven improvement (though still a relatively tight pattern in those years), in the 1980s a lock-step relationship emerged. By 2019 one million Btus of energy buttressed economic activity so that it supported both $190 of GDP, together with an average income of nearly $46,000 per year. While the improvement is a highly positive outcome, the bad news—as we have already hinted—is that the rate of improvement for both income and energy productivity appears to be declining.

[180] Drawing from information published by the Energy Information Administration we learn that one million British Thermal Units (MBtu) is equal to 8.8 gallons of gasoline or 293 kilowatt-hours of electricity.

Figure 1. Trends in U.S. Energy Productivity as it tracks Per Capita Income (1950-2019)



Source: *Calculations by John A. "Skip" Laitner using EIA and BEA data for the United States (July 2020).*

As measured here, aggregate efficiency (i.e., again "energy productivity") is a function of three key elements. The first is the familiar energy efficiency improvements at the end-use level. By this we mean more efficient household or business lighting, more efficient heating and air-conditioning systems as well as the more energy-efficient appliances and equipment within our homes and businesses. It also includes the more efficient use of heat and electricity within our industrial processes. And it means greater fuel economies in our vehicle stock. The latter include not only cars and trucks, but also buses, trains, airplanes and shipping.

A second category of aggregate efficiency is greatly improving the efficiency of electricity generation. The current generation of electric power plants as well as the transmission and distribution system within the U.S. is only about 35 percent efficient. That is, for every single kilowatt-hour (kWh) of electricity delivered to our homes and businesses, the electric utility industry requires the energy of about 2.9 kWh (of heat equivalent) to generate and deliver that electricity to end-users. What our nation wastes just in the production and distribution of electricity is more than Japan uses to power its entire economy (EIA 2021).

What is the solution in this second case? We can move toward the much greater deployment of renewable energy systems. The reason? Renewable energies can transform the ratio of primary energy needs from a needlessly high level of 2.9 to a much lower and much more productive index closer to 1.0. That move alone could eliminate the need for more than 23 quadrillion Btus of energy (or Quads),[181] or on average, about 23

[181] One quadrillion (10^{15}) British Thermal Units, or a quad, is sufficient energy to power ~5.8 million homes or ~20 million cars for an entire year.

percent of both current and future energy requirements through the year 2040. In effect, the transition to renewable energy systems opens up a critical energy productive pathway.

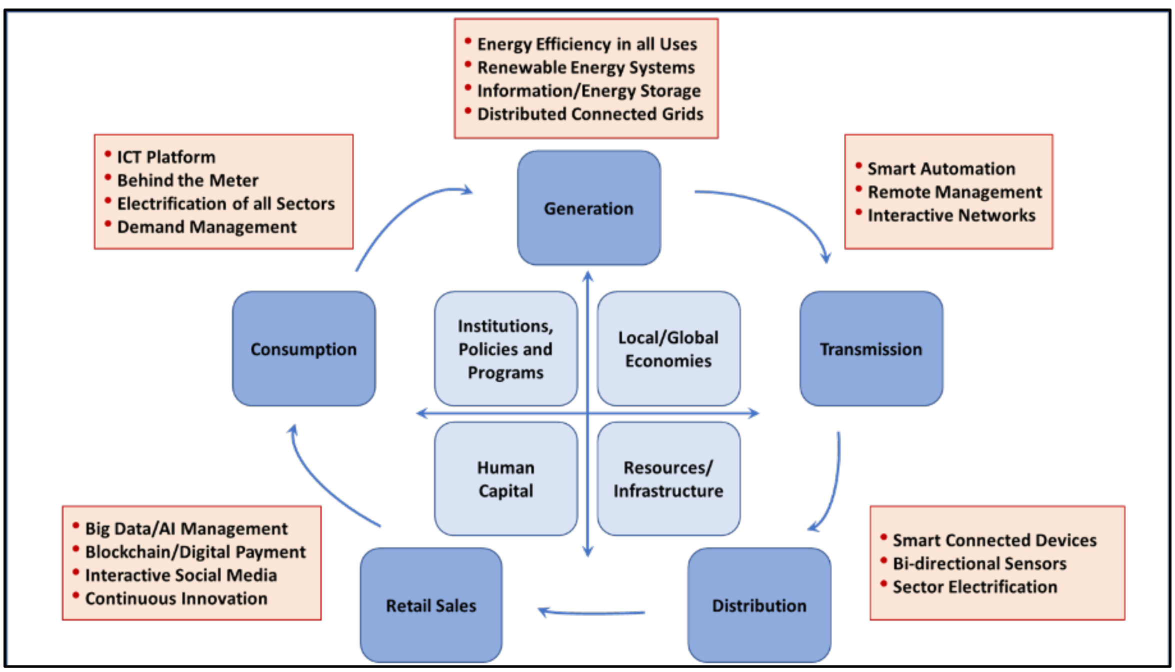
The last element of these three variables is the more productive use of capital, materials, chemicals and water. By reducing the aggregate of wastes in all of those categories, we can further reduce the energy necessary to transform such resources into the desired goods and services and distribute them in ways that support our social and economic well-being. Adding up all of these three elements—(i) greater end-use energy efficiency, (ii) the bigger deployment of renewables; and finally, (iii) the full reduction of waste in the use of all other resources—can greatly lower total energy needs, even as the nation's economy can become a more robust and a more sustainable social enterprise in the decades ahead. In other words, the elimination of waste of all kinds would amplify our aggregate efficiency that, in turn, can drive up the potential for an even greater levels of job opportunities and average personal income.

4 CRITICAL BUILDING BLOCKS AND JOBS

Notwithstanding a slow erosion in the robustness of the U.S. economy, two critical ideas emerge in how we might encourage a more positive outcome, including an expanded, renewables-oriented national grid for electricity. This follows an ongoing set of interviews and discussions with more than 100 people since August 2018,[182] as well as a detailed review of several major assessments (see, especially the narratives provided by Black & Veatch and Smith + Gill Architecture in the larger framing document of this document, as well as Laitner et al. 2012, and also 2018; Jadun et al. 2018; and IRENA 2019; among many others).[183]

First, greater aggregate efficiency, and therefore an increasing social and economic well-being, is a clearly desired outcome. Second, the transition toward that desired outcome will require a substantial upgrade in both existing and also new capital stock and infrastructure to enable the more productive use of all resources. Underpinning that transition, as highlighted in Figure 2, is an array of information and communication technologies which support a highly productive electrification of the economy.[184]

Figure 2. Array of Systems and Technologies to Transform the Energy Ecosystem



Source: *Graphic Illustration adapted from the World Bank by John A. "Skip" Laitner (July 2020).*

[182] The many interviews began as part of an invitation to help lead a three-day deep dive, "Rethinking Energy Demand," initiated by colleagues with a European team from the International Institute of Applied Systems Analysis (IIASA) and the Japanese-based Research Institute for Innovative Technologies for the Earth (RITE). This was convened September 2018 with literally dozens of interviews and discussions since that gathering.
[183] A variety of other critical assessments of future opportunities might include Blok et al. (2015), Hawken (2017), Ekins and Hughes et al. (2017); Jacobson et al. (2017), MRDH (2017), Teske et al. (2015), and Zuckerman et al. (2016).
[184] As discussed more completely in the Black & Veatch contribution to the America 3.0 assessment.

4-1 Buildout of a More Productive Infrastructure

The United States is the largest global economy with an annual Gross Domestic Product (GDP) in 2019 of more than $19 trillion per year (in constant 2012 US dollars). As big as the economy may be, a variety of documents and assessments suggest a reasonable transition of an economy, from one that uses ~100 quads of energy today, into an economy that is perhaps 80 percent larger by 2050 (EIA 2020), but also one that uses as little as 65 quads of energy in that year (as adapted from Laitner et al. 2012). This is about 40 percent less than we might otherwise require in that year. What may be less appreciated, however, is the scale of the nation's existing capital stock—a financial accounting of all fixed assets (roads, buildings, electrical generating units, as well as other structures and equipment) and consumer durables (cars and appliances with a three-year or longer life). According to data from the Bureau of Economic Analysis, our physical assets are on the order of $60 trillion (again, in constant 2012 dollars; BEA 2020). This is about 3.1 times the size of the overall scale of our economic activity. Most would agree that is a very tall order. And even more judiciously, that transformation will require a number of critical interconnected attributes as highlighted in Figure 2 above.

To drive that transition, a working estimate from IRENA (2019) suggests a total expenditure of perhaps 60 percent of one year's GDP. That is, to ensure the upgrade of the nation's infrastructure, also enabling the transition toward a more productive electrification of the economy, may require on the order of $10 to $12 trillion expended over the period 2019 through 2050.[185] The investment would enable a greater level of energy and resource productivity—again, aggregate efficiency—even as it supports a larger number of jobs as discussed in the next section that follows.

Nevertheless, a much greater level of energy and resource productivity, together with a conversion to 86 percent renewables in the generation of electricity (as suggested in IRENA 2019, but especially with contributions from Black & Veatch and Smith + Gill highlighted in this report), might lower total energy demand in 2050 to as little as 65 quads of primary energy equivalent (adapting further insights from Laitner et al, 2012). Following the assessment published by IRENA (2019), for every $1 spent for the energy transition, there would be a payoff of between $3 and $7 over the current period through 2050. This might actually increase overall GDP by 2.5 percent relative to the 2050 Reference Case published earlier this year by the Energy Information Administration (EIA 2020). If that logic holds, the implication is an economy that uses 40 percent less energy but does so in ways that greatly boosts overall economic activity. Nonetheless, a central question to be explored is how investments might actually drive new job creation, an issue explored in the next subsection.

[185] This estimate is to provide more insight than precision at this point. While various studies (see, for example, Laitner et al. 2018) support a magnitude of this scale, a better estimate would require further and a deeper analysis. This is also true for the illustration of an innovation scenario shown in Figure 2.

4-2 Exploring the Jobs Creation Benefits

The United States has a number of promising opportunities that can point the way to a more productive use of its many resources; and to do so in ways that build a more robust, resilient, and sustainable economy. Yet, in the opening of this report it was noted that the current oil and gas industry now supports about 10.3 million jobs in the United States. So, the question becomes, how might we imagine or understand the possibilities of providing an even larger number of jobs through aggregate efficiency?[186] The data in Figure 3, on the following page, provides the first really big clue of what might be possible.

Based on 2019 data from the IMPLAN U.S. national-level data sets (which, in turn, draws on public data made available through a variety of agencies and institutions), we can explore what are called total job coefficients. A subsequent discussion will identify what are called the direct, the indirect, and the induced jobs which add up to a total gain of employment for every million dollars spent within a given sector which is part of the national economy. From the summary Figure 3 graphic we can quickly see that the array of energy resources within the U.S. economy supported an estimated 11.3 total jobs for each one million dollars of purchased energy. That compares to a somewhat larger 14.7 total jobs per million dollars of manufactured goods which might be purchased, as well 19.9 jobs in the construction industry.

In a similar way, for every one million dollars spent on all other goods and serves, the nation's economy supports an average of 18.2 total jobs per million dollars of goods and services that might be purchased within a given year (IMPLAN 2021).[187] Hence, for every one million dollars of energy bill savings generated and that is spent within the country, through greater cost-effective energy efficiency improvements and investments in cost-effective renewable energy technologies, the national economy will gain a net increase of 6.9 new jobs. So, instead of supporting 11.7 total jobs for conventional supplies of energy, the economy will support an average of 18.2 jobs as the energy bill savings are spent, instead, for other goods and services within the United States.

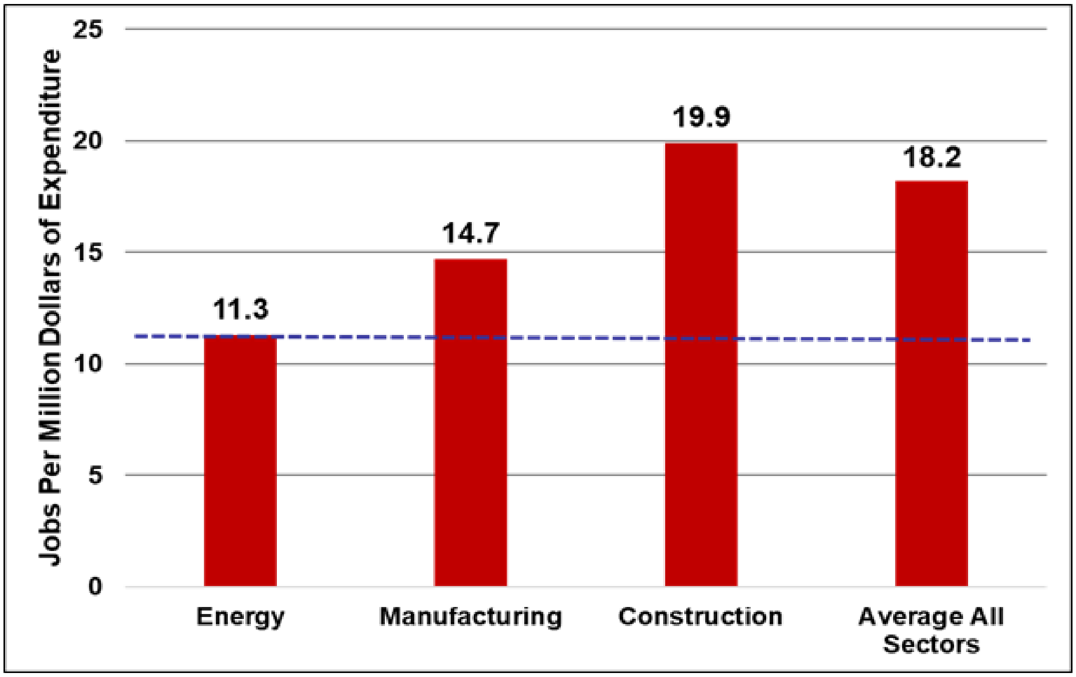
If we did the math, we conceivably can imagine more total jobs from the transition to a higher level of aggregate efficiency, but the story is much more complicated so we turn to what we might call "indicative analytics" or "indicative narratives" that describe four different links of an employment chain as a first step to understanding the full job creation potential, again within the United States. In successive order they are: (i) the seven economic drivers; (ii) the three job effects; (iii) the four substitution impacts; and finally (iv) a set of three deployment variables—all of which can affect the net job benefits. Table 1, that follows, helps open a discussion around the list of at least seven key drivers

[186] Critical to the explanation that follows is understanding that aggregate efficiency is the result of 3 key drivers, as explained in the discussion explaining Figure 1 of this report, including: (i) greater end-use energy efficiency, (ii) the move to renewable energy technologies which eliminates the need for significant magnitudes of primary energy otherwise lost in the conventional combustion process, and (iii) an improved use of capital, materials, water, and food—further reducing energy needs as part of the production process.

[187] IMPLAN LLC, Huntersville, NC. https://implan.com/. Users of the input-output economic data include academia, federal, state, and local governments, and the private sector.

that are likely to enable a more robust economy as a result of any given Innovation Scenario .

Figure 3. Total Labor Intensities for Key Sectors within the United States Economy



***Source:** John A. "Skip" Laitner, using IMPLAN 2017 Data for the United States (July 2020).*

4-2-1 Understanding the Major Drivers of Employment and Economic Benefits

The economy is not any one isolated element or even an array of investments and expenditures; rather it is a system of many interdependent interactions. We can begin to get a sense of those interactions by exploring in Table 1 at least seven different interactive influences or drivers which can positively or negatively help shape the nation's long-term social and economic well-being.

Table 1. The Seven Major Drivers of Employment and Economic Benefits

Driver	Primary Impact
Intensity Shift	Moving away from capital-intensive to labor-intensive activities
Supply Chain Build Up	Building up greater local production and local services
Energy Cost Reduction	Both unit cost and total cost savings for efficiency and non-efficiency
Productivity Boost	Expanding non-energy benefits
Managing Volatility	Smoothing out price shocks
Minimizing Disruption	Avoiding the inconvenient interruption of supply
Innovation Plus	Cost and service breakthroughs in the delivery of energy and other services

***Source:** John A. "Skip" Laitner as described and discussed in* the *text of the manuscript.*

(1) Intensity Shift: Just as some energy resources are more carbon-intensive than others—for example natural gas produces less carbon-dioxide per million Btus of energy than does coal, while renewable energy resources produce no direct emissions compared to any form of fossil fuels—different economic sectors have different income and employment intensities. As already reviewed in the Figure 3 discussion, one million dollars' worth of expenditures in various economic sectors supports different levels of employment. Although not explored in detail here, these data demonstrate the idea that the more capital-intensive energy sectors tend to support fewer jobs than almost all other sectors within the U.S. economy.[188]

(2) Supply Chain Build Up: The United States generates, perhaps not surprisingly, a large rate of value-added from the intermediate goods and services it purchases (IMPLAN 2021). To the extent that the nation is able to increase its local production capacity for key goods and services, this will increase both the resilience and vitality of the nation's economy. In the context of energy markets, reducing imports of the renewable energy systems, fostering local markets for efficiency and renewable-related industries, further enhances local economic development.[189]

(3) Energy Cost Reduction: Investments in energy efficiency and renewable energy reduce the demand for traditional energy sources, generating benefits associated with reduced purchases of traditional energy. Additionally, this reduced demand puts downward pressure on the price of traditional energy, spreading the benefits of clean energy beyond those that consume that energy. This is often referenced as the "Demand Reduction Induced Price Effects," or DRIPE (Taylor, Hedman and Goldberg 2015). Lower prices largely stem from two complementary outcomes. The first is that as less conventional energy may be required, only the lesser-cost marginal resources will be necessary for purchase. That can reduce the total wholesale costs for consumers. Second, greater productivity will place an otherwise downward pressure on other remaining resource costs.

Drawing on data from the EIA's *Annual Energy Outlook 2020* (EIA 2020), for example, if energy demand in 2050 is 70 percent of the projected level, then energy prices might be 15 to 20 percent lower than would otherwise be the case. The reduced quantity of energy that is consumed, assuming the changes are cost-effective, will directly benefit those who make improvements. The lower cost of energy will benefit all remaining uses of energy which translates into cost reductions in the purchase of other goods and services—whether food and household appliances or business equipment and industrial feedstocks. Again, as both the direct energy savings, together with the savings of less-costly resources

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[188] In economics, an input–output model is a quantitative method that represents the interdependencies between different sectors of a national economy or different regional economies. We can think of this as an economic recipe for how different sectors buy or sell goods and services to each other, and how their unique pattern of spending might support total jobs. For a more complete look at the input-output analytical technique, see Miller and Blair (2009).

[189] We can illustrate how building up greater local supply capacity can increase the robustness of the U.S. economy by adapting the idea of the Keynesian multiplier. In this case we substitute the use of domestic resources (DOM) in place of the marginal propensity to consume (MPC). Hence the formula, OUTPUT = [1 / (1 – DOM)]. For example, if a 45% of a given sector's total output is the value-added component (including profit and labor income), and if the sector imports 13% of its needed resources, then 42% of its output recipe is the domestic or local use of resources. In that case, the formula of [1 / (1 – 0.42)] suggests a base economic multiplier of 1.72 for each dollar spent by local businesses and consumers. But if that sector reduced its economy-wide imports, and if it increased the domestic purchase coefficient from 42% to 47%, then the base multiplier increases to 1.89. In other words, instead of a $100 consumer purchase that supports $172 of overall economic activity, a more internally resilient sector might support $189 of activity, without any other additional costs to the market. Presumably, the number of job opportunities will increase at roughly the same rate.

more broadly, are respent on more labor-intensive activities within the economy, the demand for employment also tends to increase.

(4) Productivity Boost: Investments in efficiency and renewable energy may impact broader economic productivity as well. For example, a given business might upgrade a variety of industrial processes that not only reduce energy needs, but a more energy-efficient industrial process might also lower the need for quantities of chemical feedstocks and water, even as it also lowers other operating and maintenance costs (Worrell et al. 2003). This, in succession, can also expand further economic opportunity.

Focusing not on GDP, but total economic output (of which GDP is a significant share), we can examine the potential scale of energy-led productivity gains within the United States as a whole. The Bureau of Labor Statistics estimated that the United States generated a 2019 economic output of $34.0 trillion as measured in 2012 constant dollars. Total wage and salary employment that year was recorded at 163 million jobs (BLS 2020). This implies that each one million dollars of economic activity supported 4.78 direct jobs within the 2019 economy. Had the nation's economic productivity been just 0.5 percent higher over the period 2009 through 2019, total output would have been $1.7 trillion larger (in 2019). Despite normal growth in labor productivity (as opposed to productivity gains in energy or capital), that extra $1.7 trillion might have supported an additional 8.2 million more jobs in that year. This underscores the importance of the productive use of all resources—whether capital, labor, materials, water, and especially energy.

(5) Managing Price Volatility and (6) Minimizing Supply Disruption: These benefits include reducing the disruption in the availability of energy and other resources, while also minimizing the negative impacts of unexpected price volatility. As the U.S. supports a more productive economy that uses fewer or less-costly energy resources, as well as other goods and services, both the nation and the global markets will enjoy a reduced exposure to unexpected market risks and price volatilities. This ensures, therefore, a greater certainty in the availability of those resources which, in turn, provides a strong foundation for both career opportunities as well as a more resilient economy.

(7) Innovation Plus: Although harder to quantify, the seventh major driver summarized in Table 1 is the greater employment and economic benefits that likely will follow a productivity-anchored energy transition which stimulates the prospects for continuous learning and the encouragement of new innovations. The likely consequence of catalyzing a broader set of improvements—whether the development and deployment of new general-purpose technologies, or innovative changes in business models—can better satisfy the social, economic, and environmental needs within a nation's economy. Equally critical, the America 3.0 Innovation Scenario and infrastructure buildout can become a way to catalyze the seventh benefit of community-based plans—an enhanced push of the economy-wide production frontier. In effect, future technologies and markets are encouraged, developed, and implemented to the long-term benefit of the economy. This thought is explored more fully within Appendix A of this report, *Further Insights on Energy Productivity and the Economy*.

4-2-2 The Three Effects of Job Creation

Each of the economic drivers described in the preceding section has a series of three separate, but interconnected, job coefficients which are described next. At this point, then we now have a series of 21 separate interactions (7 drivers, each with their three different job effects) which must be accounted for in determining the opportunities for net job creation. These interactions will be further expanded depending on the number of sectors involved in any analysis or modeling system which might be used to estimate net jobs. While the IMPLAN database has as well over 500 sectors, for example, Table 2 reports the direct, indirect, and induced effects for 6 aggregated sectors within the entire U.S. economy for 2019, the base year of this analysis.[190]

Table 2. Jobs Per One Million 2019 Dollars for Key Sectors of the U.S. Economy

Key Sectors	Direct Jobs	Indirect Jobs	Induced Jobs	Total Jobs	Average Gains in Labor Productivity/Year
Construction	6.7	3.1	10.2	19.9	0.91%
Manufacturing	2.1	4.1	8.5	14.7	1.89%
Energy	1.3	2.4	7.6	11.3	2.62%
Finance	3.0	4.0	10.1	17.0	1.32%
Government	8.8	0.5	11.5	20.8	0.91%
All Other Sectors	5.3	3.2	9.7	18.2	1.47%

Source: *IMPLAN U.S. 2019 data and BLS estimates of labor productivity improvements (January 2021).*

The three separate effects for different categories of total job impacts affected by the spending in any given sector, include:

Direct Effect: These are the on-site jobs created by any given investment. In the case of building a renewable energy system, the direct effect would be the on-site jobs of the construction contractor hired to carry out the work, as well as others who might be carrying out related tasks to ensure the successful completion of the project. In the construction sector shown above, for each $1 million dollars spent on a new utility-scale renewable energy system, 6.7 people might be employed on average. For Manufacturing it would be 2.1 jobs while for the energy industry as a whole, it would be about 1.3 jobs.

Indirect Effect: When a contractor receives payment for installation of the PV system, he or she is able to pay others who support their businesses. This is the indirect effect which includes the staff of vendors who delivered the PV system, the banker who finances the contractor, the accountant who keeps the books for the vendor, and wholesale suppliers who provide the construction firm with other needed goods and

[190] In effect, all of IMPLAN's 544 sectors have been aggregated using a weighted average of each sector's output. Construction, for example, has 13 different subsectors combined into the single sector characterized here, and manufacturing has about 329 different subsectors which are averaged into the single sector shown in Table 2.

services. Again, for the construction sector these indirect jobs add up to about 3.1 jobs per million dollars received.

Induced Effect: The people who are directly and indirectly employed by the construction firm are able to turn around and spend their weekly paychecks within their communities. Hence, they are said to "induce" other economic activity. This refers to money received by the grocer, for instance, who hires people to work in his or her store. Referring once again to construction, the induced effect shows 10.2 jobs for each million dollars spent.

The sum of these three effects within construction yields a Total Effect of 19.9 jobs supported by a single construction expenditure of $1 million. A final category of impact is the anticipated rate of sector labor productivity as drawn from the BLS (2020) data.[191] Even at this point, however, the analysis is still incomplete since it only deals with the direct, indirect and induced effects of the investment upgrade itself. The substitution impacts must now be considered.

4-2-3 The Four Changeover Impacts of Job Creation

Following the story logic to this point, there is a third category of what we might call the four changeover impacts in how total employment can be affected by large-scale changes in the way a country might transition its overall energy services. There are two equal components, each with their positive and negative elements. The first is project implementation such as installing new commercial building upgrades or building a new photovoltaic energy system; the second are changes in energy spending patterns that result from the change or turnover in energy systems. The implementation component includes both the impact of construction and the purchase of new manufactured technologies as well as the influence of programs, policies, and practices (whether done by the private or the public sectors) to enable a desired set of upgrades to happen.

The energy expenditure component includes changes in the type of energy saved or used as they affect overall consumer costs. This incorporates both changed patterns of commodity purchases (e.g., renewable energy compared to, say, natural gas combustion generation), as well as the influence of (presumably) lower unit costs of the energy services that are delivered. Both components, in turn, are affected by linkages to other sectors, the capacity to deliver local versus imported goods and services, and an array of non-energy benefits that might also follow.

In this section we begin with an analytical (rather than the conceptual) review of how an input-output analysis might unfold by exploring the impact on different economic sectors of a nation which invests an assumed $100 million dollars in some form of a technology upgrade. For example, let us suppose (in a highly

[191] As explained more fully in Appendix B, about the DEEPER Modeling System, labor productivity means that while, say, in the average sectors of the larger economy there are 5.3 direct jobs in 2019, by 2040, at an annual rate of productivity improvement of 1.47% per year, there may be only 3.9 jobs per million dollars. The critical element is whether information technologies, greater energy productivity and productive infrastructure investments can stimulate the economy at a greater rate than gains in labor productivity. If so, and the data currently suggests, then employment can, indeed, be greater than under more conventional patterns of investments.

simplified example) that a utility-scale photovoltaics (PV) system is installed at a cost of $100 million. Drawing on data from Lazard (2020), let us further suggest that the PV installation has a 9-year payback over a 20-year lifetime. This is a conservative estimate as PV systems might now cost as little as $29/megawatt-hour (MWh), or less, while conventional generation technologies may have a cost of $42/MWh, or more (again, Lazard 2020). But if the more conservative comparison holds, then it is possible to save about $11.1 million year in lower wholesale electricity costs which are then passed onto businesses and household consumers.

The first set of job impacts occur when the utility purchases the system and then pays a construction firm to install the new system as part of the utility's generation assets. The construction firm, in turn, may buy PV equipment from an array of manufacturing industries. Those with jobs in both the direct and indirect categories then spend their incomes which induces even more employment benefits. Pulling information from Figure 3 in our example, then each $1 million of investment in the PV system supports a total of 19.9 jobs. Again, this is the sum of interconnected direct, indirect and induced effects made possible by the system upgrade. Consumer spending on local goods and services for each $1 million chunk of savings (made possible by the variety of lower energy costs) might support a total of 18.2 jobs. At the same time, each $1 million in lower utility revenues might also reduce total employment by 11.3 jobs.

In the meantime, a utility might also delay or defer all or some spending on conventional power plants or other needed upgrades in the utility system. That represents an interim economic loss to the economy. But once the new system is installed, businesses and consumers will be able to spend about $11.1 million each year for other goods, equipment and services. While that $11.1 million of savings benefits the local economy, the energy company may lose some part of its revenues which represents a loss to the overall economic activity. At this point, then, we have identified four separate changes in normal purchase patterns. Two were positive and two were negative.

As already alluded to, there are more effects than simply those directly created, for example, by the money paid to a construction firm to install the new PV system.

Investment Impact: This is the outlay for a potential system upgrade, including both equipment and labor costs as well as related services necessary to carry out the construction effort. In the case just described, it is the $100 million cost of the PV system.

Revenue Impact: This refers to the transfer of funds from one place to another which must be recorded as a loss in the overall set of transactions. In the system upgrade described here, while the construction firm receives $100 million, the energy company might defer or delay other investments or expenditures to enable building of the new systems. For this example, we might imagine the deferral of $60 million (or some other amount) that might have been spent elsewhere.

Substitution Impact: With the PV system now installed, the improvements are effectively "substituted" for some amount of conventional energy use. If that amount generates a net savings, the result is increased local spending equal to some portion of the energy savings. In this example, the assumption is that wholesale energy costs might be reduced by $11.1 million per year as the new system begins to generate electricity. As those savings are passed on to businesses and consumers, they may buy another appliance, replace some clothing, or provide a bonus to employees.

Displacement Impact: Any money saved by the lower wholesale cost of electricity may create a loss of income for the energy provider. If it occurs, such displacement may create an economic forfeiture that leads to an economic loss to the community, which will also have indirect and induced effects. In this case, a local utility may find revenues sufficiently reduced so that open jobs slots are unfilled or that some employees are asked to retire early.

From a discussion of these terms, it can be seen that a complete multiplier analysis captures the direct, indirect and induced effects of each major change in local expenditure patterns. Thus, there are two major tasks in completing an employment analysis of this type. The first is to understand just how the expenditure patterns affect each sector of the economy. The second is to identify and calibrate an appropriate economic model to reflect the total impacts of those four spending changes, both positive and negative.

Two major steps in the input/output analysis have been completed — setting up the initial dollar amounts associated with the energy system upgrade, and then developing the initial set of multipliers. We can understand how these steps fit together within an analysis by setting up a simple problem to solve.

The multipliers already referenced, and found in both Table 2 and Figure 3, reflect the direct, indirect and induced effects of an expenditure made (or lost) for each sector of the economy. At this point all we need to do is match the proper change in spending with the correct multiplier. In this example there are four such calculations to be made and summed. The steps for the first year in which the PV system is built and operated are shown next (in millions of dollars):

(1) Investment Impact = + $100 PV System * 19.9 Construction = + 1,990 Job Gains
(2) Revenue Impact = - $100 PV System * 0.6 Interim Deferral * 11.3 Utility = - 678 Job Losses
(3) Substitution Impact = + $11.1 Lower Energy Costs * 18.2 Other Sectors = + 202 Job Gains
(4) Displacement Impact = - $11.1 Energy Revenue Loss * 11.3 Utility = - 125 Job Losses
Net Impact = 1,389 net employment gains in year one

In this highly simplified example, overall employment will be strengthened by a net gain of about 1,389 jobs compared to current patterns of electricity production. This includes the direct, indirect and induced effects of all four sets of expenditures. Similar calculations also can be done for net value-added or net GDP contributions to the economy.

Under the (unrealistic) assumption that the PV system is up and running quickly in the first year, and even with paying for the system over the next 20 years but with a continued bill savings for the electricity that is generated, the benefit to the economy would be driven by equations 3 and 4. This suggests an ongoing net employment benefit of 77 jobs.

On the other hand, if a second PV system or equivalent were installed in year 2, then the economy would again benefit, in this illustration, by a net gain of 1,389 jobs PLUS the 77 jobs from the year 1 investment, or for a net total of 1,466 jobs in year 2. And should new PV systems continue to be constructed at the same scale over a 20-year period, by the year 20 the net employment gain would be 2,852 total jobs. Although that may seem a rather small number of jobs within a given economy, as the America 3.0 Transformation emerges, those $100 million upgrades would actually require a transition on the order of many billions of dollars. Hence, the scale of net jobs could accumulate to hundreds or thousands of times (or more) in the example used in this explanation.[192]

4-2-4 Three Key Deployment Variables of Job Creation.

The set of the calculations to explain and illustrate the overall methodology of an input-output analysis nicely illustrate the direct, indirect, and induced effects as they might influence the outcomes of the investment, revenue, substitution and displacement impacts. And as much has been explained to this point, there are still a few more angles to the story. They include: (i) an accounting of policy and program costs to help drive an optimal scale and resource mix; (ii) how the investment will be paid for or financed; as well as (iii) the actual payback and/or expected returns on the anticipated investments. If we can also integrate these sets of variables into our calculations, we are likely to have a more robust estimate of the employment benefits which can emerge from different technology scenarios.

Policy and Program Costs: As the old adage suggests, “It takes money to make money.” In this case, it takes policy and program efforts necessary to drive the required scale of investment and the optimal mix of resources necessary to ensure the desired outcome (Laitner et al. 2018). Lebot and Weiland (2020) comment that it will take an adequately funded set of smart policies and effective programs, including a skilled work force, to drive the optimal scale of energy efficiency investments. Early in any given economic scenario, they note policy and program costs might require about 20 percent of needed investment. But they also suggest this might decline to perhaps 8 percent over the following two or three decades once the programs are launched. Long-time designer and implementer of community energy programs George Burmeister agrees. He notes, for example, that in May 2020 a one-megawatt (MW) photovoltaics farm cost about $1 million to build and install. At the same time, the convening local government incurred a variety of employment and other soft costs amounting to $200,000, or 20 percent of the required investment. Burmeister also indicated that the mix of policy and program costs, depending on the financial involvement of the local government and the market response, might decline to 10 percent in years 2 and 3, and even ‘approach zero’ over the next two decades.[193]

Financial Costs: A significant level of investment will have to be provided through some form of public funding or borrowing. That will clearly add to the overall cost of any upgrade. For example, if investment funds are borrowed, over a 20-year period, at an interest rate of 4.36 percent within that time-span, this will effectively increase the cost by approximately 50 percent compared to funds with a zero-interest rate or through some other form of out-of-pocket expenditures. And if the interest rate rises to as high as 7.95

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[192] As economic activity actually unfolds over time the pattern of investment and spending will actually differ compared to the very simplified example discussed above. Construction will likely proceed over a period of a couple years before energy bill savings begin to accrue. And as noted in the previous footnote, rates of future labor productivity will reduce the number of jobs in year 20 compared to year one. But while a simplified example, the logic still holds.

[193] Memo and personal communication from George Burmeister, President of the Colorado Energy Group. May 21, 2020.

percent over that same 20 years, it will effectively double the cost of investment. By way of comparison, current home interest rates are within the 3 to 9 percent range, depending on levels of down payment that might be made, credit scores and other variables.[194] As it turns out, investor-owned utilities are allowed to earn a Return on Equity invested (ROE), which is typically around 9 to 10 percent per year.[195] Given the scale of impact likely supported by the financial community, a financial cost variable, including interest or borrowing rates, should be included in any jobs assessment.

Energy Cost Savings: From an investment standpoint, whether a household consumer or an established business enterprise, the reduction in energy costs should outweigh the combination of both program and policy costs as well as the cost of financing the upgrades. For example, a 2012 study by the American Council for an Energy-Efficient Economy (Laitner et al. 2012) found that to cost-effectively reduce energy costs by 42 to 59 percent compared to business-as-usual projections for the year 2050, that annual investments would need simple energy savings paybacks on the order of 6-8 years. In simple terms, a $100 investment should lower overall energy and operating & maintenance costs on the order of $12.5 to $16.7 per year. In effect, some form of cost-effectiveness of any investment portfolio should become part of the employment analytics.

[194] When accessed on January 15, 2021, a typical range of home mortgage interest rates of ~3-8 percent can be found at: https://www.valuepenguin.com/mortgages/average-mortgage-rates
[195] https://newenglandcleanenergy.com/energymiser/2018/02/22/how-electric-utilities-make-money/

4-3 Laying Out a Representative Analytical Framework

Garrett-Peltier (2017) provided a thoughtful review that compared the employment impacts of energy efficiency, renewable energy, and fossil fuels using U.S. Bureau of Economic Analysis Input-Output tables to create a model that compared conventional fossil fuel (FF) and Energy Efficiency and Renewable Energy (EERE) expenditures. She then posed the question of what might happen if we shifted $1 billion out of fossil fuel subsidies and into public spending for EERE technologies. Her model found that there were 2.65 direct and indirect jobs/$Million while EERE expenditures supported 7.72 direct and indirect jobs/$Million. Her policy scenario, not surprisingly, found that removing $1 billion in fossil fuel subsidies cause a loss of 2,650 total jobs. Employment in EERE industries, alternatively, would increase by a total of 7,720 jobs. That change, therefore, implies a net employment increase of 5,070 total jobs per million dollars throughout the full economy.

While the Garrett-Peltier model provides a useful first approximation, it is an incomplete assessment. It does not include the induced effects of employment, nor does it include the likelihood of lower energy costs that might emerge over a 20-year period. Moreover, it does not include program costs, financing costs, the expected gains in labor productivity, and other parameters described in section 4.2 above.

4-3-1 A More Complete Assessment

In providing a more complete assessment of the job benefits which might be driven by a given America 3.0 “Innovation Scenario”, one can imagine a large number of variables that will likely impact any estimate of the absolute number of jobs created for a given year. In the illustration that follows, we demonstrate the impacts using five critical variables (with subsection 4.3.6, that follows, highlighting other variables which may also affect the job benefits reported here—both negatively and positively). As a means to explore the full scale of employment opportunities associated with the transition to an America 3.0 economy more completely, an employment assessment tool was developed for this exercise. The tool is a modified version of what is called “DEEPER Lite” within the DEEPER Modeling System.[196] The core of that tool consists of five critical components. The first, following the example of replacing fossil fuel subsidies with a share in EERE technologies, is a one-time $1 billion investment stimulus. The second is a policy and program stimulus of $200 million to drive ahead the effort in the first year of a 20-year time horizon. The third element of the DEEPER Lite employment tool is to set a range of both payback periods and interest rates to see how these might impact the net employment benefits over time. A fourth element is to include the appropriate sector job coefficients as well as their anticipated labor productivity rates. Both the job coefficients and the projected rates of labor productivity used in the employment assessment tool are those shown in Table 2. The final component summarizes the results as shown in Tables 3A, 3B, and 3C that follow.

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[196] The DEEPER Modeling System stands for the **D**ynamic **E**nergy **E**fficiency **P**olicy **E**valuation **R**outine which is consistent with the idea of “aggregate efficiency” referenced in footnote 13, and as discussed more completely within Appendix B of this manuscript. In short, here “Energy Efficiency” means all three forms of aggregate efficiency: (i) end-use energy-efficiency, (ii) the transition to renewables, and (iii) the productive upgrade to the nation’s infrastructure in a more circular economy.

Tables 3A, 3B, 3C. Annual Net Benefits from a $1 Billion Energy Upgrade over 20 Years

Table 3A. Net Energy Savings (in Millions of Dollars)

The Key Assumptions (Payback/Interest Rates)		20-Year Loan Interest Rate		
		3%	5%	7%
Simple Payback (in Years)	5	104	89	72
	7	50	34	17
	9	20	4	-13

Table 3B. Net Average Annual Jobs

The Key Assumptions (Payback/Interest Rates)		20-Year Loan Interest Rate		
		3%	5%	7%
Simple Payback (in Years)	5	2,127	2,073	2,014
	7	1,529	1,475	1,417
	9	1,197	1,144	1,085

Table 3C. Benefit-Cost Ratio (BCR)

The Key Assumptions (Payback/Interest Rates)		20-Year Loan Interest Rate		
		3%	5%	7%
Simple Payback (in Years)	5	2.38	2.00	1.70
	7	1.73	1.45	1.23
	9	1.37	1.15	0.97

Source: *Results from the DEEPER Lite Employment Assessment Tool as described in the narrative.*

With the DEEPER Lite employment tool properly benchmarked and calibrated, the tables shown above provide the reader with an overview of three different economic impacts over the years 1 through 20: (i) Table 3A, the average net energy bill (or other) savings in millions of 2019 dollars for the 20-year timeframe; (ii) Table 3B, the net annual average of jobs which might be gained; and (iii) Table 3C, the benefit-cost ratio—if we assume a discount rate of 5 percent over the same 20-year time horizon.

More critically, the tables also show how each of the three impacts might be affected under a different set of interest rates (ranging from 3 to 7 percent) and different payback periods (ranging from 5 to 9 years). Theoretically, we could show results which might stem from interest rates ranging from zero to 25 percent or more, and payback periods from six months to 20 years or more; yet, this set of results focuses on what we might think of as a central tendency—based both on common sense, as well as a larger number of studies cited here and as shown in the literature. From this backdrop, there are a number of outcomes that are worth examining.

The first big outcome is that as interest rates rise from 3 percent to 7 percent, the benefit-cost ratio (BCR) in Table 3C declines significantly; but that same ratio especially declines if there is a change in the payback period. For example, a 3 percent interest rate with a 5-year payback shows a discounted benefit-cost ratio over the 20-year period of 2.38. If we simply change the payback to 9 years, the benefit-cost ratio changes to a significantly lower value of 1.70. Similarly, if we assume a 7 percent interest rate and a 9-year payback then the benefit-cost ratio drops to below one.

From a consumer perspective—whether a household or a business—those who must pay for both the program costs, likely through some form of taxes, and similarly the investment through some combination of taxes and/or borrowing, a 0.97 BCR indicates a greater cost than benefit to the consumer. But from a macroeconomic perspective, a 0.97 BCR (Table 3C) still returns a net gain in employment for the American economy. That result is shown in Table 3B in which there are 1,085 net jobs on average per year.

4-3-2 Evaluating the Economy-Wide Net Job Benefits

Although the consumer vantage point suggests a less than desirable return from a Benefit-Cost Ratio of less than 1.0, the economy-wide perspective continues to show net positive job benefits. In fact, there is a net job creation benefit within all nine versions of the assessment calculations. One big reason as suggested in Table 2, stems from *cost-effectively changing the spending patterns away from capital-intensive energy industries to more labor-intensive sectors of the economy*. One possible interpretation of these outcomes? A positive macroeconomic outcome may be a smart reason to provide individual incentives so that consumers benefit more widely as individuals, even as the economy is also better off.

We can use the array of Table 3 insights in a variety of ways to determine the potential net job creation if we scale up from a simple one-year perspective, and then examine the full possibilities of net job creation over the full 20-year time horizon. To begin this scaling effort, we first turn to the separate investment analytics within this report provided by Adrian Smith + Gordon Gill Architecture (ASGG) and Black & Veatch Management Consulting LLC (Black & Veatch). Among their tasks was to determine the financial scale necessary to build out the *America 3.0 Next Generation Pathway*. ASGG reviewed the likely cost of the residential and commercial buildings performance upgrades. Black & Veatch examined the magnitude of the investments necessary to create the next generation of an interconnected ICT, electricity, and mobility grid. Both examined the investments required over a 21-year period. The total for all components evaluated in this report is $16.4 trillion (in 2020 dollars).[197]

[197] The reader can review and evaluate the ASGG and Black & Veatch separate assessments by turning to their contributions elsewhere in the report. Their engineering assessments focused on a 21-year period over the years 2020 through 2040 to determine the scale of investment which might be necessary. The deployment scenario characterized here also assumes a 21-year period, but it covers the years 2022 through 2042.

With a robust "first order" estimate of the investment magnitude, the DEEPER Lite Employment Assessment Tool can provide what we might again call "indicative analytics" to imagine the potential scale of jobs should, as suggested: (i) the nation increase the stimulative investment, and (ii) evaluate a cost-effective energy bill savings with other economic benefits emerging from that stimulus. Two initial first steps are helpful in building a first approximation of the likely job creation process. The first is to ensure that the $16.4 trillion is a reasonable magnitude. The second is to convert that total to the 2019 base-year dollars of the model, and to provide the equivalent of an annual stimulus over the 21-year period.[198]

As to the first step, recall that to drive a global energy transition, the IRENA (2019) study suggests a total expenditure of perhaps 60 percent of one year's GDP, or on the order of $12 trillion expended over the period 2019 through 2050. In fact, the $12 trillion magnitude fits nicely with the ASGG estimate of $12.14 trillion for the revamping and upgrading of the nation's building stock. This also includes installation of solar photovoltaic systems as part of the building upgrades. Black & Veatch has provided a detailed engineering assessment for four different components of upgrades not generally integrated into the analysis: (a) roadmapping the continental electricity internet; (b) building out microgrids; (c) deploying high-level broadband infrastructure; and (d) advancing mobility and electric vehicle support. Their total investment is $4.23 trillion. Consequently, the $16.4 trillion dollars (rounded) seems like a reasonable aggregate sum that, if properly invested, would enable a greater level of energy and resource productivity for the U.S. economy.

In the deployment scenario explored here, the assumption is that the first policy and program efforts begin in 2022 while the initial investments to upgrade the nation's infrastructure start in 2023. Over the 20-year period (2023 through 2042) the aggregate investment of $16.4 trillion becomes an average annual $820 billion stimulus.[199] And following the logic explained in section 4.2.3, each of the 20 years for which an investment is made, and in the remaining successive years of that investment, the energy and other productivity benefits add up cumulatively over time. Rather than assume an average of $820 billion per year for all years, however, the first investments begin at a lower initial effort of $300 billion in 2023, growing to $850 billion by 2027, and continuing with an annual investment of $900 billion through 2042—with all the years from 2023 through 2042 summing to the same $16.4 trillion previously noted. In effect, the scenario starts slowly and smaller in the first several years, but as more experience and successes are actually achieved, it then continues with a solid pattern through 2042.

In the assessment that follows, the first policy and program efforts are launched in 2022 with an initial spending of about $60 billion with first upgrade investments of $300 billion beginning in 2023.[200] These first

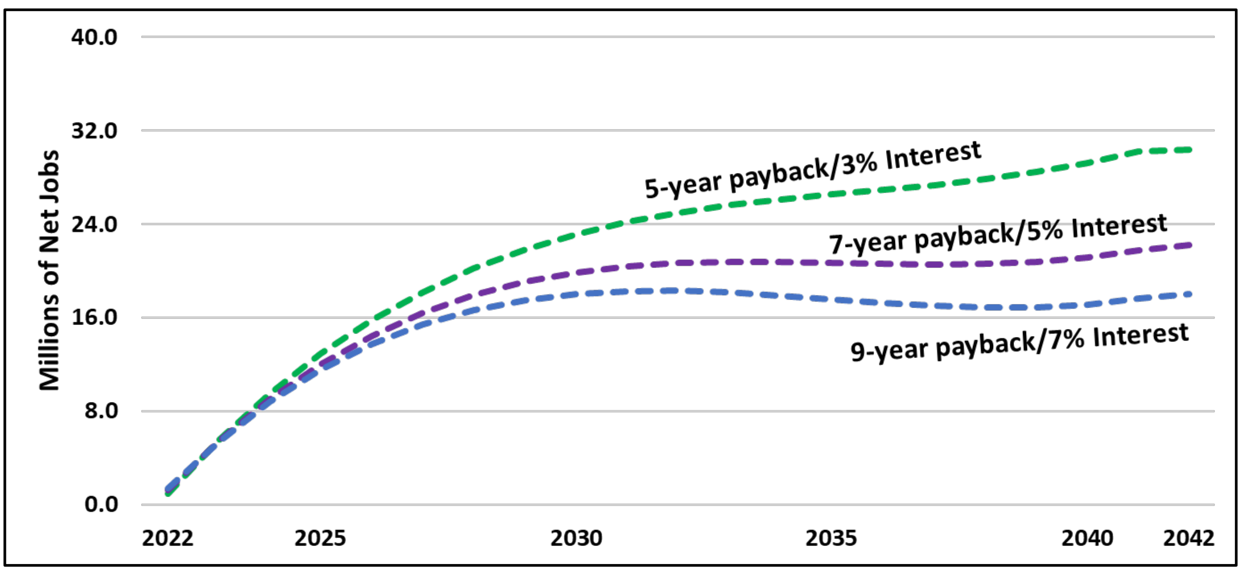
[198] Because the DEEPER Lite employment tool is benchmarked to the year 2019 IMPLAN data, we necessarily convert all 2020 financial values to 2019 constant dollars. However, the analysis will report findings based on either 2020 dollars, or in the case of GDP or other impacts using 2012 constant dollars since the America 3.0 Innovation Scenario is compared to the to the business-as-usual AEO 2020 macroeconomic scenario which is reported in 2012 dollars.

[199] The conversion of the $16.4 trillion assumes a deflator in which $100 reported in 2020 are equal to $92.05 for the year 2019. Hence, for modeling purposes, therefore, the aggregate investment total reflected in DEEPER Lite is more like $16.2 trillion.

[200] There is nothing magical about these numbers. The first policy and program expenditures, as well as the first investment amounts, could be more; and they could be less. This assessment provides only what we previously referred to as a set of "indicative analytics" to explore the logic of a major performance upgrade and its likely positive benefits. As

expenditures drive an increase of about 70,000 net new jobs in 2022 which jump to a much larger increase of 6 million new jobs in 2023 as construction and manufacturing activities begin to take hold. As highlighted in Figure 4 below, a somewhat different pattern of employment will emerge as a function of, not only the annual investments, but the different scale of benefits which might be driven by those investments. For example, and as explained further, if investments drive technologies with a high productivity benefit suggested by a 5-year payback, and if they are also financed at a low 3 percent interest rate, the transition might drive as many as 30 million new jobs by 2042 (the green line in Figure 4). On the other hand, if those investments show a lower rate of return, or a 9-year payback, and if they are financed at a significantly higher 7 percent interest rate, the net employment benefits might fall to 18 million new jobs by 2042 (the blue trajectory). Figure 4 summarizes the array of three different patterns of a net employment benefit for the U.S. economy. Rather than focus only on the number of jobs in any given year, the average number of net jobs across the full 21-year period (including the first policy and program jobs deployed in 2022) is 15 to 22 million jobs within the United States across all three scenarios.

Figure 4. The Possible Range of Jobs Given Different Payback Periods and Interest Rates



Source: *Scenario Results from the DEEPER Lite Employment Assessment Tool.*

Again, to summarize the potential employment opportunities driven by the America 3.0 Innovation Scenario, we've identified three trajectories that approach a near-zero greenhouse gas emissions target by 2042, but each with different assumptions on what the cost-effective different technologies might be (represented by the idea of a simple payback),[201] and what the interest rates might be over a 20-year investment period as

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the U.S. Congress and the Administration begin to lay out more concrete plans, both the timing and the values in any given year would vary in a pattern consistent with the actual strategy which might be implemented.

[201] We can think of the inverse of a simple payback as an indication of the annual return on investment. A 5-year payback, for example, indicates a 20 percent annual return based on some combination of energy savings and/or other economic benefits. Likewise, a 7-year payback indicates a roughly 14 percent return while a 9-year payback reflects an 11 percent return.

consumers and businesses borrow funds to drive the many different ventures.[202] Under even the more conservative assumptions, however, the productive investment in the America 3.0 infrastructure strategy should lead to a highly positive "jobs, jobs, jobs" outcome for the entire nation.

4-3-3 The Scale and Categories of Employment Benefits and Opportunities

To help us better understand how the jobs might grow, and which sectors of the economy might be affected more than others within the America 3.0 Innovation Scenario, this subsection investigates a more specific mid-range scenario. In this case, the first assumption begins with an initial 5-year payback in 2023 which grows to a 9-year payback by the year 2042. The intent is to show that as early investments rely on first returns that are more productive, later investments may have somewhat fewer benefits. It also assumed all investments are funded over 20-years at a 3-percent interest rate. To quickly review, the America 3.0 innovation upgrade begins with an initial policy and program effort in 2022, followed by the initial investment of $300 billion in 2023 which grows to $900 billion by 2028 through 2042. The annual investments then sum to the aggregate $16.4 trillion previously referenced. Again, the large initial employment benefit is estimated to be 6 million net jobs in 2023, rising to 22 million net jobs by 2042. The average annual gain of this more specific scenario, over the full 21-year time horizon, is 18.7 million net jobs.

While the analytical methodology described in earlier subsections pointed to as many as 17 key variables driving the overall result, we can more easily summarize and explain the results by referring here to three major catalysts which propel a net positive job increase in support of the nation's workforce.[203] These three catalysts are summarized next.

The first catalyst is the result of the "Stimulus Spending" itself, again with a direct and indirect benefit to the nation's demand for employment. It begins with a multi-year set of policies and programs which encourage both private and public investment, as well as workforce development, training and deployment in support of an optimal investment pattern.[204] Hence, the key sectors for this phase of the catalyst consists of

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[202] To the extent that investments may be supported by grants or zero interest loans, the net consumer savings would likely drive an even larger net-benefit for household and business consumers. As shown in Table 2, the energy industry has a total jobs coefficient of 11.3 per million dollars, while finance and the "all other sectors" show higher total coefficients of 17.0 and 18.2, respectively. So, if consumers—whether households, businesses or government enterprises—pay some level of interest on their necessary loans, that will drive more jobs than energy expenditures; but if the interest levels are lowered more completely, that will leave more consumer spending at the highest job coefficient. Hence, a small but also larger demand for labor.

[203] Again, as described in subsections 4.2.1 through 4.2.4, the 17 analytical and highly interdependent variables are (i) the 7 economic drivers; (ii) the 3 job effects; (iii) the 4 substitution impacts; and finally (iv) a set of 3 deployment variables.

[204] The assumption here is that the stimulus is exactly that—a set of policy and program expenditures, as well as investments, which drive infrastructure upgrades above business-as-usual levels. Hence, there are likely few negative impacts. On the other hand, as greater productivity enhancements take both revenue and work from existing patterns of business and employment, and then channels them into other sectors, there are indeed job losses in some sectors—although, as we shall see, there are greater job benefits elsewhere in the economy so that the net gain in jobs are entirely positive gains. Presumably, there will be programs in place to retrain workers and to ease their transitions into a new set of job skills or careers. See UAW (2020) for one useful discussion on the value of an industrial policy which emphasizes workforce retraining and deployment as part of the needed transition.

Government, Professional Services, Technical Support, and other Consulting Service sectors, each with their direct and indirect employment demands. As the policies and programs encourage the actual investments, the second phase of this catalyst draws primarily on the *Construction, Manufacturing, Technical Services and Finance* sectors.[205]

The second catalyst is what we might call the “Transition Influence.” This has both a positive and a negative consequence, also with their direct and indirect effects, consisting of: (a) fewer jobs in the current conventional energy-related sectors; and (b) more jobs supported by the purchase of the many goods and services other than the conventional energy supplies. Because conventional energy services tend to be more capital than labor-intensive, and because the purchase of other goods and services tend to be more labor-intensive, lower energy costs will drive greater employment benefits.[206]

The final catalyst is a more resilient and “Enhanced Economy” in which the direct and indirect jobs create additional consumer income that is spent on the typical pattern of goods and services throughout the economy.[207] With an appropriate accounting, and based on more conservative mid-range assumptions, again referencing an average of just under 19 million net new jobs over the period 2022 through 2042, all of these impacts are summarized in Table 4 that follows.

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[205] As described more Table 2, the direct effect is the number of immediate jobs per million dollars of spending from policies and programs as well as the actual buildout of the nation’s infrastructure. Government efforts, for example, might provide 8.8 direct jobs per million dollars of spending while construction activities might support 6.7 direct jobs. As both government programs and construction sector activities get underway, they must rely, in turn, on other sectors to support these efforts. These are sometimes referred to as the indirect jobs. Government programs may turn to other professional and technical services, for example, to enable a positive outcome. The construction sector will purchase equipment from manufacturers and other technical services to complete its efforts. These are sometimes referred to as “supply-chain” jobs. As shown in Table 2, construction activity creates an indirect 3.1 jobs per million dollars of spending while government programs may need only 0.5 indirect jobs.

[206] As also highlighted in Table 2, spending for conventional energy supports tend to support about 3.7 jobs directly and indirectly for each million dollars of revenue while other sectors tend to support about 8.6 jobs directly and indirectly. In this example, reducing conventional energy costs by one million dollars will initially reduce employment by 3.7 jobs, but as those savings are spent elsewhere within the economy, employment will increase by 8.6 jobs. In this simplified example, this becomes a net gain of 4.7 jobs throughout the economy.

[207] In this final example, the direct and indirect jobs created by the first two catalysts are said to induce an estimated 9.7 jobs per million dollars of typical consumer spending. It should be noted that this is a simplified estimate as each sector will actually “induce” a slightly different effect ranging from 7.6 induced jobs in the existing energy sectors to 10.2 and 8.5 jobs from spending by the construction and manufacturing sectors, respectively.

Table 4. Employment Catalysts – Average Impacts 2021-2040

Catalysts of Job Creation	Key Sectors	Average 21-Year Share	Net Job Creation (Millions)
Stimulus: Policy/Program Jobs	Government, Education, Technical Services, Consulting	5.3%	1.0
Stimulus: Investment/Finance Jobs	Construction, Manufacturing, Technical Services, Finance	39.5%	7.4
Transition: Redirected Energy Spending Jobs	All Sectors Supporting Households, Businesses, Government	8.3%	1.6
Transition: Energy Jobs	Mining, Production, Processing, and Utilities	-1.7%	-0.3
Enhanced Economy: Induced Jobs	All Sectors Supporting Households, Businesses, Government	48.6%	9.1
Totals		**100.0%**	**18.7**

Source: *Author calculations based on the narrative described within the text (January 2021). The totals are not consistent because of rounding.*

As already alluded to, the stimulus-related jobs are, perhaps, a surprisingly smaller part of the net increase in employment than most policymakers might imagine within the United States. The policy and program jobs drive an increase of 1 million jobs on average while investments and financial activities support 7.4 million jobs. The combined 8.4 million jobs is about 45 percent of the total 18.7 million jobs realized in the America 3.0 Resilient Society. Yet, the remaining 55 percent, or the 10.3 million net jobs, while a hugely positive impact for the American economy, would not be possible without the work of the investment stimulus.[208] Because of greater aggregate energy efficiency (including the more productive use of capital and other resources), the current mix of energy services would lose an average of 0.3 million (or 300,000) jobs per year.[209] Nonetheless, the respending of the energy bills savings on other goods and services tend to support 1.6 million jobs per year. And with an enhanced consumer spending made possible by the 9.7 million stimulus and transition jobs, an "enhanced economy" supports just under half of the total 18.7 million jobs within the 21-year period.[210]

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[208] The 10.3 million jobs cited here are coincidental to the 10.3 million jobs supported by the Oil & Gas industry referenced in the "Execs' Open Letter" found in footnote 1.

[209] We can think of the loss of 300,000 jobs more as a transition than a net loss to any given sector. In other words, while the current operation of any given utility may lose one set of jobs—say the operating staff of a coal-fired combustion turbine, those jobs can be replaced as that same utility moves to greater utility-scale photovoltaic systems. Or as that utility shifts its staffing requirements way from electricity production to provide other customer services which may also require a comparable scale of labor activities.

[210] In one sense this appears to be a large number of jobs. But including both wage and salary workers, as well as proprietor jobs, the Bureau of Economic Analysis documents as many as 203.8 million full, part-time, and proprietor jobs in 2019 alone. Hence the average increase of 18.7 million jobs is only 9.2 percent of the 2019 total jobs. For more information in this regard, see table SAEMP25N on total employment. https://apps.bea.gov/.

4-3-4 Impact of Various Occupations

Although the initial focus of this supplemental review explores how an investment stimulus, together with the resulting improvement in aggregate efficiency and greater resource productivity, can increase the social and economic well-being within the many sectors of the economy, each sector may require hundreds of different occupations or categories of jobs to support the larger activities of the economy. For example, what we might call the "utility sector" – requiring in 2019 an estimated 549,000 jobs to maintain electricity, natural gas and water services within the United States – actually requires more than 200 different occupations. And the 7.5 million jobs found within the various construction sectors also require an estimated 200 separate occupations or more to provide its many different categories of services. The occupational categories range from operation managers, human resource specialists, and clerical support to software developers, architecture and engineering professionals and a long list of production workers. Indeed, the Occupational Employment Statistics (OES) program of the Bureau of Labor Services produces employment and wage estimates annually for nearly 800 occupations.[211]

In many ways it is not so much the specific sectors that provide the benefit of a more resilient and productive economy. Rather it is combination of productive labor (given its many occupational enterprises), capital (including an array of appliances, equipment, machines together with the new infrastructure), and the more productive use of clean energy resources that animate both labor and capital. One recent study by researchers with the Brookings Institution suggests that as many as 320 unique occupations may be needed to fully promote a productive combination of clean energy production, energy efficiency, and environmental management.[212] Most of these jobs, they note, will require some level of "both vocational and professional training in design, engineering, and mechanical knowledge."

Perhaps more interestingly, the Brookings study suggests that hourly wages in these "new green jobs" exceed the national average by 8 to 19 percent. And equally important, they indicate that workers at the lower end of the income ladder can make $5 to $10 more per hour than in comparable jobs in the old economy. One big problem, they note, is that much of the existing infrastructure workforce is nearing retirement age. This poses an important question of how the U.S. might prepare the new generation workforce with the skills necessary to contribute to the active development of the America 3.0 Resilient Society. State, municipal, and county governments are just now beginning to establish what has been called "infrastructure academies" that can both retrain the existing workforce and also prepare a younger generation for the new infrastructure jobs.

Black & Veatch, on the other hand, notes that deploying this infrastructure will require a considerable focus to successfully integrate and optimize numerous hardware, software, and firmware systems from an ecosystem of multiple vendors and service providers. This will, in turn, require a new array of occupations which may: (i) either not currently exist, or (ii) may be wholly underdeveloped at this time. These new jobs may include grid update design & planning, logistics management, distributed energy resources installation, intelligent electronic device controllers, cloud architects, fiber design specialists, power quality engineers,

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[211] For more details on the many occupational and industry aggregations, see generally, https://www.bls.gov/oes/.

[212] "Advancing Inclusion Through Clean Energy Jobs." April 2019. Washington, DC: Brookings Institution. https://www.brookings.edu/research/advancing-inclusion-through-clean-energy-jobs/

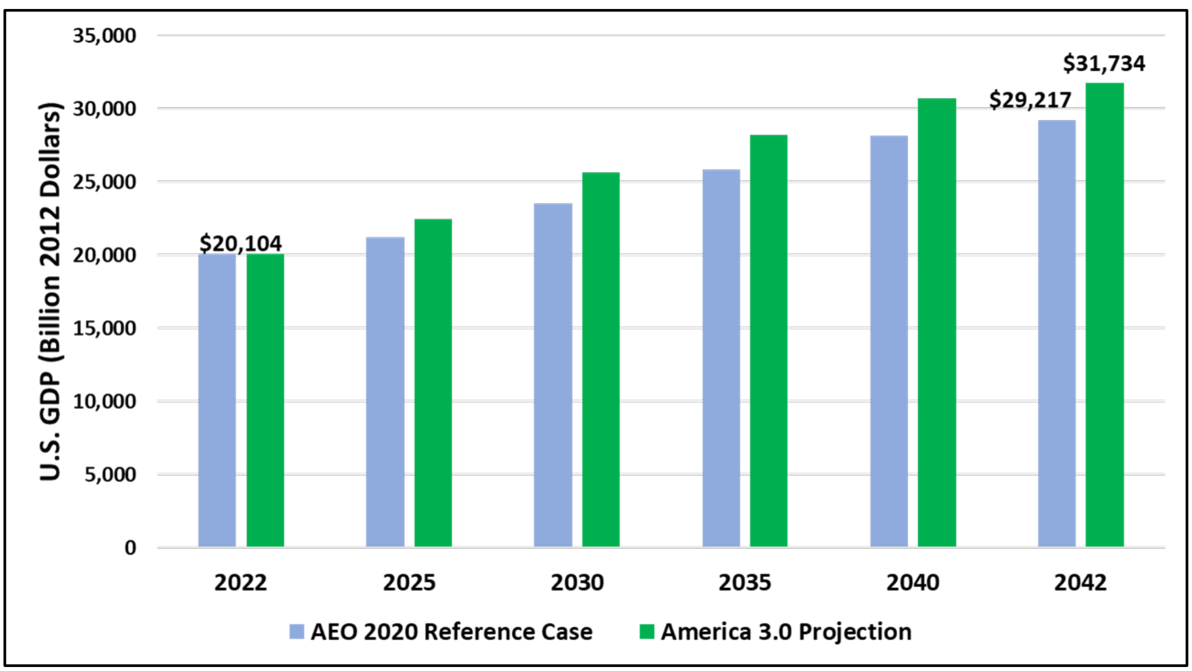
and distribution automation specialists, to name but a few.[213] To advance the deployment of an America 3.0 paradigm shift, communities across the country will need to create planning roadmaps, both to develop the new occupational skills as well as to deploy a more productive infrastructure that brings together telecommunications, smart sensors, cybersecurity, data science and new analytic skills.

4-3-5 Translating Employment into GDP Impacts

Even as we understand the positive employment benefits of an America 3.0 strategy, people will want to also know what job increases of this magnitude might imply for the larger economy – in this case, as measured by Gross Domestic Product, or GDP. Although the DEEPER Lite employment tool is exactly that—an employment assessment tool which did not evaluate the investments necessarily for their contributions to GDP, we can provide some useful metrics which point to the scale of potential GDP benefits, as they might otherwise ensure a more robust and resilient economy. Figure 5 illustrates the results of this step in the analysis.

As it turns out, a number of economic projections for the nation's GDP suggest a slow erosion of economic activity compared to post-World War II activity. In fact, the AEO 2020 forecast suggests that the nation's economy may increase by a rather lackluster performance of 1.9 percent economic growth, between 2022 and 2042 (measured in constant 2012 dollars).[214] By comparing a projected increase in GDP per job by 2042, we can – with appropriate caveats – suggest a more vigorous economic well-being as a result of the America 3.0 stimulus. Again, Figure 5 underscores the scale of that potential GDP bonus.

Figure 5. Comparing US GDP Reference Case Projections with an America 3.0 Stimulus



Source: *Scenario Results from the DEEPER Lite Employment Assessment Tool.*

213 See "Interconnected Infrastructure," pages 46-98, of *America 3.0 The Resilient Society*, TIR Consulting Group, LLC, Jeremy Rifkin, President.

214 Historically, U.S. GDP has increase about 2.8% annually over the period 1970-2019 (Woods and Poole 2020).

How did we estimate the GDP implications? The Annual Energy Outlook 2020 (AEO 2020) underpins a significant portion of the energy and economic projections used in the America 3.0 assessment. Based on the pre-Coronavirus pandemic, AEO 2020 pointed to the U.S. economy, as measured by GDP, going from $19,342 billion in 2020 to $29,217 billion by the year 2042 (in constant 2012 dollars).[215] As already indicated, that scale of change implies a growth rate of 1.9 percent per year. Analytics from Wood & Poole Economics (2020) indicate that GDP activity supported by each job within the U.S. economy will grow from $97,249 in 2022 to $112,922 in GDP outcomes by 2042 (still in 2012 constant dollars). While there are further nuances and caveats to be observed or respected, by adapting middle of the three job growth categories – that is, a net increase of 22.3 million jobs by 2042, those gains to the employment figures could boost GDP by about $2.5 trillion dollars compared to a "reference case" forecast for that year. That would, in effect, bump up the nation's GDP in 2042 to $31,734 billion. That extra bump in GDP would mean that the annual growth rate would increase from 1.9 percent, to a somewhat more robust 2.3 percent increase per year.

4-3-6 The Many Other Variables Impacting Jobs and GDP Estimates – Plus and Minus

The key macroeconomic and employment impacts described to this point—that is, an America 3.0 Innovation Scenario that positively impacts GDP by more than $2.5 trillion by 2042 (reported in constant 2012 dollars), and with an initial net gain of 6 million jobs in 2023, rising to as many as 22.3 million jobs also by 2042—is the result of what we refer to as "indicative analytics" or an "indicative narrative." That is, there currently is no set of national, state, or local plans which actually identify the actual scale and timing of investments, together with their resulting outcomes as they circulate throughout the US economy. Nor is there an actual set of programs and policies that can drive those results. Moreover, the analytic efforts are the function of only a few key economic coefficients and variables. These include the set of investments, the anticipated returns on those investments, the cost of financing the infrastructure upgrade, and relevant sector job coefficients. Yet, there are many other influences which might affect, positively or negatively, the range of benefits characterized here. They can range not only from the magnitude of capital and operating costs as they may vary over time, or the cost of financing the investments whether through incentives, tax credits, and guaranteed low-cost loans, but also the degree of imported goods and services which might support both construction and operation of new systems and the magnitude of supporting policies, programs, workforce training and deployment efforts which might drive the eventual outcomes.

While many of the emerging occupations will provide improved hourly wages and salaries, there may also be a number of lower paying jobs. But presumably, a more productive economy will lower the cost of living by a significant margin. This can help stretch the value of even lesser incomes throughout the entire workforce. For example, lower air pollution and healthcare costs, a much lower economic burden associated with improved climate change mitigation and adaptation strategies can reduce what might be termed "defensive expenditures" which give rise to a more positive spending through available personal and family income. Among other indicators are the lower costs of commuting, the reduced direct costs of pollution control, fewer automobile accidents, significantly less water pollution, a lower cost of noise pollution, and

[215] See "Table 20. Macroeconomic Indicators" in the AEO 2020 (EIA 2020).

reduced long term environmental damages.[216] Finally, as we become more productive through the Internet of Things (IoT), and related communication platforms, we can think about transitioning more of the returns on investment in ways that further benefit increased wages and salaries. And this is even before we review the lower costs of climate and air pollution impacts which we consider next.[217]

[216] Among the first efforts to compare defensive expenditures with personal income was a 1989 book by Herman Daly and John B Cobb Jr, *For the Common Good: Redirecting the Economy Toward Community, the Environment, and a Sustainable Future*. Boston, MA: Beacon Press (Second edition 1994).

[217] It is worth noting that the scale of macroeconomic benefits reported here are broadly consistent with other recognized assessments completed by the Economic Policy Institute (Biven 2017) and the Business Roundtable (BRT 2019). Bivens notes, for example, that "each $100 spent on infrastructure boosts private-sector output by $13 (median) and $17 (average) in the long run." Meanwhile, the BRT comments that "every additional $1 invested creates $3.70 in economic growth over 20 years." Also worth noting, however, is that the America 3.0 strategy similarly drives more employment and economic well-being, but in ways that also increase aggregate efficiency, and dramatically reduces both greenhouse gas emissions and air pollution. The overall benefit-cost ratio this scenario described in Table 4 is a rather conservative 1.4. In other words, each dollar of cost generates a benefit of $1.4 over the 21-year period of analysis (assuming a 5 percent discount rate).

5 AIR POLLUTION AND CLIMATE BENEFITS

As good as the larger employment outcome appears to be, it is merely one aspect of the benefit from a stimulus investment that also results in a lower total cost of energy-related services. We can also account for other social, economic, health, and environmental costs that will impact the nation's economy. As one example, a Stanford University study assessed the economic benefits that might arise should cities transition to a 100 percent renewable energy strategy. The analysis included specific impacts and benefits for the nation as a whole. Among other things, the analysts found that the cleaner air resulting from the full mix of clean energy technologies might avoid health costs generally the equivalent of 1.5 percent of America's GDP by the year 2050 (Jacobson et al. 2017).

Adopting the Stanford methodology as it might be applied to the anticipated energy consumption patterns and scale of GDP by 2042, the combined avoided air quality health effects and global climate-change could exceed $500 billion in just the year 2042 alone (with values expressed here in constant 2020 dollars). But this is a point estimate based on one published assessment. How might other studies and assessments better help us understand what those environmental, health and climate costs might be? And what exactly might the scale of those impacts be? Because of the dynamic interaction between the dispersion of aerosols and particulate matter, and the changing patterns of heat, wind, and rain, there is an overlap in many studies which examine the impacts of both air pollution and climate change. In the brief sections that follow, we principally focus, first, on the avoided costs of air pollution (or clean air benefits) and then the prospective damages that might unfold from the growing burden of climate change.

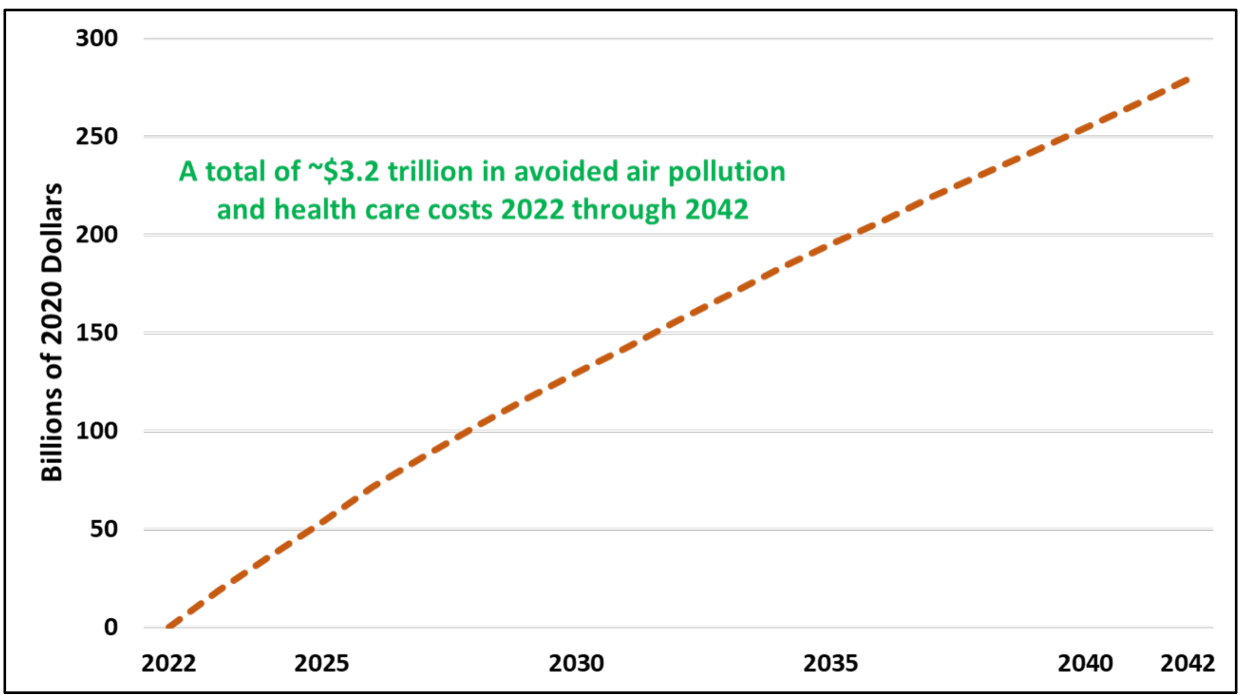
5-1 Evaluating the Clean Air Benefits

The impact of air quality can affect our lives in many unexpected ways. As but one example, the annual labor income losses from premature mortality due to air pollution exposure totaled nearly $179 billion globally in 2015. This was an increase of about $47 billion, or 36 percent in real terms, since 1995 (in constant 2014 dollars). For North America, the annual labor income losses were estimated to be $21 billion in 2015, a $5 billion or 30 percent increase since 1995 (Lange et al. 2018). The International Renewable Energy Agency documents an array of fossil fuel externality costs that range globally from $5.7 trillion to $7.7 trillion per year (IRENA 2019). On the other hand, the International Energy Agency reports that fossil fuel dependence costs of $450-900 billion per year (counting costs for health impacts of fossil fuel combustion, macroeconomic costs, and military costs for securing fossil fuel supplies) might create an economic penalty 1.5 to 4 percent of US GDP (IEA 2011).

We can bring these types of projections closer to home by using a series of air pollution externality cost factors as they might be applied to the America 3.0 strategy. There is a surprisingly large literature and research data available for this purpose. Some of the difficulty in using the different assessments is that they all use different metrics, with different base years and different time periods against different currencies. For example, the Parry et al. (2014) book cited in the opening of this narrative evaluated the impacts for coal and natural gas in terms of $/gigajoule, but they used $/liter for both gasoline and diesel fuel. Those were reported in 2010 dollars. At the same time, the U.S. Environmental Protection Agency uses current year benefits per kilowatt-hours (BPK), as measured against 2017 dollars (EPA 2019). The Stanford University report of a 100 percent renewable energy scenario evaluates the health and climate externality costs of fossil fuels in 2050 using $/kWh as reported in 2013 dollars.

The range of cost estimates vary widely. When converted from other units to dollars per Million Btu ($/MBtu), and then weighted to the same mix of fossil fuel consumption and the same year currency (2020 $), the air pollution externality for EPA is around $3.80/MBtu with a range of $1 to $8 per MBtu. The IMF cost appears to be $10.60/MBtu with a range of $2.90 to as high as $20.50 per MBtu (again in 2020 $). The central estimate for the Stanford University study is $6.50/MBtu. Some reasonably central appraisals, derived from a series of European assessments, are reported in the Regional Center for Renewable Energy and Energy Efficiency based in Cairo, Egypt (RECREE 2013). Adjusted again to 2020 dollars, they note externality costs of $2.02, $6.42, and $7.01 per MBtu for natural gas, coal, and oil, respectively. Given the current pattern of fossil fuel consumption in the United States, the fuel-weighted average is $4.75 per MBtu. This compares to an estimated average price of $15.72/MBtu for delivered energy in the United States.

Figure 6. Potential Scale of Air Pollution/Health Benefits from Reduced Fossil Fuel Usage



Source: *Scenario results as described in the narrative.*

If we apply these externality costs to the projected pattern of energy consumption within the United States over the years 2022 through 2042, adjusting for decreasing energy intensities and improved electric generation efficiencies over time, Figure 6, above, highlights the avoided air pollution and health costs annually, as the America 3.0 strategy reduces fossil fuel consumption to zero by 2042. Current AEO 2020 projections indicate that while total energy consumption is likely to rise from about 100 quadrillion Btus (Quads) of energy in 2022 to 104 Quads by 2042, fossil fuel usage is likely to remain at ~80 quads over that time horizon. But as the America 3.0 scenario begins to unfold over that same time period, and the demand for fossil fuels year-after-year begins to drop, the avoided externalities slowly begins to increase. By 2025 the benefits have grown to more than $50 billion in that year, rising steadily to just under $280 billion by 2042. The cumulative total over that time, as emphasized in Figure 6, suggests a total air pollution and set of health benefits on the order of $3.2 trillion over the 20-year period (all in 2020 dollars).[218]

5-2 Understanding Climate Opportunities

December 2020 marked the 432nd consecutive month in which nominal temperatures were above the 20th century average. The year 2020 marks the 44th consecutive year (since 1977) with global land and ocean temperatures, at least nominally, above the 20th-century average. The average temperature in 2020, across both global land and ocean surfaces, was 1.76°F (0.98°C) above the twentieth-century average of 57.0°F (13.9°C). That makes 2020 the second-warmest year on record. More critically, the annual global land and ocean temperature has increased at an average rate of +0.14°F (+0.08°C) per decade since 1880; however, since 1981 the average rate of increase is more than twice that rate (+0.32°F / +0.18°C).[219] Many assessments of externality costs, as noted above, integrate elements from both air pollution and climate change; and they are indeed interactively connected. Greenhouses gases, as one example, catalyze a heating up of the atmosphere while the increased releases of particulate matter compromises human health making people more susceptible to the coronavirus.[220]

Table 5. Period Comparisons of United States Climate Disasters Statistics

Time Period	Deaths/Year	Cost/Year (Billion 2020 $)
1980s (1980-1989)	287	18
1990s (1990-1999)	305	27
2000s (2000-2009)	309	52
2010s (2010-2019)	522	81
Last Year (2020)	262	95

Source: *Data from NOAA (January 2021)[221] with a working projection out to the year 2042 as described in the text.*

In this last subsection of the narrative, however, we can focus more closely on the climate burden that is growing in real time, and we can then get a sense of how large that impact might be if continued

[218] Because of the large variability in unit externality costs, coupled with many uncertainties on energy intensities and pollution control technologies, and other variables over time, there is likely a wide variation in potential outcomes. With time and resources, we could run a series of Monte Carlo simulations to integrate more variables and a wider range of those variables to see what that central tendency would be. Yet, this is an indicative result which is highly consistent with many other study outcomes.

[219] A more complete review of the shifting burden climate impacts is available from NOAA's Climate.gov website. At https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.Additional information and background can also be found at https://www.ncei.noaa.gov/news/global-climate-202012..

[220] See a New York Times story that, among other things, explores the links link between air pollution and coronavirus risks, https://www.nytimes.com/2020/04/07/climate/air-pollution-coronavirus-covid.html.

[221] https://www.ncdc.noaa.gov/billions/summary-stats. Statistics valid as of January 2021.

unmitigated. The investigation begins with some useful insights shown in Table 5 (above) from the National Oceanic and Atmospheric Administration (NOAA). While people and businesses are generally aware of the threats from wildfires, droughts, flooding and severe storms, they are less likely to be aware of the rising tide of such events.

Looking closely Table 5 we can see the economy-wide impacts are growing. The climate-related disasters rang up a cost of $18 billion per year in the 1980s (with 287 deaths per year), jumping to $81 billion per year by the 2010s (522 deaths per year), and in the last year alone (2020) rising to $95 billion per year (with a somewhat lower but still significant 262 deaths in that year). Without the use of any formal statistical trending technique, one could easily imagine the number of deaths per year rising into the thousands with damages which could grow hundreds of billions of dollars per year.

The question then becomes, how might we compare these historical data with magnitudes reported from other projections? We can first recall the $500 billion (also referenced in 2020 dollars) estimate from the Stanford University study mentioned in the introduction to this subsection. At the same time, we can also integrate insights from Nobel Prize economist William Nordhaus. In 2017, Nordhaus published a useful paper in the *Proceedings of the National Academy of Sciences of the United States of America* (PNAS), entitled "Revisiting the social cost of carbon" (Nordhaus 2017).

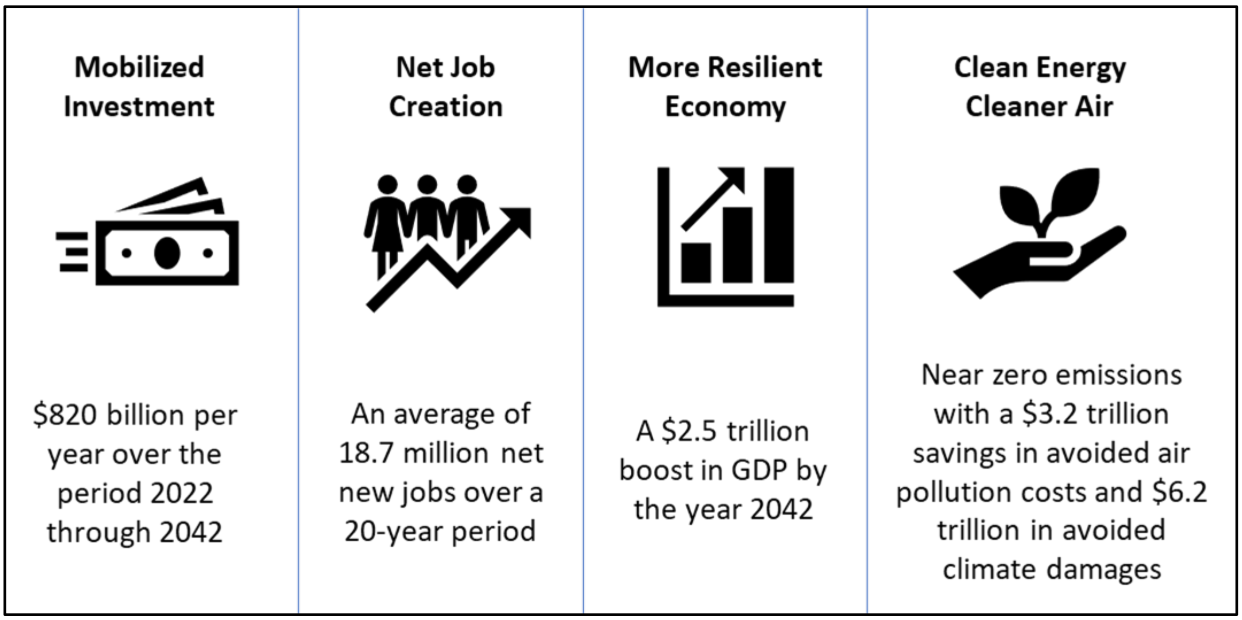
Without laying out the analytic details of the Nordhaus PNAS article, he suggests that if we move perhaps from 1°C above the twentieth-century average (where we are roughly now) to 3°C above (where we could be by 2042, if not higher), the economy may weaken by perhaps $319 billion dollars (also in 2020 dollars), which is just a little bit under the adjusted costs suggested by the Stanford University assessment. On the other hand, if we assume what is termed the *social cost of carbon* (SCC) with an average economic impact of $135 per metric ton of carbon dioxide emitted in the United States (IWG 2016), that may cost the market perhaps $640 billion by 2042 (in 2020 dollars). If that cost moves annually along the suggested pace of energy-related greenhouse gas emissions as suggested by the Annual Energy Outlook (EIA 2020), it could imply a cumulative climate cost of about $12.8 trillion over the period 2022 through 2042 (expressed in 2020 dollars). On the other hand, if America 3.0 succeeds in reducing the use of fossil fuels to near zero by 2042, that could save taxpayers, businesses, and households as much as $6.2 trillion over that 21-year period of effort. So, we have several different approaches which converge on an exceptionally large and potentially negative impact on the U.S. economy – if we do not act immediately within the framework of America 3.0.[222]

[222] The $135 per metric ton of CO_2 is an average of two data series, reflecting the rising costs of carbon over time, as documented in a working paper published by a U.S. International Working Group (IWG 2016). The original values were expressed in 2007 dollars, here updated to 2020 values. Other studies suggest that the current social costs of carbon represent a less than complete assessment which indicates an even higher social cost of carbon (Howard 2014; also, Howard and Sterner 2017). Perhaps a more disturbing report by climate research scientists (Ricke et al. 2018) underscores the importance of confronting, mitigating, and adapting to climate change. They note that the global social cost of carbon, including both climate and other health effects, may be on average $417 per metric ton (in 2005 dollars) of carbon dioxide. If those costs are paid as we purchase each tankful of gasoline, for example, that might raise the cost of gasoline by about $3.78 per gallon.

5-3 A Graphic Summary of the Potential Benefits

As highlighted in Section 4.3 of this report, and summarized in Figure 7, below, a hefty stimulus investment in the upgrade of the nation's infrastructure can deliver a large benefit to the nation's economy – both in terms of a larger return on GDP and also a greater number of jobs. In a preliminary assessment, mobilizing an upgrade of $16.4 trillion over the years 2022 through 2042 could lead to an average annual employment increase of 18.7 million net new jobs even as the nation's GDP might increase more than $2.5 trillion (in constant 2012 dollars) by the year 2040.

Figure 7. Estimated Cost and Benefits of a More Resilient, Resource Productive America 3.0



Source: *As summarized here, and Sections 4.0 and 5.0 of the main narrative for the years 2022 through 2042.*

In annual terms, over the period 2023 through 2042, the $16.4 trillion investment (expressed in 2020 dollars) is assumed to be spent evenly throughout each of the 20 years of the assessment. Although the main analysis reviews three different scenarios, for the purposes of this supplemental review the focus is on a mid-range scenario in which employment quickly increases by 6.2 million in 2021. By the year 2042 this grows to a total of 22.3 million new jobs. In effect, the resulting work that must be undertaken, together with other benefits which also boost employment, is estimated to drive an average net gain of 18.7 million new jobs over that 21-year period. Given the increased productivity of each job, total GDP in the year 2042 is projected to grow by $2.5 trillion (expressed here in constant 2012 dollars).

At the same time, both greenhouse gas emissions and the array of fossil fuel air pollutants are expected to approach near zero by 2042 under an America 3.0 strategy. That could result in a cumulative benefit of a further $3.2 trillion in avoided air pollution and health costs (expressed in 2020 dollars). Finally, the cumulative cost of avoided climate damages conservatively estimated might be on the order of $6.2 trillion, also through 2042 (with these last costs also reported in constant 2020 dollars).[223] Indeed, these findings are consistent with many other assessments. Among the more recent studies, the House Select Committee on the Climate Crisis (2020), determined that by 2050, the cumulative estimated health and climate benefits might reach almost $8 trillion (in real 2018 dollars). In 2050 alone, the House Committee report noted, the estimated health and climate benefits would exceed $1 trillion.

[223] While the investment magnitudes were first provided in 2020 dollars, the economic projections in the reference case of the *Annual Energy Outlook 2020*, op cit., were provided in constant 2012 dollars. Hence, the reference to different base-year dollars provided in this supplemental analysis.

6 POLICY IMPLICATIONS

As noted in the "Part 1: The Vision" of *America 3.0: The Resilient Society*, there is growing awareness of the possibility of a large number of programs and strategies which can enable a more skilled and more productive set of occupations.[224] As one immediate example, there is interest in establishing green academic apprenticeships in the 50 states—a Green Corps, a Conservation Corps, a Climate Corps, an Infrastructure Corps—that will provide "a living wage" and technical and professional certification and / or clinical learning credits toward academic degrees upon completion of service, allowing a younger generation of Americans to advance careers in the emerging green economy. These academic apprenticeships should be universally available, but they should also prioritize student engagement in the most disadvantaged communities. There is ample precedent for these initiatives in the United States. The Peace Corps, VISTA, and AmeriCorps have proved invaluable in encouraging public service and providing opportunities for young people to learn new skills, which have helped them find career paths and employment. Universities, trade schools, unions, and local governments across the US will play an important role in partnering with the various service corps in preparing the new green workforce of the twenty-first century.

Granting paid apprenticeships, technical and professional certification, and clinical learning credits toward academic degrees to millions of young people will provide the coming generation with the talent and skills to engage in trade, technical, and professional employment in a climate change economy increasingly focused on new resilient business models and accompanying careers. These proposed clinical learning agencies at the state, county, and local level will also be among the first responders in climate events and disaster relief and recovery missions that will increasingly be a constant reality rather than a rare anomaly.

Priorities should also be given to a "Just Transition Fund" to assist the coal regions and other regions tightly coupled to the fossil fuel civilization in making the transition into the resilient economic paradigm and the new business opportunities and employment that accompany it. Prioritizing these heavily impacted regions will be critical to securing widespread acceptance of the inevitable transformation into a new ecological era. All of this will require effort and investment beyond the working estimate of $16.4 trillion. Yet, the returns are clearly worth the added investment.

[224] See "Part I: The Vision," pages 5-44, of *America 3.0 The Resilient Society*, TIR Consulting Group, LLC, Jeremy Rifkin, President.

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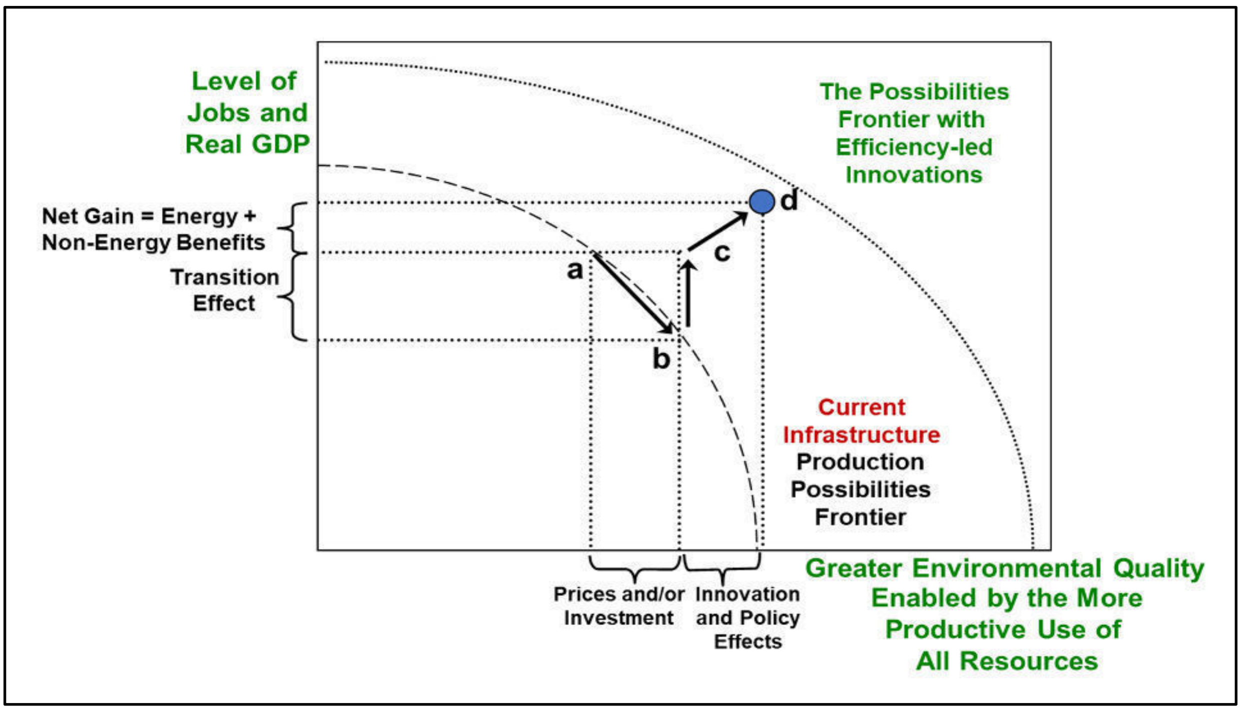
APPENDIX A
FURTHER INSIGHTS ON AGGREGATE EFFICIENCY AND THE ECONOMY

Table 1 in Section 4.2 of the main report lays out the seven major economic and employment drivers, which fully understood can help promote a more robust and sustainable economy. We can conceptually summarize all elements in Table 1 as the graphical illustration shown the diagram below which helps pull the key ideas of any likely America 3.0 "Innovation Scenario" into a useful perspective. While we cannot know at this time the scale of detectable responses to the complete set of economic stimuli, we can offer a positive overall explanation of how multiple benefits are likely to emerge through the implementation of a collaborative and productivity-led investment strategy.

Conceptual Framework for Evaluating the Global Energy Transformation



Source: *John A. "Skip" Laitner, adapted to illustrate the equivalent of an America 3.0 Transition as cited in the narrative.*

Assuming that current energy consumption and production patterns continue indefinitely would imply that the U.S. economy is already optimized on what is called a production frontier at point "a" in the above diagram. If all resources are, indeed, optimally arrayed and utilized, the country faces a tradeoff whereby increasing economic growth can only come at a cost to the environment (e.g., through the increased consumption of fossil fuels) and vice versa (i.e., that improving environmental quality means a reduction in our social and economic well-being). Any change to satisfy a demand for greater efficiencies, or the demand for large reduction in greenhouse gas emissions, must likely result in a move down and to the right to a point like "b." Although the U.S. might achieve some mix of isolated productivity improvements, and there might be some reduction in greenhouse gas emissions, conventional wisdom suggests that this must surely come at the cost of a reduction in jobs and GDP.

Alternatively, a shift to increased deployment of energy efficiency and renewables may instead allow the economy to shift to a point like “c.” The transition toward cleaner and more efficient energy systems can improve the environment while also spurring increased local economic growth. The result is an improvement in overall aggregate efficiency, especially with the more productive use of clean energy resources, even as the economy remains at a relatively stable level of GDP.

At some point, however, the various energy and non-energy benefits that result from an array of incentives and policy initiatives can boost the performance of the economy to a higher than expected level of performance. Although the figure in this appendix is not drawn to scale, the migration from point “a” to the eventual point “d” might represent an eventual doubling of energy productivity that drives a concomitant increase in economic activity or per capita GDP. Hence, a net energy savings, together with a transition to an economy powered by 80 percent or better renewable energy systems, in turn, might rouse a significant boost in net jobs, career opportunities and GDP. Equally critical, a clean energy transition can become a way to catalyze the seventh benefit of such strategies—an enhanced push of the production frontier so that future technologies and markets are encouraged, developed, and implemented to the long-term benefit of jobs and the economy.

APPENDIX B
NARRATIVE ON THE DEEPER MODELING SYSTEM

The foundation for the overall economic assessment that has been completed as part of America 3.0 planning process is the proprietary modeling system known as the ***D**ynamic **E**nergy **E**fficiency **P**olicy **E**valuation **R**outine* (DEEPER). The model, developed by John A. "Skip" Laitner in early 1992, is a compact 15-sector dynamic input-output model of a given regional or national economy. The model is essentially a recipe that shows how different sectors of the economy are expected to buy and sell to each other; and how they might, in turn, be affected by changed investment and spending patterns. Setting up that production recipe is a first step in exploring the future job creation opportunities and other macroeconomic impacts as, in this case, the United States shifts from a less productive infrastructure to the higher level of performance that is likely to be associated with what we have called here the *America 3.0 Innovation Scenario*.

Although it has been updated here to reflect the economic dynamics specific to the United States, the formal "DEEPER model" has a 29-year history of development and application while even earlier versions of the tool were used by entities like the Arizona Energy Office and the Nebraska Energy Office in the mid-1980s. The model was utilized to assess the net employment impacts of 2012 proposed automobile fuel economy standards within the United States. It also underpinned the 2012 Long-Term Energy Efficiency Potential Study previously referenced in this narrative (Laitner et al. 2012). It has been employed to evaluate the macroeconomic impacts of a variety of energy efficiency, renewable energy, and climate policies at the regional, state, national and international levels. As a recent illustration, it was used in 2017 to assess the potential outcomes and economic benefits of the Third Industrial Revolution in the Metropolitan Region of Rotterdam and Den Haag, an industrial region 2.3 million people in South Holland (MRDH 2017).

The timeframe of the model for evaluating energy efficiency and renewable energy technology policies and investments is 2018 through 2050. The years 2018 through 2020 (or earlier as needed) provide a useful historical benchmark. The period 2021 through 2050 affords an assessment of future trends. As it was implemented for this analysis, the model maps in the changed spending and investment patterns which might be undertaken as a result of the America 3.0 roadmap. The Innovation Scenario relies on a variety of data made available by IMPLAN (2020), Woods and Poole Economics (2020), the Bureau of Labor Statistics (2020), and the U.S. Energy Information Administration (2020). The Figure below provides a diagrammatic view of the DEEPER Modeling System as it was reflected within the dynamics of all previous assessments.

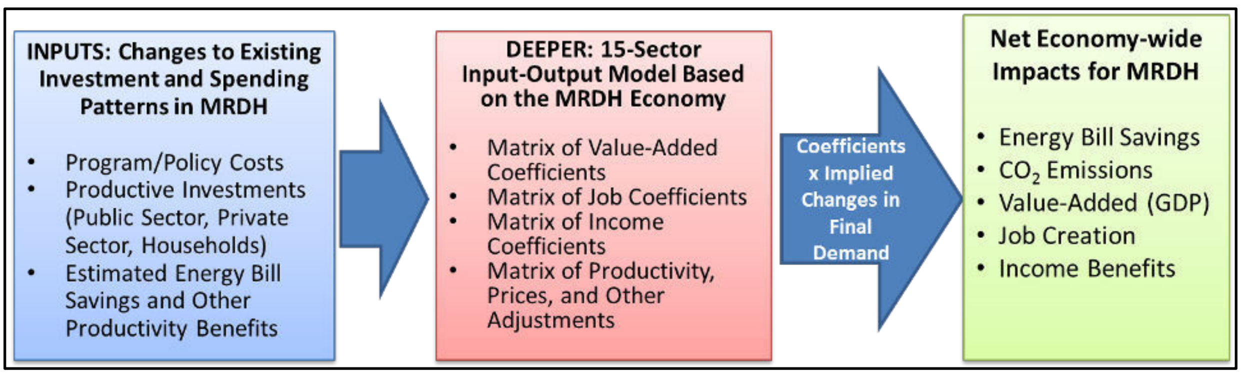
Although the DEEPER Model is not a general equilibrium model, it does provide sufficient accounting detail to match import-adjusted changes in investments and expenditures within one sector of the economy and balance them against changes in other sectors.[225] More to the point of this exercise, the model can specifically explore the energy and non-energy productivity benefits from what may often be characterized

[225] When both equilibrium and dynamic input-output models use the same technology, investment, and cost assumptions, both sets of models should generate a reasonably comparable set of outcomes. For a diagnostic assessment of this conclusion, see, "Tripling the Nation's Clean Energy Technologies: A Case Study in Evaluating the Performance of Energy Policy Models," Donald A. Hanson and John A. "Skip" Laitner, Proceedings of the 2005 ACEEE Summer Study on Energy Efficiency in Industry, American Council for an Energy Efficient Economy, Washington, DC, July 2005.

as Innovation Scenarios—especially as those scenarios are transformed into a pro-active "Roadmap Next Economy."

One critical assumption that underpins the core result of the DEEPER analysis is that any productive investment or spending—whether in energy efficiency, renewable energy, and/or a more dynamic infrastructure that pays for itself over a reasonably short period of time—will generate a net reduction in the cost of energy services (as well as a lower cost of other resources which are needed to maintain the material well-being of the nation's economy). That net reduction of energy and resource expenditures can, then, be spent for the purchase of other goods and services. We noted in the discussion surrounding Figure 3, the redirecting of $1 million in spending away from energy suggests there may be roughly a net gain of about 6.9 jobs. Depending on the many sectoral interactions, as well as the complete assessment of the many effects summarized and discussed in Tables 3A, 3B, and 3C of this assessment, the net gain in jobs may widen or close as the changed pattern of spending works its way through the model and as shifts in labor productivity change the number of jobs needed in each sector over a period of time.[226]

The DEEPER Modeling System



Note: *As discussed within this Appendix.*

Once the mix of positive and negative changes in spending and investments has been established for the America 3.0 Innovation Scenario, the net spending changes in each year of the model are converted into sector-specific changes in final demand. Then, following the pattern highlighted in the diagram of the DEEPER Modeling System (above), the full array of changes will drive a dynamic input-output analysis according to the following predictive model:

$X = (I-A)^{-1} * Y$

where:

[226] Note that unlike many policy models, DEEPER also captures trends in labor productivity. That means the number of jobs needed per million dollars of revenue will decline over time. For example, if we assume a 1.5 percent labor productivity improvement over the 23-year period from 2019 (the base year of the model) through 2042, the last year of the assessment, the 19.9 construction jobs supported by spending of $1 million within the United States in 2019 may support only 12.1 jobs by the year 2042. The calculation is $19.9 / 1.015^{(2042-2019)}$ = 14.1 jobs (rounded to the nearest tenth).

X = total industry output by a given sector of the economy

I = an identity matrix consisting of a series of 0's and 1's in a row and column format for each sector (with the 1's organized along the diagonal of the matrix)

A = the matrix of production coefficients for each row and column within the matrix (in effect, how each column buys products from other sectors and how each row sells products to all other sectors)

Y = final demand, which is a column of net changes in spending by each sector as that spending pattern is affected by the policy case assumptions (changes in energy prices, energy consumption, investments, etc.)

This set of relationships can also be interpreted as

$\Delta X = (I-A)^{-1} * \Delta Y$.

A change in total sector output equals the expression $(I-A)^{-1}$ times a change in final demand for each sector.[227] Employment quantities are adjusted annually according to exogenous assumptions about labor productivity. From a more operational standpoint, the macroeconomic module of the DEEPER Model traces how each set of changes in spending will work or ripple its way through the regional economy in each year of the assessment period. The end result is a net change in jobs, income, and GDP (or value-added).

For a review of how an Input--Output framework might be integrated into other kinds of modeling activities, see Hanson and Laitner (2009). While the DEEPER Model is not an equilibrium model, as explained previously, we borrow some key concepts of mapping technology representation for DEEPER, and use the general scheme outlined in Hanson and Laitner (2009).[228] Among other things, this includes an economic accounting to ensure resources are sufficiently available to meet the expected consumer and other final demands reflected in different policy scenarios.

[227] Perhaps one way to understand the notation $(I-A)^{-1}$ is to think of this as the positive or negative impact multiplier depending on whether the change in spending is positive or negative for a given sector within a given year.

[228] "Input-Output Equations Embedded within Climate and Energy Policy Analysis Models," by Donald A. Hanson and John A. "Skip" Laitner, in Sangwon Suh, Editor, *Input-Output Economics for Industrial Ecology*. Dordrecht, Netherlands: Springer, 2009. See also, "A Pragmatic CGE Model for Assessing the Influence of Model Structure and Assumptions in Climate Change Policy Analysis," by Stephen Bernow, Alexandr Rudkevich, Michael Ruth, and Irene Peters. Boston, MA: Tellus Institute, 1998.

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John A. "Skip" Laitner

AMERICA 3.0

POLICY CHALLENGES AND RECOMMENDATIONS

WORLD RESOURCES INSTITUTE

*See Appendix for a description of World Resources Institute’s (WRI) scope of work

TABLE OF CONTENTS

1 NATIONAL INFRASTRUCTURE COMMISSION

The Pathway to the Next Generation Interconnected Infrastructure – America 3.0 – requires a transformation of U.S. infrastructure in the power, telecommunications, mobility, and distributed energy domains. This can be accomplished in a generation – with the fundamental architecture and most of the superstructure completed by 2040 – but only with a unified vision of where we are headed and an unprecedented degree of cooperation between governments at all levels and the private sector. The establishment of a U.S. national infrastructure commission, like the National Infrastructure Commission in the UK,[229] would provide a strong foundation to support the broad ambitions of America 3.0.

This commission would ideally be made up of county, municipal, state, and federal regulatory authorities and the critical industry sectors of ICT/Telecom, power/gas/water utilities, mobility and logistics, and the buildings sector. The national commission would apply sophisticated modeling approaches, such as integrated dynamic systems and complex adaptive systems (CAS) modeling,[230] to recommend investment priorities and regulatory changes necessary to support an integrated, connected, and seamless infrastructure across the United States.

[229] NIC, https://www.nic.org.uk/
[230] Edward J. Oughton et al., "Infrastructure as a Complex Adaptive System," Public Policy Modeling and Applications Special Issue (November 4th, 2018): 1-11 https://doi.org/10.1155/2018/3427826.

2 REGULATORY CHALLENGES AND RECOMMENDATIONS: LONG-DISTANCE TRANSMISSION

The U.S. electricity system evolved from a series of local and regional utilities that built power lines to distribute power from centrally located coal-fired or oil-fired power plants, often located in city centers, or to transmit power in the form of electricity from more distant hydroelectric dams. Over time, neighboring utilities found that they could increase reliability and reduce costs by interconnecting their grids. Even so, large parts of the United States had no power until the 1930s when New Deal programs, including the Rural Utility Service and the Tennessee Valley Authority financed and helped construct an electricity grid that reaches nearly every household in America (with the notable and disgraceful exception of many Native Americans' homes on Reservations).

While the system that emerged successfully powered the Second Industrial Revolution, it is too limited, too fragmented, and too vulnerable to support the Third. Even now, our electricity system consists of three distinct and almost wholly separate interconnects: The Eastern Interconnect (EI), the Western Interconnect (WI), and Texas. With the exception of a few small ties between them, very little energy is exchanged between the three grids. Each of these Interconnects remains largely analog, with power flowing along the path of least resistance, with only limited controls available to system operators. The system remains designed for power to flow in one direction—from central power plants to distributed consumers. And the system is at risk of sabotage by terrorists and disruption by climate-change fueled wildfires, floods, and hurricanes.

To power the Third Industrial Revolution, the electricity transmission infrastructure, which serves as the backbone of the U.S. energy grid, needs a major upgrade. Increased capacity and connectivity are needed to move wind power from the Great Plains to demand centers in the East and solar power from the Southwest and Southeast to demand centers on the Pacific and Atlantic seaboards. Digitalization is needed to provide efficient, controllable power flow, not only from large scale wind farms and solar arrays, but also from solar roofs to electric vehicles and data centers. Underground power lines and microgrids that are capable of operating independently are needed to harden the system against attack and make it more robust in the face of extreme weather.

Several interrelated challenges must be overcome to build the electricity infrastructure we need to create a clean and prosperous society:

- We need a fair and efficient process to plan, site, and permit construction of new transmission infrastructure;
- We need an equitable approach for allocating and recovering the costs of building new transmission infrastructure; and
- We need to ensure that the benefits of new infrastructure are shared equitably, including with residents of states that transmission passes through, but that do not host the primary power generators or consumers.

Technological innovation is part of the solution. Despite limited applications in the current transmission network, high-voltage direct current (HVDC) lines offer a number of potential benefits. HVDC lines can efficiently carry electricity long distances with few losses, allowing for diversification of renewable energy supplies across large geographic areas and the smoothing of changes in demand for power across multiple time zones. HVDC lines can also be installed underground, easing the process of gaining siting approval, particularly if existing highway and railroad rights-of-way are used. Based on reviews of regulatory filings and recent project proposals, the potential costs of constructing HVDC lines have been estimated to range between $1.17 million and $8.62 million per mile;[231] innovation could lower these costs. In addition to HVDC lines, new transmission related technologies are also emerging to enhance the capacity, reliability, and efficiency of existing and new transmission infrastructure including high temperature lines, underground cables, enhanced power device monitoring, and mobile transformers and substations.

Regulatory innovation is also needed. Since transmission projects more often than not straddle multiple jurisdictions, the planning, permitting, and siting process can be inordinately lengthy and challenging. Today, we do not have an effective process for determining cost allocation and accurately assessing the benefits that will accrue from new transmission across jurisdictions. Despite the interstate nature of the electric grid and electricity markets, states have almost complete authority to approve (or deny) the siting and permitting of proposed power lines within their borders and typically find that the benefits of the lines to their state exceed the costs and environmental impacts in their state. Moreover, this jurisdictional split between states' jurisdiction to review and approve power lines even for lines with significant benefits in regional markets is inconsistent with the approval framework in place for natural gas pipelines that cross state boundaries, which gives FERC the exclusive authority to review interstate gas pipelines. This difference reflects the varied ways in which the electric and gas industries evolved over the last century, but it is genuinely problematic today. It creates a perverse advantage for fossil fuel infrastructure relative to electricity infrastructure needed for the development and delivery of zero- and low-carbon energy.

In addition, in some non-RTO areas, existing transmission assets are underutilized because capacity is scheduled such that the line is not fully utilized in all hours. This can lead to an overbuild of transmission in some areas that could be avoided if efficient scheduling procedures were used.

Collectively these challenges continue to slow and even stop the build out of several proposed transmission projects and are out of sync with the aggressive commitments from a growing number of states and utilities with 100% clean energy goals, which will increase demand for renewable energy to meet the targets. Despite an increase in transmission investments from $17.7 billion in 2013 to $23.7 billion in 2018, the miles of built transmission projects has declined during the same period. Only 1,300

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[231] The United States Energy Information Administration, "Assessing HVDC Transmission for Impacts of Non-Dispatchable Generation," June 2018 (accessed May 22nd, 2020) https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf.

miles were completed in 2018 versus a peak of about 4,500 miles in 2013.[232]

Recommendations

FERC Order 1000 was a well-intentioned attempt to fix some of the deficiencies in U.S. transmission policy but has suffered from lackluster implementation. Issued in July 2011, it was intended to expand the nation's transmission network by removing barriers to planning and paying for regional and inter-regional transmission projects. Reviews of FERC Order 1000 have been mixed, and the ruling has resulted in very little expansion of inter-regional transmission capacity. Almost 10 years after Order 1000, the time is ripe for federal policymakers to fix the nation's broken transmission policy. This will entail reform of transmission planning and cost allocation (what transmission facilities should be built and who will pay for them), as well as siting and permitting policies (who will decide where transmission projects get built).

Transmission Planning and Cost Allocation:

- Due to their benefits for renewable energy deployment, resilience and viewsheds, Congress should incentivize the rapid expansion of underground HVDC transmission capacity by providing a 50% investment tax credit or grant for projects that begin construction by 2025, falling to 30% for projects that begin construction between 2026 and 2030, and 15% for projects after 2030.
- Congress should direct FERC, under the Federal Power Act, **to require RTOs to use a broader set of evaluation criteria** when assessing electric transmission needs in order to properly anticipate the demand for clean energy that will be needed to decarbonize the electricity system by 2040.
- Congress should **direct FERC, under the Federal Power Act, to develop evaluation methods and approaches that enable cost-effective transmission solutions regionally**. Congress could, for example, direct FERC to establish a synchronized planning process across neighboring regions and to align interconnection rules more closely with interregional transmission planning processes in order to facilitate regional planning and align project and planning timelines.
- Congress should create **new incentives for states to take into consideration**, in their own reviews of whether to approve proposed high-voltage transmission facilities within their boundaries. These considerations should include the importance of the facilities in terms of providing net benefits to the regional power systems to which the states' electric systems are interconnected and on which they depend for meeting their own electricity needs. For example, states that host transmission could receive preferential access to grants for environmental remediation.
- Congress may also want to consider **whether amendments are needed to the Natural Gas Act and/or the Federal Power Act** to establish consistent approaches to approving and exercising siting authority for natural gas pipelines and electric transmission lines in order to eliminate any perverse

[232] Jeff St. John, "Transmission Emerging as Major Stumbling Block for State Renewable Targets," *Green Tech Media*, January 15th, 2020 (accessed May 22nd, 2020) https://www.greentechmedia.com/articles/read/transmission-emerging-as-major-stumbling-block-for-state-renewable-targets.

advantages for fossil fuel infrastructure relative to the electricity infrastructure needed to achieve decarbonization targets.

Siting and Permitting:

Current policies which give states almost exclusive control over siting inter-state transmission lines often pose a hurdle to their approval. Some form of enhanced federal siting authority for inter-state transmission lines is required. This could take several forms:

- In order to address the shortfalls of the Fixing America’s Surface Transportation Infrastructure (FAST) Act’s efforts to streamline transmission permitting, Congress should amend the FAST Act to **give FERC backstop siting authority for certain transmission projects** if states fail to do so within a reasonable period of time. This model retains state control over siting but allows the federal government to intervene under a well-defined range of situations where the state siting process breaks down.
- Incentivize the creation of new, **regional entities with authority to site interstate transmission lines**. Under the Energy Policy Act of 2005, there is a provision that allows three or more contiguous states to enter into interstate compacts to establish regional siting authorities which can carry out the transmission siting responsibilities of those states. No states have entered into such compacts and currently there is no incentives for them to do so. Congress can provide incentives for states to cooperate by providing additional transmission-related planning funds for those states that enter into a compact and create a regional siting entity. If they do not do so within a certain time period, FERC could take over siting authority. These regional entities would communicate between states, generating buy-in from impacted states and ensuring a smoother process.
- Congress can also grant transmission project siting authority to RTOs. Given that RTOs already play an important role in regional transmission planning in many parts of the country and are able to bring together a diverse groups of stakeholders, including state PUCs, utilities, consumer advocates and local governments, RTOs can potentially play a role in resolving multi-state and multi-party siting challenges. There is some precedence for a not-for-profit entity to exercise quasi-governmental authority in the electric grid system. The Energy Policy Act of 2005, for instance, authorized FERC to designate an electricity reliability organization to ensure grid reliability. FERC designated the North American Electric Reliability Corporation (NERC) to be that entity.
- If a regional approach to transmission siting is not possible, either via RTOs or the creation of new regional entities, Congress could consider requiring states to consider regional benefits in making siting decisions. This would leave siting authority with the states but would mandate state PUCs to consider regional “need” and regional “public use” and document these considerations in their siting decisions.

3 REGULATORY CHALLENGES AND RECOMMENDATIONS: TRANSPORTATION

Unlike the nation's electricity transmission system, which evolved organically from a collection of local and regional grids, the U.S. Interstate Highway system was conceived as a national system and built under the direction of an Act of Congress—the Federal-Aid Highway Act.[233] This landmark legislation, also known as the National Interstate and Defense Highways Act, was signed by President Dwight D. Eisenhower on June 29, 1956. It declared that a national system of highways was in the national interest and authorized $25 billion to complete 41,000 miles in thirteen years. While the highways were built by, and are owned by, the states, the Federal government paid for 90% of the cost and was authorized to acquire the necessary land or rights-of-way on behalf of states. Importantly, the federal government also set nationally uniform "geometric and construction" standards.

The Interstate Highway system has since been expanded to 48,000 miles, but the basic blueprint established in 1956 has remained unchanged. Unfortunately, the unprecedented expansion of commerce enabled by the Interstate Highway system has been accompanied by an unprecedented increase in carbon dioxide emissions and the dominance of automobiles to the near exclusion of all other modes of transportation. Now is the time to conceive and build a transportation system based on the technologies of the Third Industrial Revolution that is designed to give people access to jobs and recreation, while realizing the vision adopted by General Motors of zero emissions, zero crashes and zero congestion.[234]

Just a few years ago such a vision could be easily dismissed as a fantasy. Not anymore. Advances in vehicle, energy, and information technology are driving our transportation system towards electric, autonomous, and shared vehicles that can move people and goods cleanly, safely, efficiently, and more economically that our current system.

Realizing this vision requires redesigning our transportation system around these outcomes, rather than around the current goal of simply moving vehicles as quickly as possible. We must also be sure that our transportation system serves everyone and brings people together, rather than keeping them apart, as the placement of much of our current urban highway infrastructure was designed to do.

Recommendations

- **Establish Federal transportation planning and performance metrics based on access, safety, and emission reductions**, rather than capacity and speed. Most transportation planning today is

[233] The 84th Congress of the United States of America, *The Federal Highway Act of 1956*, Effective June 29th, 1956 (accessed May 22nd, 2020) https://www.govinfo.gov/content/pkg/STATUTE-70/pdf/STATUTE-70-Pg374.pdf.
[234] General Motors, "Commitment: We See A Future With Zero Crashes, Zero Emissions, Zero Congestion," (accessed May 22nd, 2020) https://www.gm.com/our-stories/commitment/for-crashes-emissions-and-congestion-zero-is-more.html.

focused on increasing vehicle speed and throughput. Refocusing on desired outcomes—improving people's access to employment and leisure opportunities and delivering goods efficiently—would shift investment towards multi-modal approaches, including complete streets that provide safe routes for pedestrians and cyclists, and creative last mile solutions such as single payment systems that cover transit, van pools, bikeshare and scooters. For example, Virginia has adopted the Smart Scale program to assess transportation funding priorities and uses a CityLab software tool to measure accessibility among other outcomes metrics.[235]

- **Invest $10 billion to establish a smart national electric vehicle fast charging network** covering the Interstate Highway System and urban fleet needs.[236] While most EV charging is currently done at home using either 240 Volt or even standard 120 Volt outlets, broader adoption of EVs will require a complementary national fast-charging network to enable worry-free road trips as well as daily commuting. Urban fast charging is needed to allow taxi and ride hailing drivers (e.g., Uber, Lyft) to recharge during the day and provide an option for drivers who do not have access to off-street parking at home.
- **Require all newly constructed parking facilities to be EV-ready**. It is far less expensive to install conduit and cabling for EV charging during initial construction rather than have to tear up concrete later to retrofit facilities to accommodate a growing EV fleet. The Federal government should provide model building codes for EV ready construction and require it for projects that receive federal support.
- **Establish tax incentives for employers to provide smart EV charging at workplace parking facilities.** As the EV fleet grows the total storage capacity of vehicle batteries will vastly exceed the amount of stationary storage installed on the electricity grid. At the same time, as the amount of rooftop and utility-scale solar power capacity expands it will be increasingly desirable to charge EVs during the middle of the day when solar generation peaks. That means workplace charging for EVs used to commute to work. Employers who install workplace charging with demand-response capability so they can maximize the use of solar energy on the grid should be eligible for the same investment tax credit available for electricity storage directly tied to solar power facilities.
- **Establish national protocols for vehicle-grid integration** to communicate real-time electricity prices and manage charging to maximize the use of variable renewable energy generation. While many utilities are beginning to offer time-of-use rates to customers with EVs, these rate structures are typically fixed for each season of the year, rather than varying dynamically based on the real-time marginal cost of power (which will be zero for an increasing number of hours per year as the wind and solar power capacity expands). Standardized two-way communications protocols are needed to optimize the dispatch of power for EV charging based

[235] CitiLabs, "Sugar Acccess Helps State of Virginia Connect People With Jobs," April 3rd, 2017 (accessed May 22nd, 2020) https://www.citilabs.com/citilabs_blog/citilabs-sugar-access-enables-transportation-project-scoring-virginia/.

[236] EVGo, "Clean Energy Key to COVID-19 Economic Recovery," May 5th, 2020 (accessed May 22nd, 2020) https://www.evgo.com/about/news/clean-energy-key-to-covid-19-economic-recovery/.

on both the state of the electricity grid and the state of the vehicle's batteries. This will enable new business models, such as EV charging subscription services similar to cell phone data plans (e.g., with unlimited Level 2 charging during periods when renewable energy is readily available on the grid, with more limited "premium power" when a driver needs Level 3 fast charging or to recharge during times when electricity is more expensive).

- **Replace all diesel transit and school buses with electric or hydrogen buses with vehicle-to-grid capability by 2030**. Replacing diesel buses with zero-emission buses should be a priority because of the health benefits, particularly for disadvantaged communities, the operating cost savings, and the resiliency benefits offered by Vehicle-to-Grid technology. Diesel exhaust is classified as a carcinogen by the International Agency for Research on Cancer,[237] and inhaling diesel pollution can impair lung function and aggravate asthma symptoms. Electric buses not only eliminate these emissions but also have much lower operating and maintenance costs than diesel buses, with savings of as much as $300,000 over the lifetime of a transit bus. Electric buses can also be grid assets: A fleet of electric buses with vehicle-to-grid (V2G) capability, for example, could be deployed to critical locations during red flag warnings before transmission lines are powered down. The electric buses could quickly restore power to critical infrastructure in communities that are blacked out as a result of fire or storm damage to transmission lines. Los Angeles has committed to replacing all of its diesel transit buses with electric buses by the time it hosts the Olympics in 2028, and Virginia is planning to replace all of its school buses with electric buses by 2030, but most other jurisdictions have not committed to a timeline for making the transition.[238] The Federal government should provide 90% cost-share to local school and transit districts to achieve a 100% zero emissions bus fleet nationally by 2030.
- **Require all new delivery trucks (USPS, Amazon, UPS, FedEx) to be electric or hydrogen starting in 2025.** The postal service is currently considering bids for replacing its aging fleet of delivery vehicles but has not committed to selecting electric vehicles.[239] Meanwhile, Amazon has ordered 100,000 electric delivery trucks from Rivian, the electric truck startup based in Michigan. Delivery trucks' predictable routes, stop-and-go driving, and centralized management make them ideally suited for early electrification.
- **Provide a federal tax credit to ride-hailing drivers (e.g. Uber, Lyft and Taxi) per zero-emission passenger mile.** Targeting incentives towards vehicles that are driven the most miles per year is an effective way to rapidly increase the share of mobility provided by zero-emission vehicles. At current prices hybrids still have a lower total cost of ownership for ride-hailing drivers over five years, particularly for drivers who need to rely on public fast charging because they don't have

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[237] Debra T. Silverman, "Diesel Exhaust Causes Lung Cancer: Now What?," *Occupational and Environmental Medicine* 74, no. 4 (April 1, 2017): 233–34, https://doi.org/10.1136/oemed-2016-104197.

[238] Dan Lashof et al., "Build Back Better: Rebooting the U.S. Economy After COVID-19: Manufacturing Electric School and Transit Buses: Creating Jobs and Economic Growth" *The World Resources Institute*, April 2020 (accessed May 22nd, 2020) "https://www.wri.org/publication/manufacturing-electric-school-and-transit-buses-creating-jobs-and-economic-growth.

[239] David Roberts, "A no-brainer stimulus idea: Electrify USPS mail trucks," *Vox*, April 22nd, 2020 (accessed May 22nd, 2020) https://www.vox.com/energy-and-environment/2020/4/22/21229132/usps-coronavirus-electrify-postal-trucks.

access to lower cost overnight home charging. A tax credit of $0.07 - $0.14 per mile linked directly to transporting passengers with zero emission vehicles (or a similar fee on miles driven using a polluting vehicle) would make EVs competitive with hybrids and encourage more drivers to take advantage of EV leasing programs, such as that offered by Maven Gig until GM closed the program during the COVID-19 pandemic. Tying the incentive to passenger miles would also encourage increased carpooling and reduced deadhead miles, which would help these services reduce, rather than exacerbate congestion.[240]

- **Require rental car companies to offer EVs at all major locations** by 2023, increasing to 100% of their fleets being electric or hydrogen by 2035. Making more EVs available through rental car companies would be a great way to expose more Americans to the benefits of driving electric. Many renters only drive a limited number of miles before returning the car and they could be encouraged to return the car without recharging, allowing the rental car company to centrally manage charging to take advantage of off-peak electricity rates.
- **Require 10% of new passenger vehicles to have zero emissions starting in 2026, increasing to 100% by 2035.** Current federal vehicle emissions standards go through Model Year 2025 and can be met with internal combustion engine technology. While it will be important to continue improving the efficiency of conventional vehicles, we cannot achieve our climate and clean air goals without making a complete transition to zero emission (electric or hydrogen fuel cell) vehicles. Given that new cars typically stay on the road for 15 years, combustion engine vehicles need to be phased out by 2035 to put us on the pathway to zero net emissions. Setting the phase out schedule now will give the auto industry the certainty it needs to transition to a 100% zero emissions fleet in a timely manner, which will be essential to be competitive in international markets. Norway leads the world in EV adoption and has set 2025 as its target date for 100% of new vehicle sales to be electric, the earliest of any country in Europe. Several countries have set 2030 targets, including Denmark, Ireland, Netherlands, and Sweden. The UK recently moved its target date up from 2040 to 2035 and will consider moving it up further to 2032, the target set by Scotland. France and Spain have set 2040 targets, with France being the first European country to cement its target into national law.[241] China, now the world's largest automobile market, has also adopted a variety of policies to promote the transition to zero emission vehicles and will require 20% of vehicle sales to be "new energy vehicles" (electric, plug-in hybrid or fuel cell) by 2025,[242] but the national government has not yet set a target date for reaching 100% EVs.
- **Establish a federal zero emission truck rule and a cash-for-clunkers rebate program targeting**

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[240] Peter Slowik et al., "How Can Taxes and Fees on Ride-Hailing Fleets Steer Them to Electrify?" *The International Council on Clean Transportation*, September 2019 (accessed May 22nd, 2020) https://theicct.org/sites/default/files/publications/EV_TNC_ridehailing_wp_20190919.pdf.

[241] Sandra Wappelhorst, "The end of the road? An overview of combustion engine car phase-out announcements across Europe," May 2020 (accessed May 22nd, 2020) https://theicct.org/sites/default/files/publications/Combustion-engine-phase-outs-EU-May2020.pdf.

[242] Yilei Sun and Brenda Goh, "China to cut new energy vehicle subsidies by 10% this year," *Reuters* April 23rd, 2020 (accessed May 22nd, 2020) https://www.reuters.com/article/us-china-autos-electric-subsidies/china-to-cut-new-energy-vehicle-subsidies-by-10-this-year-idUSKCN225177

the replacement of diesel trucks with electric or hydrogen trucks. The California Air Resources Board recently proposed a new rule requiring that a growing share of new trucks have zero emissions, including 40% of the largest tractor-trailers (Class 7-8) by 2032.[243] This is an important step and EPA should adopt coordinated federal clean truck standards. Because it will likely take longer to achieve 100% zero emission new heavy duty trucks compared to passenger vehicles, and because the life expectancy of diesel trucks can be as much as 20 years,[244] it will also be important to accelerate the replacement of diesel trucks with zero emission trucks with a rebate program, particularly targeting independent truckers who own their own rigs.

- **Allow and promote congestion pricing on Interstates Highways in urban areas.** The Federal-Aid Highway Act generally prohibits charging tolls for the use of Interstate Highways, except for bridges, tunnels, and a few grandfathered toll roads, such as the New Jersey Turnpike. The Department of Transportation is, however, authorized to allow congestion pricing "pilot projects," which more cities and states are exploring to address persistent and growing traffic woes and transportation funding shortfalls. New York City is poised to become the first U.S. city to adopt a comprehensive congestion pricing system, charging a fee to all vehicles that enter midtown or lower Manhattan starting in 2021, although the start date may be delayed by the need to obtain federal approval.[245] The Department of Transportation should provide grants and technical assistance to localities to establish congestion pricing systems and expedite approvals by conducting a programmatic environmental review. Depending on local circumstances, cities could reduce or eliminate congestion fees for zero emission vehicles and/or carpools (aka High Occupancy Vehicles).
- **Establish zero-emission zones in densely populated and pollution-burdened areas.** In addition to congestion pricing designed to reduce traffic jams, cities are increasingly considering the establishment of no pollution zones. For example, six U.S. mayors have signed onto the C40 Fossil Fuel Free Streets Declaration, which includes a pledge to make a major area of their cities zero emissions by 2030.[246]

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[243] Patricio Portillo, "CA Takes a Step Forward with New Clean Truck Proposal," The National Resources Defense Council, April 25th, 2020 (accessed May 22nd, 2020) https://www.nrdc.org/experts/patricio-portillo/ca-takes-step-forward-new-clean-truck-proposal.

[244] The California Environmental Protection Agency Air Resources Board, "Truck Sector Overview Technology Assessment," September 2nd, 2014 (accessed May 22nd, 2020) https://ww3.arb.ca.gov/msprog/tech/presentation/trucksector.pdf.

[245] Dana Rubinstein, "Why congestion pricing might be delayed," *Politico*, February 18th, 2020 (accessed May 22nd, 2020) https://www.politico.com/states/new-york/city-hall/story/2020/02/14/why-congestion-pricing-might-be-delayed-1261628.

[246] C40 Cities Climate Leadership Group, "Fossil Fuel Free Streets Declaration," (accessed May 22nd, 2020) https://www.c40.org/other/green-and-healthy-streets.

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APPENDIX A: COLLABORATORS

ABOUT THE TIR CONSULTING GROUP

TIR CONSULTING GROUP LLC

Jeremy Rifkin is the President of the TIR Consulting Group LLC. He has been an advisor to three past presidents of the European Commission - Romano Prodi, Jose Manuel Barroso, Jean-Claude Juncker – and is advising the current European Commission under the presidency of Ursula von der Leyen, as well as the current president of the European Parliament, David Sassoli. Mr. Rifkin has also advised numerous EU heads of state over the past 20 years, including Germany's Angela Merkel, on the ushering in of a smart green Third Industrial Revolution economy.

Mr. Rifkin is a principal architect of the European Union's long term Third Industrial Revolution economic vision and development plan to usher in an Internet of Things digital infrastructure across the European Union and its partnership regions to create a smart post-carbon economy, ecological society, and the world's largest single integrated economic marketplace. The plan is called "Smart Europe."

Mr. Rifkin is also advising the leadership of the People's Republic of China and is a principal architect in the build out and scale up of the country's Internet Plus Third Industrial Revolution infrastructure to usher in a sustainable low-carbon economy.

Mr. Rifkin has taught in the Executive Education program at the Wharton School since 1995.
Mr. Rifkin is ranked 123 in the WorldPost / HuffingtonPost 2015 global survey of "The World's Most Influential Voices." Mr. Rifkin is also listed among the top 10 most influential economic thinkers in the survey. The survey was prepared at Massachusetts Institute of Technology and used collective intelligence to correlate the rankings.

TIR Consulting's global team is comprised of leading Third Industrial Revolution scientific and technical experts in the fields of engineering, information & communication technology, energy efficiency, renewable energy, power and electricity transmission, transport and logistics, construction, real estate, architecture, urban planning, economic modelling, social-ecological systems theory modelling, and climate modelling.

TIR Consulting and its experts noted above have <u>prepared low-carbon master plans for the following clients from 2009 to 2016:</u>

- CPS Energy and the city of San Antonio, Texas (San Antonio is the seventh most populous city in the United States)
- The City of Rome, Italy
- The Principality of Monaco
- The Province of Utrecht, The Netherlands

Third Industrial Revolution master plans for the following three regions currently in deployment from 2012 to present. Please see links to the most recent master plans in deployment:

- The region of Hauts-de-France
- The Grand Duchy of Luxembourg
- The Metropolitan Region of Rotterdam and The Hague

Rifkin is the author of 21 bestselling books about the impact of scientific and technological changes on the economy, the workforce, society, and the environment. The books have been translated into more than 35 languages. His most recent books include the international bestsellers, *The Green New Deal* (2019), *The Zero Marginal Cost* Society (2014), *The Third Industrial Revolution* (2011), and *The Empathic Civilization* (2010).

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- Security design and consulting

Black & Veatch is more than just an engineering and construction company. We work to create the fundamental framework that enable cities, companies, systems, and civilizations to progress and thrive by understanding and delivering integrated infrastructure solutions. We are the 7th largest employee-owned company in the United States, with more than 100 years of creating a better world for humanity today, and for generations to come.

Mitigating and adapting to climate change, decarbonizing supply chains, protecting our water, creating a more diverse and inclusive workforce are just some of the challenges we are committed to addressing head on. Together with our clients, partners and investors, our work designing and building tomorrow's infrastructure will play a powerful role in improving sustainable outcomes. We bring the capabilities of a proven, fully-integrated engineering and construction company with the mindset of reshaping the industry and society to unlock the next generation of innovation in sustainable infrastructure.

Adrian Smith + Gordon Gill Architecture

Ranked the number one architectural firm in the United States of America by *Architect* magazine in 2015, Adrian Smith + Gordon Gill Architecture is dedicated to the design of high-performance, energy-efficient and sustainable architecture on an international scale. The firm approaches each project, regardless of size or scale, with an understanding that architecture has a unique power to influence civic life. Adrian Smith + Gordon Gill Architecture strives to create designs that aid society, advance modern technology, sustain the environment and inspire others to improve our world.

Adrian Smith + Gordon Gill Architecture's practice includes designers with extensive experience in multiple disciplines, including technical architecture, interior design, urban planning and sustainable design. Architects also have expertise in a range of building types, including supertall towers, large-scale mixed-use complexes, corporate offices, exhibition facilities, cultural facilities and museums, civic and public spaces, hotels and residential complexes, institutional projects and high-tech laboratory facilities.

Our office is dedicated to the creation of new paradigms for sustainable development. We use a holistic, integrated design approach that emphasizes symbiotic relationship with the natural environment -- a philosophy we've termed "global environmental contextualism." This approach, which takes into consideration building orientation, daylighting, generation of wind power, solar absorption, and a site's geothermal properties, represents a fundamental change in the design process, in which form facilitates performance. It's predicated on the understanding that everything within the built and natural environment is connected, and that a building's design should stem from an understanding of its role within that context -- locally, regionally and globally. Such a pluralistic approach acknowledges the interaction among building systems as well as between those systems and the natural environment, and seeks to improve each individual system's performance. By using this principle in the design of buildings, we can create structures that not only reduce their negative environmental impact, but in some cases, virtually eliminate it altogether.

The firm was founded in 2006 by partners Adrian Smith, Gordon Gill and Robert Forest. Today there are 100 employees in offices in Chicago and Beijing.

The Hydrogen Council

Daryl Wilson

Executive Director, The Hydrogen Council

Daryl Wilson is the executive director of the Hydrogen Council a global consortium of more than 100 CEOs who share a vision for the place of Hydrogen as an energy carrier. Mr. Wilson has a forty year career industry including 14 years in the hydrogen industry. Previously Mr. Wilson was the CEO of Hydrogenics a Canadian public company and global leader in hydrogen technology. The company delivered some of the best know benchmark projects in the field including the first power to gas projects with EON in Germany, the first fuel cell trains with Alstom and the world's largest PEM electrolysis plant with Air Liquide. Mr. Wilson is a global citizen, resides in Canada and has had 35 years of engagement with public policy and civil society on sustainability issues.

Economic and Human Dimensions Research Associates

John "Skip" Laitner

Chief Economist, TIR Consulting Group

John A. "Skip" Laitner is a resource economist who leads a team of consultants, the Economic and Human Dimensions Research Associates, based in Tucson, Arizona. He also serves as the chief economist for Jeremy Rifkin's Third Industrial Revolution initiatives as well as a senior economist for the Russian Presidential Academy of National Economy and Public Administration (RANEPA). He previously worked almost 10 years as a Senior Economist for Technology Policy with the US Environmental Protection Agency (EPA). He left the federal service in June 2006 to focus his research on developing a more robust technology and behavioral characterization of energy efficiency resources for use in energy and climate policy analyses and within economic policy models.

In 1998 Skip was awarded EPA's Gold Medal for his work with a team of economists to evaluate the impact of different strategies that might assist in the implementation of smart and more productive climate policies. In 2003 the US Combined Heat and Power Association gave him an award to acknowledge his contributions to the policy development of that industry. In 2004 his paper, "How Far Energy Efficiency?" catalyzed new research into the proper characterization of efficiency as a long-term economic development resource. Author of more than 320 reports, journal articles, and book chapters, Skip has 45 years of involvement in the environmental, energy and economic policy arenas.

His expertise includes benefit-cost assessments, behavioral assessments, resource costs and constraints, and the net employment and macroeconomic impacts of energy and climate policy scenarios. His most immediate research focuses on two areas. The first area builds on the work of Robert U. Ayres and examines the links between energy inefficiency and a productive economy. In a book chapter published in 2014, Skip provides a time series dataset that suggests the United States may be only 14 percent energy-efficient, and that it is this level of inefficiency which may constrain the future development of a more robust economy. The second area explores the ways that nations, communities and the energy industry can maximize the economic opportunity of productivity-led investments while minimizing the risk of rising energy prices and disruptive energy supplies.

World Resources Institute

In today's turbulent world, WRI is more needed than ever. While WRI's mission has remained constant, our way of operating has changed to match the changing world. In the past decade we have internationalized, with offices now in 10 countries, programs in 60 countries and experts from more than 50. We have also become leaders in the use of new technologies and big data, while expanding the "do tank" side of our work to ensure better impact from our traditional "think tank" role. Most of our experts today are actively engaged with decision-makers on the front line. While we are proud of our achievements, we know that what we've done is not enough. We are deeply aware that incremental change will not deliver the world we want, and neither will pilot successes. We thus expend great effort on the question of scale. What triggers the move from high quality design and successful demonstration to irreversible wide-spread adoption? Our last strategic plan (2014–2017) explored this in some detail. Our new strategy takes this approach to a deeper level. We are aware that while our institution is expert at analysis and policy engagement, scaling is always a team effort. This explains why all our programs are in partnership with others. We are deeply grateful for our rich array of partners, and to our supporters and donors, who make our important work possible.

WRI's more than 750 staff and experts work in more than 60 countries. We have international offices in Brazil, China, India, Indonesia, Mexico and the United States; regional hubs in Ethiopia (for Africa) and the Netherlands (for Europe) and program offices in Istanbul, Kinshasa and London.

In working to achieve global change at scale, we apply a threefold approach that is WRI's hallmark: We start with data, creating user-friendly information systems, protocols and standards. We conduct independent, unbiased research to analyze relationships and design solutions, and communicate our findings in a compelling manner; We work with leaders of cities, companies and countries to achieve change, testing our ideas in complex, messy, real-world situations. We set clear objectives and hold ourselves accountable; We identify and overcome barriers to change so that proven solutions spread quickly and widely. We work with coalitions of remarkable leaders who transform business sectors, societies and economies, nationally and globally.

WRI's five-year strategy is built upon these insights. For more than 35 years we have been providing pioneering research, data, analytical insights and tools that have informed decision making and led to tangible impact. But in light of today's threats, we will focus more sharply on achieving systemic change at scale.

Our biggest successes have had three common elements:

- Rigorous research and analytical work, based on the best data, presented and communicated clearly for specific groups of decision-makers
- Building coalitions for change, in which WRI adopts an unselfish stance, with others owning the initiative as much as we do
- Sustained political and corporate engagement over several years, with a continuous focus on the opportunity for change at scale

As the world's largest economy and the number-one historical emitter, the U.S. carries enormous influence as to whether climate challenges can be successfully addressed. WRI-U.S. works at the federal, state and local levels to develop solutions to the most pressing environmental challenges. We conduct rigorous, peer-reviewed research and convene stakeholders from the public and private sectors to identify practical solutions. You can learn more about our work here: https://www.wri.org/our-work/topics/united-states