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How Congress and the Biden Administration Could Jumpstart Smart Cities With AI

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AI promises to help cities save money, address infrastructure needs, and reduce emissions. But to unlock these benefits and help smart cities reach their full potential, the federal government has an important role to play in funding RD&D and facilitating cooperation.

KEY TAKEAWAYS

- There are many potential applications of AI for smart cities in transportation, the electrical grid, buildings, and city operations. By implementing these AI energy solutions, cities can significantly reduce their environmental footprint.
- Cities face significant challenges in researching, developing, demonstrating, and deploying AI and other smart city technologies. The United States can draw lessons from how other countries have overcome these obstacles.
- For example, risk and uncertainty limit adoption of AI technologies. To address that challenge, Singapore has developed a "digital twin" of the island that the government, businesses, and researchers can use as a test bed to run simulations.
- To scale AI adoption at a national level, policymakers need to be able to evaluate cities according to their success at exploring, experimenting, operationalizing, optimizing, and transforming through AI.
- Some federal government programs are investing in AI or smart cities, but there remain significant funding gaps in demonstration and deployment. There are also no cross-cutting AI and smart city initiatives.
- City governments ultimately must take the lead in deploying AI smart city applications, but there is an important role for the federal government in funding R&D and coordinating activities at a national level.

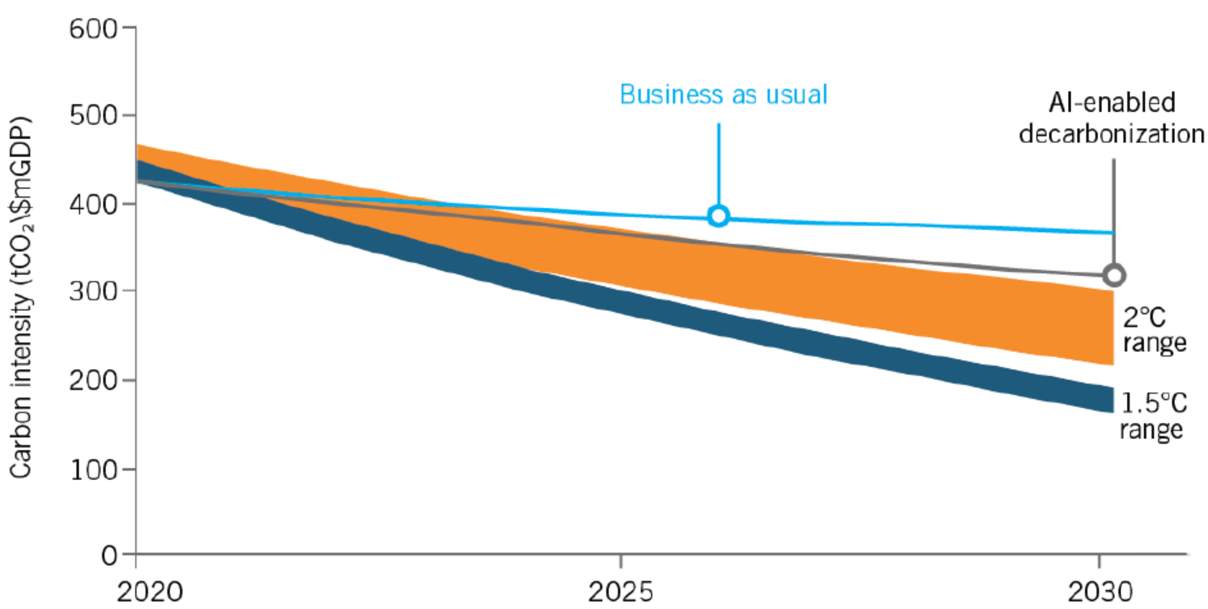
INTRODUCTION

The next wave of connected and intelligent technologies, including sensors, 5G, and artificial intelligence (AI), holds great promise for improving the energy efficiency of many systems, including urban systems.[1] Building automation systems can automatically monitor, control, and optimize a building's heating and cooling, lighting, and other mechanical systems. Real-time traffic data coupled with smart traffic lights can reduce energy use. Digitalization is also enabling integration of previously isolated systems: Grid-integrated buildings provide demand response to the grid; and smart electric vehicles (EVs) shift their charging times to off-peak hours.

At the same time, cities are increasingly making their own climate commitments and looking for ways to reduce their own emissions—and the emissions of businesses and residents who live in cities. Alliances such as Climate Mayors, a network of 465 U.S. mayors, and the Global Covenant of Mayors for Climate and Energy, which includes 172 U.S. cities, represent the growing movement toward local action on climate change.[2]

By embedding smart technologies in the grid, buildings, and transportation systems, cities can reduce their energy use and emissions. A 2018 McKinsey report finds that a city deploying smart city applications "to the best reasonable extent" could reduce its total emissions by 10 to 15 percent.[3] Similarly, Microsoft and PwC found that AI-enabled decarbonization technologies could reduce the carbon intensity of the global economy (figure 1).[4] These applications help cities plan and govern more efficiently, reduce their energy use and emissions, attract and support businesses, and discover new sources of revenue.

Figure 1: Carbon emissions intensity in a "business as usual" scenario compared with AI-enabled decarbonization[5]



But cities are facing revenue shortfalls as a result of the COVID-19 pandemic, which is stalling smart city investments. Even the most capable cities struggle to evolve into smart cities, because cities are ill-equipped to overcome the key challenges limiting smart city development. The first challenge is research in the underlying technologies for smart cities is a public good. Few want to bear the costs of "going first," when the benefits mainly accrue to others. Second, few cities have the tools to share data with one another, which hampers the development of accurate AI models. Third, cities have little incentive to bear all the risk of failure involved in adopting technology fueled by emerging technologies. Finally, without a federal data privacy law, cities struggle to address unchecked privacy fears.

Smart cities offer an important opportunity to address both infrastructure needs and strained state and local budgets at the same time.

The federal government should play a role in helping U.S. cities overcome these challenges. It is able to provide funding and coordination on a larger scale than cities working individually. While the federal government has undertaken an array of activities to support the development of smart cities, these efforts have mostly been uncoordinated, and the government has had no strategic vision for AI research, development, and deployment (RD&D) of smart city technologies. Smart cities offer an important opportunity to address both infrastructure needs and strained state and local budgets at the same time.

This report examines the specific subset of smart city technologies that use AI to generate insights for cities, businesses, and individuals in order to reduce energy use and emissions. It begins by describing the range of potential AI energy applications in smart cities, including intelligent transportation systems (ITS), smart buildings and electric grids, and city operations. The next section identifies the challenges cities face in implementing these applications and includes a cross-national survey to learn how national governments around the world are helping cities address these challenges. The report then presents an AI maturity model that reflects the degree to which a city has adopted AI and provides a framework for scaling adoption across cities. Next, the report summarizes current U.S. federal government initiatives in AI-enabled smart city systems. It concludes by proposing a set of policy recommendations for Congress and the Biden administration to expand research in AI energy applications, increase resources for cities making smart city investments, and work with cities to demonstrate real-world AI solutions.

POTENTIAL ENERGY APPLICATIONS OF AI IN SMART CITIES

Smart cities are those that use sensors, data, and analytics to tackle important citywide issues. Most smart city applications are built around the Internet of Things (IoT)—objects embedded with sensors and connectivity to enable them to send and receive data. The massive amount of data generated by IoT devices is the foundation of a smart city, but data alone does not make a city smart. That data is analyzed and acted upon, often through AI applications, to generate valuable insights for cities and their businesses and citizens.

AI systems are computer systems that perform tasks such as learning and decision-making.[6] There are many potential applications for AI in smart cities, and many more will arise as AI technologies continue to develop and improve. This section examines AI applications in ITS, building energy systems, electric power grids, and city operations, all of which have direct implications for a city's energy use and environmental impact.

Intelligent Transportation Systems

Technology enables elements within the transportation system—vehicles, roads, traffic lights, signs, and more—to become intelligent by embedding them with microchips and sensors and empowering them to communicate with each other, decreasing congestion and emissions, and helping cities simultaneously cut costs and create new revenue sources. A 2015 McKinsey report analyzing over 150 IoT use cases estimates that IoT transportation applications could be worth over $800 billion per year for cities around the world.[7]

ITS include a wide and growing suite of technologies and applications, which have the potential to reduce greenhouse gas emissions by 3 to 8 percent.[8] Applications with the greatest potential for reducing emissions are those that would either lower the number of vehicles on the road—such as vehicle sharing, public transit, and financial incentives to carpool or use alternative methods of transportation—or increase the percentage of EVs. Reducing congestion and increasing efficiency also lead to reduced emissions.

Connected and Autonomous Vehicles

Connected and autonomous vehicles (CAVs), which integrate information and communications technologies into their systems in order to assist drivers, are poised to transform the way people move, providing cost savings for drivers and new revenue sources for cities, as well as safety, efficiency, and environmental benefits. By reducing accidents caused by human error, communicating with each other to travel closer together safely, and communicating with the roadway to establish more efficient traffic patterns, CAVs can reduce congestion, fuel use, and emissions.[9]

Connected vehicles incorporate intelligence and sensing capabilities to give vehicles more data, connectivity, and interactivity.[10] This increased connectivity gives drivers traffic information and provides critical safety communications between cars, enabling increased safety and reduced traffic congestion. Autonomous vehicles (AVs) include all the features of connected vehicles in addition to the ability to operate with little to no driver input. They rely heavily on cameras, radar, and Lidar to collect information on the surrounding objects, including their shapes, speeds, and distances.[11] AI collects and makes sense of the data from these sensors, allowing the vehicles to "see" so they can avoid pedestrians and other vehicles, obey road signs and signals, change lanes, make turns, and do everything else a human driver would do.

Fully autonomous vehicles present new opportunities for ridesharing and carsharing, potentially moving from the current system of individual car ownership to a system of cars-as-a-service, wherein individuals subscribe to a carsharing service that they then use as needed to get from place to place.[12] This would be a potentially cheaper solution than individual car ownership as multiple riders share the cost of fuel and maintenance. It would also be a much more efficient use of capital: Currently, cars are parked 95 percent of the time.[13] Carsharing services would get more use out of each vehicle, especially a fully autonomous vehicle that could drive itself to pick up passengers.

The energy and emissions impacts of CAVs are highly uncertain, depending in large part on users' behavior in response to CAVs. As automated vehicles eliminate the inconveniences of driving (e.g., driver stress, more productive use of travel time), overall passengers and vehicle miles traveled could increase, along with emissions. On the other hand, shared and autonomous transport could reduce the need for vehicle ownership, facilitate vehicle right-sizing, and better integrate with mass public transit. A 2016 report finds that automated vehicles could reduce total U.S. road transport energy use by as much as 50 percent (in an optimistic scenario) or increase it by 100 percent (in a pessimistic scenario).[14]

Traffic Management Systems

Intelligent traffic management systems can help smart cities reduce congestion by making traffic flows more efficient, so vehicles can reach their destination faster. Technologies such as intelligent traffic signals eliminate a major source of congestion: vehicles stopped at intersections. Meanwhile, different road-pricing schemes such as congestion pricing and high-occupancy toll lanes can bring down the total number of vehicles on the road, thereby further reducing congestion. By lessening the amount of time vehicles spend on the road, traffic management systems reduce commute times, fuel consumption, and greenhouse gas emissions.

Intelligent traffic signals work by collecting information on traffic conditions from connected vehicles, roadway sensors, and other signals to adjust their timing and get drivers through intersections as expediently as possible. Unlike signals that change at predetermined time intervals or react only to sensors in the intersection they control, intelligent traffic signals are equipped with AI that collects data on overall traffic demand in the area and operates all the signals in an area as a network to identify patterns and synchronize their activity.[15]

Congestion pricing charges vehicles a fee for driving in congested areas during the busiest times of day. The goal is to incentivize drivers to carpool, use alternative methods of transportation, or drive at other times. Modern toll roads already use information technology to reduce congestion. For example, electronic toll collection enables drivers to pay tolls automatically via a device or tag placed on the windshield, such as E-Z Pass in the United States. ITS can collect real-time data on traffic conditions and the number of vehicles on the road and adjust tolls based on the amount of traffic. More-advanced congestion pricing algorithms can use AI methods, such as reinforcement learning, that can continuously optimize dynamic toll prices to minimize road congestion based on changing driving patterns.[16]

Smart Public Transit Systems

Another approach to reducing congestion and emissions is increasing public transit ridership. Per passenger, public transit is more energy efficient and less polluting than commuting by car. An individual with a 20-mile commute can save 4,800 pounds in CO_2 emissions a year by switching to public transit instead of commuting by car—a 10 percent reduction in the amount of greenhouse gases produced by the average two-adult, two-car household.[17]

Advanced public transportation systems can make public transit a more attractive option for commuters by making the process more efficient, convenient, and accessible. In a smart public transit system, all of a city's buses and trains would communicate with each other through vehicle-to-vehicle communications—sharing data on their location, arrival and departure status, and overall timeliness—and using AI algorithms to coordinate their schedules to maximize efficiency and avoid delays. This real-time data collection would allow cities to construct an accurate view of the status of all assets in their public transportation systems.

Advanced public transportation systems also benefit riders by sharing information online—through a website or app, and through signs posted at bus stops and train stations—so riders can plan their commutes and get to their destinations faster. According to one study, up to 70 percent of the time people spend commuting is "buffer time," or time riders spend waiting for their bus or train to arrive, and reducing that buffer by accurately tracking buses and trains, adjusting their schedules, and sharing real-time information with riders could lead to time savings of over $60 billion per year globally.[18]

Electric Vehicles

Smart cities can further reduce their emissions by reducing the number of gas-powered vehicles on the road and encouraging EV adoption among consumers. Meanwhile, as EV sales increase, cities can turn to smart solutions to minimize the stress EVs put on the electric grid and maximize energy efficiency.

To encourage consumer adoption, many cities are investing in charging infrastructure. In a study by Volvo, 49 percent of total drivers cited the low availability of charging stations as one of the top barriers to purchasing an EV.[19] There are a number of factors to consider when deciding where to install charging stations, including EV range, the number of EVs in an area, and the ability of EV drivers to travel from every part of the city to every other part of the city. Researchers in Hong Kong developed algorithms that could determine ideal charging-station placement in a city; and in the future, cities could use AI or machine learning to run similar algorithms.[20]

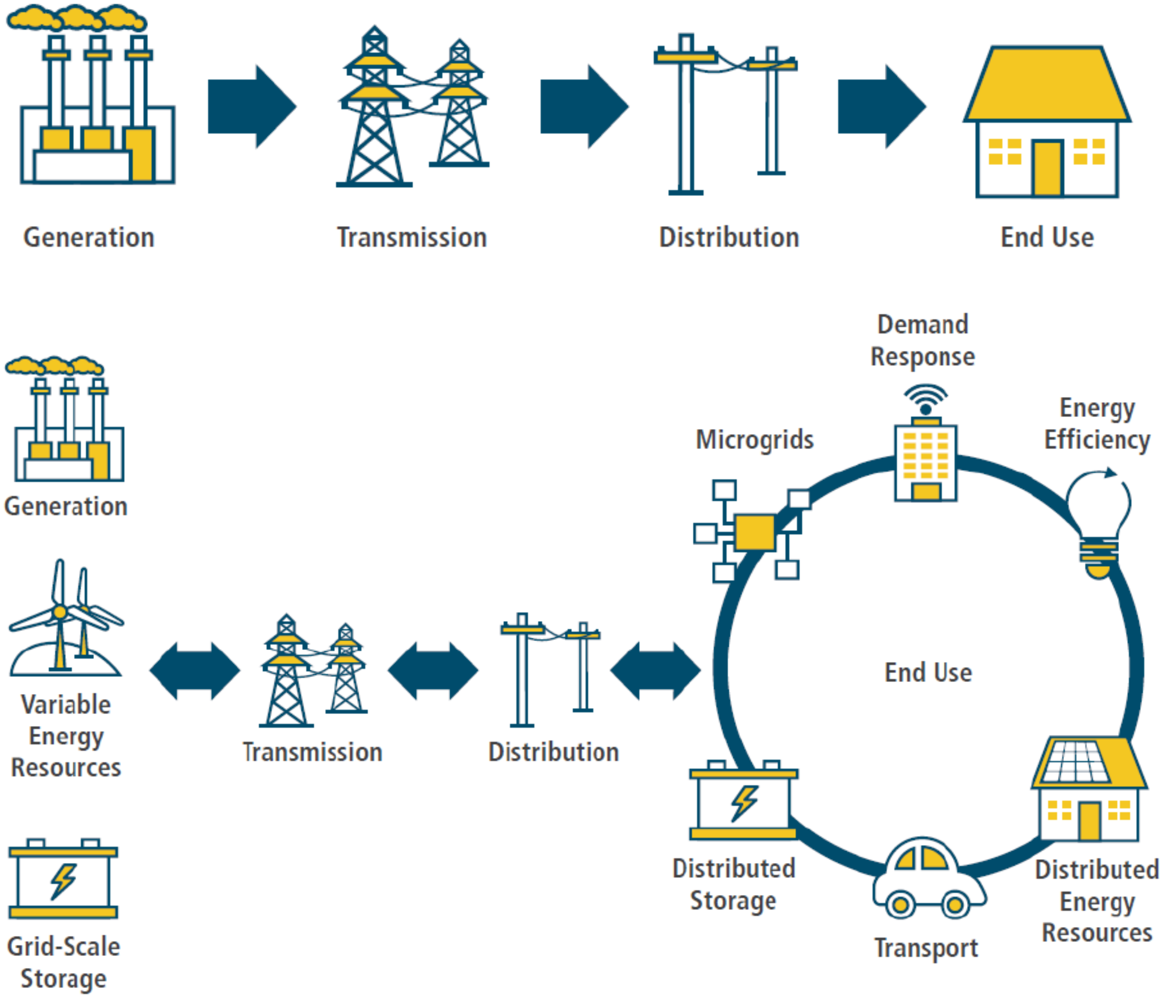
Finally, cities can turn to smart charging to minimize the stress EVs put on the electric grid. Increased adoption of EVs will lead to increased electricity demand. Given that many drivers would plug their vehicles in to charge at around the same time of day—for example, in the evening after getting home from a typical 9-to-5 workday—the demand for electricity would skyrocket during those times. But through smart charging stations, which enable EVs to communicate with the grid much like connected vehicles communicate with the roadway, cities could manage EV charging to improve grid operations by shifting charging times to off-peak hours.

Smart Grid

Traditionally, the United States' electricity distribution system has only worked in one direction: Electricity flows from power plants through power lines and substations to customers (figure 2). But the rise of smart grid technologies—the digital hardware and software embedded within the energy system, including sensors, controls, intelligent appliances, and more—is changing the way consumers and businesses distribute and consume electricity, and allows for greater informational awareness and control of energy flows. Smart grids enable decreased reliance on fossil fuels and increased use of cleaner energy sources, as well as increased energy efficiency, reliability, and security. They also provide opportunities for consumers to lower their energy bills and for cities to reduce their overall environmental footprint.

For the more than 2,000 U.S. towns and cities served by a public power utility, city governments have a direct role in grid modernization and transitioning to the smart grid. The American Public Power Association in 2018 released its smart city roadmap for public utilities, noting that public utilities are well positioned to lead in smart city programs and integrate with other city services such as transportation.[21] Cities served by investor-owned utilities have less direct control over grid operations but can work with the local utility and regulators to pilot smart grid applications.

Figure 2: A traditional grid designed for one-way power flow (top), and the smart grid that enables two-way power flows and greater integration of electricity end use (bottom)[22]



Demand Response

Smart meters and AI are unlocking new sources of previously untapped demand flexibility, and are enabling new applications including dynamic pricing and demand response. Smart meters provide real-time information on electricity consumption and enable two-way communication between utilities and customers. The explosion of data provided by smart meters has opened up new applications for AI in actively monitoring, managing, and optimizing electricity use.

Dynamic pricing can provide greater demand flexibility. Unlike traditional flat-rate pricing, in which customers are charged a flat per-kilowatt-hour (kWh) rate, dynamic pricing refers to a rate structure in which utilities set variable prices for electricity that account for real-time generation costs and local grid congestion costs.[23] By charging higher rates during peak times that more accurately reflect the cost to generate and distribute electricity at those times, utilities can encourage consumers to reduce their demand temporarily by shifting non-time-sensitive demand to off-peak times when prices are low. AI can help both design real-time prices and enable consumers to respond to those prices. While previous work has focused on reducing peak demand and minimizing grid build-out, similar techniques could use AI to create prices that optimize for greenhouse gas emissions reductions based on the real-time carbon intensity of generation.[24]

Smart meters enable consumers and businesses to respond to real-time price signals by shifting electricity use to off-peak periods. Smart appliances—those that connect to the Internet, allowing customers to control them remotely—equipped with AI would take this one step farther, collecting data about their own usage and communicating with a customer's smart meter to automatically run during off-peak times. In one case, Oklahoma Gas & Electric observed up to a 30 percent peak demand reduction for customers enrolled in its dynamic pricing program.[25] In another example, ConEd was able to avoid $1.2 billion in new grid build-out to meet rising demand by investing in demand-side solutions, including demand response and distributed energy investments.[26]

A 2018 McKinsey report analyzing the potential impact of smart city applications in three sample cities finds that dynamic pricing and demand response could cut emissions by up to 5 percent.[27] Significant untapped flexible demand exists, but further deployment of smart meters and additional development of AI applications will be needed to access it. In order to provide flexible demand and avoid the large capacity additions that would otherwise be needed in its absence, more electricity consumers will need access to the greater control afforded by smart meters and dynamic pricing. As of 2019, about 40 percent of the nation's electricity meters—39 percent of residential meters, 42 percent of commercial meters, and 46 percent of industrial meters—did not have advanced two-way communications capability that would enable visibility of real-time prices and support flexible demand.[28]

Generation Forecasting and Optimization

AI can be used to forecast and optimize electricity generation from renewable energy, for example, by incorporating hyperlocal weather data to better predict energy production from wind turbines, or adjusting the position of solar arrays based on sun and cloud positions.[29] The Electric Power Research Institute (EPRI) has identified generation forecasting and optimization as one of the key applications of AI in the electric power sector.[30]

Since electricity supply must match load (i.e., demand), fluctuations in generation from VRE (variable renewable energy) and demand must be forecast ahead of time both to optimize real-time electricity dispatch and inform longer-term system planning. For example, Xcel Energy, a Colorado-based utility, partnered with the National Center for Atmospheric Research (NCAR) to develop a wind-power forecasting system using AI that combines NCAR's data from local weather stations with sensor data on Xcel's wind turbines. The model has reduced the wind-energy forecast margin of error by 40 percent.[31] Similarly, AI has been used to create short- to medium-term forecasts of solar power, hydropower, and other generation technologies. But while many current efforts have used generic AI, future research is needed to develop hybrid physics-plus-AI techniques that incorporate climate modeling and weather forecasting to account for how weather patterns shift over time.[32]

AI can also optimize generation output from renewables. One of the next grand challenges in wind energy is management of wake interactions between wind turbines to minimize energy loss and manage turbine-to-turbine interactions.[33] AI can model turbulence in the wake of leading turbines, anticipate impacts on following turbines, and optimize positioning of the turbines on a wind farm to maximize generation output. Similarly, research is underway to improve solar photovoltaic (PV) plant operations, using AI to optimize preventative maintenance activities and diagnose underperforming equipment.[34]

Distributed Energy Resources

Traditional electricity distribution systems have struggled to maintain reliability and resilience in response to disruptions such as severe weather events, technology failures, or sudden changes in demand.[35] A 2020 economic analysis by EBP US for the American Society of Civil Engineers estimates the annual cost of power interruptions at $85 billion.[36]

Distributed energy resources (DERs) solve some of these problems by taking a decentralized approach. They typically rely on renewable energy sources and energy storage such as batteries to produce, store, and distribute energy to a small, nearby area. These localized systems are connected to the larger grid and can serve as backup power sources in case of power interruptions or outages. Households or buildings with DERs—for example, solar panels or wind turbines—can also sell power back to the grid at peak times. According to Siemens, DER operators reduce their costs between 8 and 28 percent and see a return on their investment within three to seven years.[37]

Groups of DERs can form microgrids, which are connected to the larger distribution system but can also operate separately, providing emergency power to small areas such as neighborhoods, university campuses, or military bases. Like independent DERs, microgrids can produce and store energy and sell power back to the larger bulk power system. Microgrids enable smart communities to meet climate and clean energy goals while also improving their resilience to outages on the bulk power system. For example, the Fort Collins Microgrid in Colorado is part of the district’s goal to create as much clean energy as it uses.[38]

Similarly, virtual power plants (VPPs) are networks of DERs that are independently owned and operated but linked to a central control room in order to store and sell electricity and relieve the load on the grid during peak times. The control room uses AI or machine learning algorithms to accurately forecast the demand for electricity using relevant historical data, weather forecasts, and data from the grid, and then increases or decreases production accordingly. VPPs can also use AI to track electricity prices and automatically sell energy when prices are high.

AI can also enable more decentralized methods of buying and selling electricity, such as smart contracts that make it easier for households, buildings, and communities to take advantage of DERs. Two devices would automatically execute a smart contract if one party wanted to buy renewable energy from a DER at a certain price and the other were selling energy from their DER at that price. The transaction would be automatically logged on the blockchain, which acts as a transparent and secure digital ledger that both parties can access but not change.[39] AI can enable smart contracts by negotiating and agreeing to terms on behalf of the parties.

Smart Buildings

Residential and commercial buildings account for one-third of global energy demand and 55 percent of energy consumption.[40] These numbers are even higher in the United States, where buildings are the largest electricity-consuming sector, accounting for 71 percent of the nation’s electricity usage and 32 percent of U.S. greenhouse gas emissions. Digitization of building energy systems can greatly improve buildings’ energy efficiency by ensuring energy is consumed when and where it is needed and improving the responsiveness of energy services such as lighting and air conditioning.

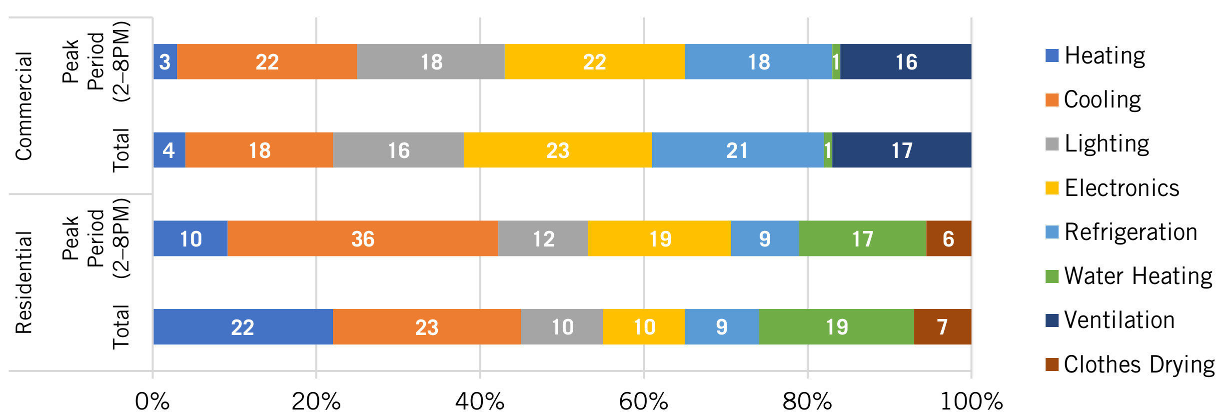
Smart buildings gather data on energy use and other daily operations and then automate various processes, from lighting and security to heating, ventilation, and air conditioning (HVAC). Sensors enable building managers to predict, measure, and monitor real-time energy performance and identify where to achieve energy savings. Active controls can lower energy use within a building while also enabling better integration within the power grid. And AI can be used to analyze sensor data to generate insights on how to optimize a building's performance. Benefits include lower energy costs, greater consumer choice, improved reliability and resilience, improved integration of DERs, avoided electricity capacity build-outs, and reduced environmental impacts.

Smart Appliances and Building Energy Systems

Smart appliances and building energy systems (e.g., lighting and air conditioning) can greatly improve energy efficiency by reducing waste and ensuring energy is consumed when and where it is needed. Connected appliances and sensors enable homeowners and building managers to collect real-time data on the energy performance of appliances and systems and remotely control equipment. AI applications can process energy data, identify where energy savings can be achieved, predict future energy demand, and automate energy systems.

In U.S. homes and apartments, cooling, heating, and water heating together account for nearly two-thirds of total final energy demand, with lighting, appliances and electronics, refrigeration, and clothes drying rounding out the remainder. Commercial-building energy use is more evenly split between cooling, ventilation, lighting, refrigeration, and office equipment, with each accounting for about 20 percent of the whole (figure 3).

Figure 3: Total and peak-period 2018 electricity consumption of major energy end uses by building type[41]



The potential energy savings from AI applications in appliances and building energy systems is large. A 2019 review of AI applications in HVAC systems identified maximum energy savings of up to 44 percent. However, out of 18 AI tools developed for HVAC control, only 3 functions—weather forecasting, optimization, and predictive controls—have become widely adopted.[42]

Whole-Building Analytics and Automation

Whole-building analytics and automation integrate multiple energy systems within a building using a single whole-building energy management system to enable greater integration and systems-level efficiencies and provide greater control. Sensors and controls are the backbone of a smart building: They can be integrated into all of a building's systems and monitoring operations, and automatically makes adjustments to optimize their performance. Building analytics is the process of converting the data collected by smart sensors into insights that can improve a building's performance, thereby saving energy and money. AI analytics automate this process, collecting sensor data and generating insights without the need for human analysis.

One of the benefits of building analytics is the ability to perform predictive maintenance on building systems as sensors detect performance issues early on, before they cause serious problems. In addition, sensors can detect when people enter or leave a building, where people are at different times of day—and which areas have the most traffic; can inform heating, cooling, and lighting needs; and guide decisions on how to increase occupants' comfort while reducing energy use.

Building automation uses insights from sensor data to connect and control buildings' HVAC, lighting, security, plumbing, emergency alarms, elevators, and more. When integrated with building automation systems, AI can optimize a building's energy use and performance. AI software can also identify where energy is being wasted and generate recommendations for building managers to reduce their overall energy use and shift their electrical load to off-peak times.

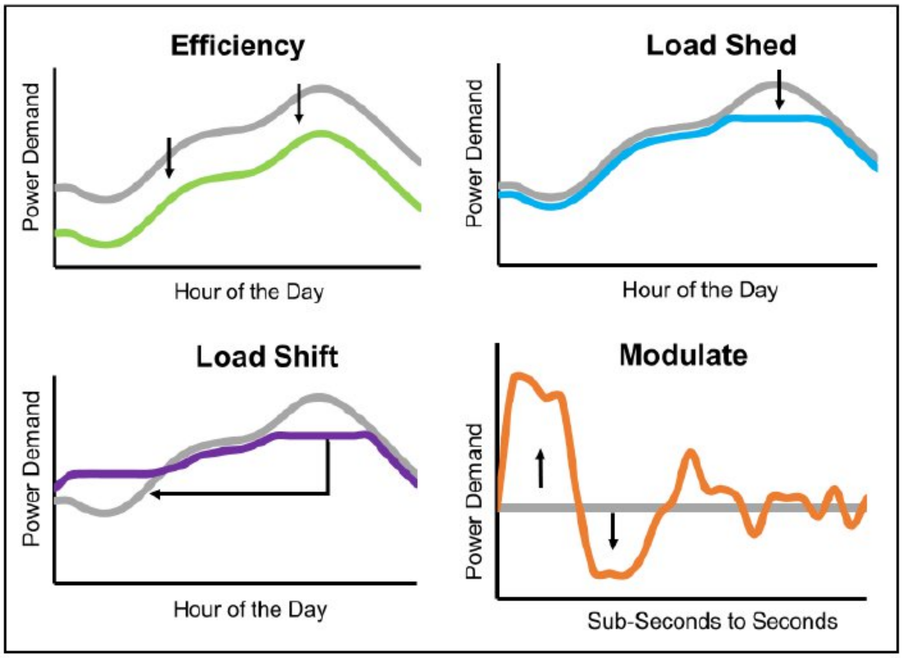
The use of AI and building automation can lead to myriad benefits, from reduced energy consumption and costs to increased security and comfort. A McKinsey 2018 report finds that building automation systems alone can lower emissions by approximately 3 percent if most commercial buildings adopt them, and by an additional 3 percent if most homes adopt them.[43] The DOE Pacific Northwest National Laboratory (PNNL) in 2017 considered a broader set of smart energy efficiency measures, finding that integrating smart sensors and controls throughout the commercial building stock has the potential to save as much as 29 percent of building energy consumption through high-performance sequencing of operations, optimizing settings based on occupancy patterns, and detecting and diagnosing inadequate equipment operation and installation problems.[44]

Grid-Interactive Efficient Buildings

Grid-interactive efficient buildings (GEBs) use smart technologies and on-site DERs to provide demand flexibility and better integration with the electric grid. GEBs have the ability to dynamically manage their electricity loads to help meet grid needs and minimize electricity system costs, while also co-optimizing DERs such as rooftop solar, battery and thermal energy storage, and combined heat and power with building energy systems. AI can optimize building energy systems to meet occupants' comfort and productivity requirements, while also responding to signals from the grid to provide ancillary services (e.g., frequency modulation) or demand response.

By communicating with the grid, AI-enabled smart buildings can engage in automated demand response, which enables adaptive algorithms to keep track of energy prices and automatically run more energy-intensive operations during off-peak times when the cost and demand for energy is low. In comparison with energy efficiency strategies that are insensitive to timing, and primarily aim to reduce cumulative building energy consumption, demand response focuses on shedding or shifting electricity demand during peak hours, when electricity is usually the most expensive. GEBs also have the potential to balance electricity supply and demand autonomously on a second-to-sub-second scale to maintain power quality (e.g., frequency) (figure 4).

Figure 4: Changes in building electricity demand as a result of four demand-side management tools[45]



For the customer, load shifting has the benefit of reducing electricity costs. For utilities, demand response avoids the build-out of additional generation, transmission, and distribution capacity that is only used during peak times, potentially saving ratepayers billions in unnecessary grid build-out. GEBs that participate in demand response can also enable greater integration of variable renewable energy from wind and solar by shifting energy loads to periods of renewable availability, thereby avoiding the need to curtail, or waste, renewable energy. New analysis from the U.S. Department of Energy (DOE) finds that GEBs could reduce peak demand by 177 gigawatts (GW) (24 percent) in the summer and 128 GW (22 percent) in the winter.[46]

Building codes and appliance standards can also unlock potential energy savings by requiring new buildings to be demand-response ready. For example, the New York State Energy Research & Development Authority (NYSERDA) publishes a voluntary “stretch code” for new building construction, which specifies that “building controls shall be designed with automated demand-response infrastructure capable of receiving demand-response requests from the utility, electrical system operator, or third-party demand response program provider, and of automatically implementing load adjustments to the HVAC and lighting systems.”[47]

City Operations and Infrastructure Maintenance

Many smart city applications that improve city operations and maintenance also lead to greater energy efficiencies, reduced waste, and fewer greenhouse gas emissions. A McKinsey report finds that deploying a suite of smart city applications in waste and water management could reduce average water consumption by 20 to 30 percent and reduce the amount of unrecycled solid waste per person by 15 to 20 percent, while also reducing greenhouse gas emissions.[48]

Many large waste systems have coupled connected trash cans with AI-enabled intelligent waste collection optimization to reduce emissions from garbage collection trucks. Boston University was able to reduce its fuel use and greenhouse gas emissions by 80 percent with the use of BigBelly Solar Compactors—solar-powered trash receptacles that compact trash and communicate when they are full, enabling the campus to reduce trash collection from an average of 14 times per week to 1.6 times per week.[49] In Japan, Mitsubishi has partnered with Groovenauts to develop an optimized waste collection and transportation route between 26 designated sites using AI and quantum computing. The optimal route has reduced the total distance traveled by waste collection vehicles from 2,300 km to 1,000 km, enabling a 57 percent reduction in greenhouse gas emissions and a 59 percent reduction in the number of vehicles needed.[50] Finland is also employing AI for smart recycling by managing waste using a robotic waste sorter.[51]

Similarly, AI-enabled smart water infrastructure can help ameliorate leaks and reduce the cost of maintaining water and wastewater systems. Syracuse, New York, uses AI to analyze its aging water infrastructure to identify leak-prone pipes for repair before leaks occur, allowing the city to make the most of a limited budget for water maintenance.[52] Water consumption tracking, which pairs smart water metering with digital feedback, can give customers greater insight and control over their water usage and nudge people toward conservation. When paired with AI-enabled real-time prices that reflect water availability, smart water meters could reduce consumption by 15 percent in higher-income cities.[53] Similar to dynamic pricing for electricity, AI can help both design real-time water prices and enable consumers to respond to those prices. Levers that curtail water demand—whether by reducing leaks or enabling customers to bring down their water consumption—can reduce electricity consumption in the water sector, resulting in greater efficiencies and fewer greenhouse gas emissions.[54]

CHALLENGES LIMITING AI FOR SMART CITY DEVELOPMENT AND THE ROLE FOR NATIONAL GOVERNMENTS

Most advanced countries are deploying AI applications in their cities. For instance, Australia, France, Germany, Japan, the Netherlands, New Zealand, Sweden, Singapore, Spain, South Korea, the United Kingdom, and the United States have all taken some steps to develop and deploy AI-enabled smart city applications. A number of developing countries, notably India and China, are also deploying increasingly sophisticated AI systems in their cities. But given the significant benefits, why have AI-enabled smart city technologies not been deployed more broadly? One reason is there are a number of challenges involved in researching, developing, demonstrating, and deploying these technologies that cities are not equipped to address but national governments are. Many countries are already overcoming these obstacles, and their initiatives are instructive for the United States.

Research and Investment in Smart City Technologies Are Public Goods

Cities will underinvest in research for AI solutions that support smart cities because they would shoulder all the costs for only a small portion of the benefits.[55] Though the entire global smart city ecosystem benefits from public AI research, it is not reasonable to expect any one city to foot the bill just so every other city can reap the benefits.[56] At the same time, while several companies have invested in developing smart city applications, the market can only play a limited role in the adoption of these technologies because many opportunities are strongly tied to areas of public sector activity (such as environment and transportation). While the market may eventually be able to establish effective interdependent systems, it will take longer and happen much more slowly than it would with government support to overcome detrimental chicken-and-egg dynamics and encourage mutual adoption of these technologies until market forces can take over and drive full deployment.

National (or in the case of Europe, supranational) governments are best suited to address these barriers, making long-term investments in research and demonstration that cities and the private sector are simply unwilling to fund.[57] These investments marshal resources and drive incentives so that state and city actions benefit the entire nation.

For example, as part of its Horizon 2020 program, a comprehensive funding program for research and innovation, the EU has established a three-year AI4Cities project that brings together leading European cities looking for AI solutions to accelerate carbon neutrality.[58] The EU is providing €4.6 million ($5.4 million) in funding to be split between Helsinki, Amsterdam, Copenhagen, Paris, Stavanger (Norway), and Tallinn (Estonia) to encourage companies and developers in these cities to come up with AI solutions for mobility and energy challenges that will reduce CO_2 emissions.[59] For example, they will be asked to come up with ways to better use AI to support demand response, improve energy efficiency, and aid in the development of renewable energy. As part of the mobility challenge, the partnering cities will ask companies to come up with innovative ideas that include using AI to optimize traffic flow and the transportation of goods. By challenging industry to develop innovative solutions for public sector needs from the demand side, the EU is offering up its partnering cities to be successful first customers, increasing market demand for nascent clean technologies and enabling companies to create competitive advantage on the market.[60]

The Australian government is supporting the development of smart city projects through its Smart Cities and Suburbs Program, an AU$50 million (US$35 million) competitive grant program.[61] Projects are co-funded by local governments, nonprofit research organizations, and businesses. One project is the Energy Data for Smart Decision Making project, which seeks to develop a tool that enables property owners to predict the potential electricity they can generate from solar panels installed on their rooftops.[62] Led by the University of New South Wales and Australia Photovoltaics Institute, the tool is now being used in 33 municipalities.[63] Although this tool does not use AI, machine learning offers an opportunity to make it even more effective. Researchers from the Technical University of Iaşi in Romania have shown that machine learning techniques can better monitor PV panels for degradation that air, water, and impurities cause—which is important because degraded PV cells convert less solar energy into usable electricity. Creating more accurate degradation profiles for PV panels can inform stakeholders including utility companies, integrators, investors, and researchers, who are making decisions about improving PV lifetime.

Difficulty in Sharing Data Inhibits Development

Developing accurate AI models requires access to large pools of data. Models that can analyze the pools of data that many cities generate will be able to extract more actionable insights and greater value than those limited to a single city. However, few cities are equipped to develop interoperable systems and share data across their jurisdictional boundaries. Additionally, while cities benefit from analyzing other cities' data, an individual city itself has little incentive to share data and may even enact policies that limit data collection and sharing, perhaps due to fears about privacy or cybersecurity risks. Finally, even if cities could and wanted to share data in a national pool, in most nations no mechanisms (e.g., urban data trusts) have been established to make it easy for them to share and use data.

As such, national governments have a coordinating role to play in developing common policies, programs, and standards for AI technologies that encourage interoperability and data sharing to increase the effectiveness of AI-enabled smart city applications.

South Korea enacted the National Transport System Efficiency Act in 2009, mandating local governments, regional administrations, public highway authorities, and agencies responsible for privately financed highways to collect and share traffic data in a standardized format with South Korea's National Transport Information Center (NTIC).[64] NTIC then collates, processes, and analyzes this data from 66 agencies and disseminates traffic information to citizens free of charge through various channels, thereby enabling the national government to analyze the impact different policies have on their cities and communities, and empowering cities with similar challenges to learn from one another. For example, when researchers from Ulsan National Institute of Science and Technology successfully developed an AI system that better predicts real-time traffic conditions using public information disseminated by a broadcasting network, the system was quickly supplied to other Korean cities, including Gwangju, Busan, Daejeon, and Incheon.[65]

The United Kingdom, on the other hand, is facilitating sharing of non-public data that would not otherwise be made publicly available due to its proprietary or sensitive nature, but that has high value. Policymakers there have recognized that creating high-quality datasets that are properly formatted, complete, labelled, and corrected of harmful biases is time consuming and expensive, which means companies and researchers often have to make do with bad data and thus unreliable or inaccurate AI tools.[66] To overcome this barrier to AI development, the United Kingdom established a model for data trusts, a type of data access and stewarding model inspired by legal trusts. These are institutions that enable companies to share data with each other, with data governance decisions made by "trustees" with fiduciary responsibilities.[67] Without a coordinating body such as a government agency specifically devoted to developing and supporting these models, it is unlikely organizations will develop them on their own. National governments can therefore facilitate AI maturity for smart cities by experimenting with data trusts and other models to make existing high-quality datasets more widely available.[68]

Risk and Uncertainty Limits Adoption

Because smart city technologies, including AI, are still emerging, many municipal governments perceive investments in AI for smart city initiatives as risky, making it harder for them to justify the spending without evidence of the return on investment these technologies can offer.[69] Economists refer to this challenge as excess inertia or, more commonly, "the penguin effect"—in a group of hungry penguins, no individual penguin is willing to be the first to enter the water to search for food due to the risk of encountering a predator. Yet if no penguin is willing to test the waters, then the whole group risks starvation.[70]

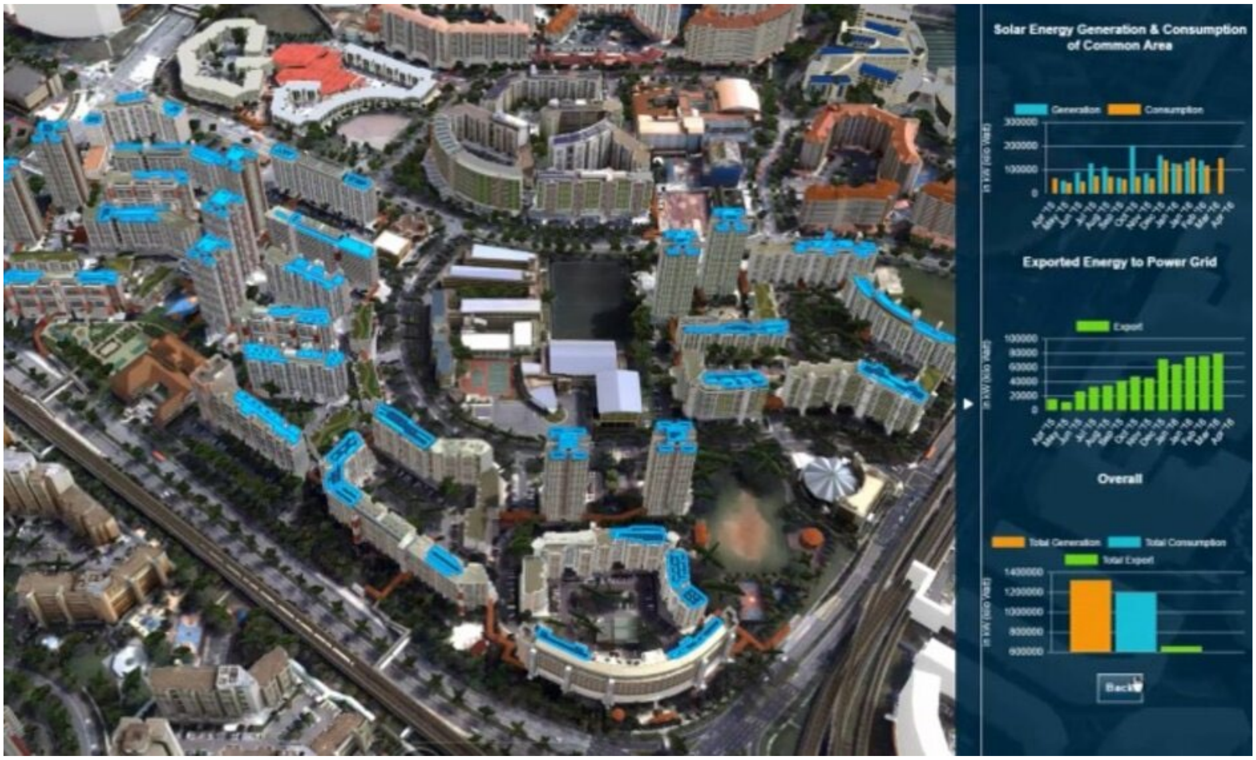
National governments can adopt policies and practices to demonstrate the value of AI technologies for cities and help address early-stage challenges. For example, the United Kingdom has created the Connected Places Catapult, a government-backed center of excellence for innovation in mobility and the built environment.[71] To tackle barriers in scaling commercial drone products and services, Connected Places Catapult partnered with the Department for Transport, the Department for Business, Energy and Industrial Strategy, and the Civil Aviation Authority on the Drone Pathfinder program. Together, these agencies developed five "first of a kind" demonstration projects, including projects using drones for infrastructure inspection and Coastguard search and rescue. In each case, Connected Places Catapult matched technology providers to priority industrial use cases, and worked with regulators to enable real world demonstration.

The center also enhanced partnerships across industry and government to commercialize innovation. For example, to help leverage the United Kingdom's position in air traffic management markets, Connected Places Catapult developed the Open Access Unmanned Traffic Management Framework Program, in partnership with the Department for Transport and leading U.K. companies, to test unmanned traffic management in flight trials.[72] The outputs from these trials will give U.K.-based industry a head start on global export opportunities.

Singapore has established AI Makerspace, a national AI platform that provides start-ups and small and medium-sized companies with access to plug-and-play AI resources, such as tools that predict future demand based on historical data.[73] This initiative is part of AI Singapore, the city-state's impact-driven, national research and AI innovation program launched in 2017.[74]

One of Singapore's most ambitious smart city ventures is Virtual Singapore, a digital twin of the island that can serve as a test bed for government agencies, businesses, and researchers.[75] Singapore has invested SD$73 million (US$53 million) in developing the platform, which will enable different sectors to develop sophisticated applications and tools that solve emerging and complex challenges. For example, Singapore's Geospatial Specialist Office is using the digital twin to explore the impact of implementing solar panels in Yuhua, an older housing estate the city has identified for green-style upgrades (figure 5).[76] Using the platform together with energy data from local authorities, the team of urban planners can analyze the buildings that have a higher potential for solar energy production.

Figure 5: Singapore uses a digital twin—Virtual Singapore—to analyze the potential for solar energy production[77]



Researchers from the National University of Singapore are also using Virtual Singapore to develop an integrated platform that utilizes machine learning to perform energy simulations at multiple scales, from the city level down to individual buildings.[78] Urban cooling strategies, such as providing parks and trees or self-shading building envelopes, are implemented at different levels of the urban environment—building, street, region—and studies on the environmental implications of these strategies are often segregated. To have a comprehensive understanding of how to mitigate urban heat, the researchers' approach is to use machine learning algorithms to predict the characteristics of a particular urban microclimate based on phenomena such as airflow, heat transfer, radiation, and air pollution and then create an integrated platform wherein different climatic models can interact with one another.

Virtual Singapore has been an essential resource for the project, which is called Building Energy Simulation and Urban Canopy Modelling, by providing detailed urban geometry modelling information. It will likely act as an important test-bed for the local architects, engineers, and scientists who will need to validate how implementing new solar panels or developing new buildings will impact building and pavement material properties such as reflectivity, emissivity, and heat capacity.

The EU is also exploring the development of shared, common, highly specialized resources to foster the deployment of AI for smart cities. In May 2020, the European Commission presented the concept of "Artificial Intelligence for Testing and Experimentation Facilities for smart cities, mobility, energy, and environment."[79] The idea behind these facilities is to create a research hub that helps close the gap between research and deployment at scale through real-life experimentation in a physical environment, including regulatory sandboxes—frameworks that enable firms to work with regulators to help discover legal gaps and test their innovative products, services, and business models with real consumers in a controlled environment on a trial basis.[80]

Privacy and Security Concerns Slow Down Deployment

Unchecked privacy fears and a lack of understanding about emerging technologies can slow smart city development. For example, the city of Toronto partnered with Sidewalk Labs, an Alphabet subsidiary, in 2017 to develop Sidewalk Toronto, a 12-acre development with integrated sensor networks and other technologies.[81] Unfortunately, largely unwarranted fears of inappropriate data collection and misuse led to the eventual collapse of this project.[82] Similarly, Chicago's Array of Things project to deploy sensor hubs throughout the city to track things such as air quality and pedestrian traffic has been hampered by privacy fears.[83] Some opponents called the sensor hubs "spy boxes" and claimed, without evidence, that the data would be used to surveil citizens. One of the main criticisms of the sensors was they estimated population counts by detecting Bluetooth signals from nearby pedestrians' mobile devices.[84] But the sensors would simply detect that a device is present, and not collect any data from the device.

To address concrete privacy harms and ensure companies are transparent about their security practices, the United States should establish a single federal data privacy law as the Information Technology and Information Foundation (ITIF) explained in its report "A Grand Bargain on Data Privacy Legislation for America."[85] But, there is not one yet. Instead, there are multiple federal and state laws that currently regulate the private sector. Where there are no sector-specific rules, the U.S. government provides oversight of industry self-regulation, allowing particular industry sectors to use voluntary agreements, peer pressure, and other methods to coordinate behavior without violating antitrust rules. This means it is up to firms and municipal governments to proactively address concerns about privacy, such as through city contracts with technology providers, in order to obtain the public buy-in that is so crucial to the success of their smart city applications.

In Europe, in an effort to increase citizens' acceptance of public services that use automation and big data, city government offices in Helsinki and Amsterdam have created online registers detailing how they are using AI.[86] The AI applications listed in Helsinki's register include health care center and parking chatbots, a recommendation system for books from the Helsinki City Library, and an intelligent management system between city libraries. Amsterdam's register, on the other hand, includes a camera system to monitor social distancing in public spaces during the COVID-19 pandemic and an application designed to help city employees sort through reports on littering submitted through an online system. Each AI system cited in both registries lists the datasets used to train algorithmic models, a description of how those algorithms are being used, how humans are utilizing predictions from AI systems, and how each algorithm has been assessed for potential bias or risks.

The majority of AI innovations overwhelmingly benefit society, and Helsinki and Amsterdam are promoting policies that ensure their robust widespread adoption, rather than establishing independent commissions to regulate algorithms that can create speed bumps—and sometimes even road blocks—to technological progress.

New York City Council demonstrated the problems with taking the latter approach in 2017 when it passed legislation creating a centralized task force within City Hall to guide agencies' management of their algorithmic decision-making systems. The council failed to account for the fact that different algorithms pose different levels of risk and require different types of oversight, depending on their application. As a result, New York City's task force itself acknowledged that it failed to find consensus on a number of issues, which led to at least one member describing her experience serving in the group as "a waste."[87]

Equally important, Helsinki and Amsterdam are focusing oversight on the parties responsible for deploying algorithms, rather than on developers, by providing mechanisms for citizens to give feedback on the algorithms their local governments are using and the name, city department, and contact information for the person responsible for the deployment of a particular algorithm.[88] This is central to building oversight around algorithmic accountability—the principle that an algorithmic system should employ a variety of controls to ensure the operator can verify algorithms work in accordance with the operator's intentions and identify and rectify harmful outcomes.[89] By identifying and holding city operators responsible, Helsinki and Amsterdam are both incentivizing city officials to act responsibly and providing citizens with a direct route to rectify harms.

HOW TO SCALE TRANSFORMATIONAL AI APPLICATIONS ACROSS SMART CITIES

Overcoming the barriers to and scaling AI adoption at a city level will require policymakers to be able to identify a city's unique needs, develop next steps for advancing its AI capabilities, and deploying AI solutions. To scale AI adoption at a national level, policymakers will also need to be able to evaluate variations in AI adoption across cities.

Technology-maturity models reflect the degree to which organizations have formalized their adoption of new technologies; and higher levels of maturity correspond with an ability to achieve desired outcomes more consistently.[90] For example, in these early stages of AI maturity, organization are exploring the technology, whereas more-mature organizations are using AI to transform their operations. Government leaders should think about AI adoption in smart cities in a similar fashion. Right now, most AI in smart cities is in the exploring or experimenting stage, and the goal of city leaders should be to fully integrate AI into their processes.

To successfully utilize AI, cities need:

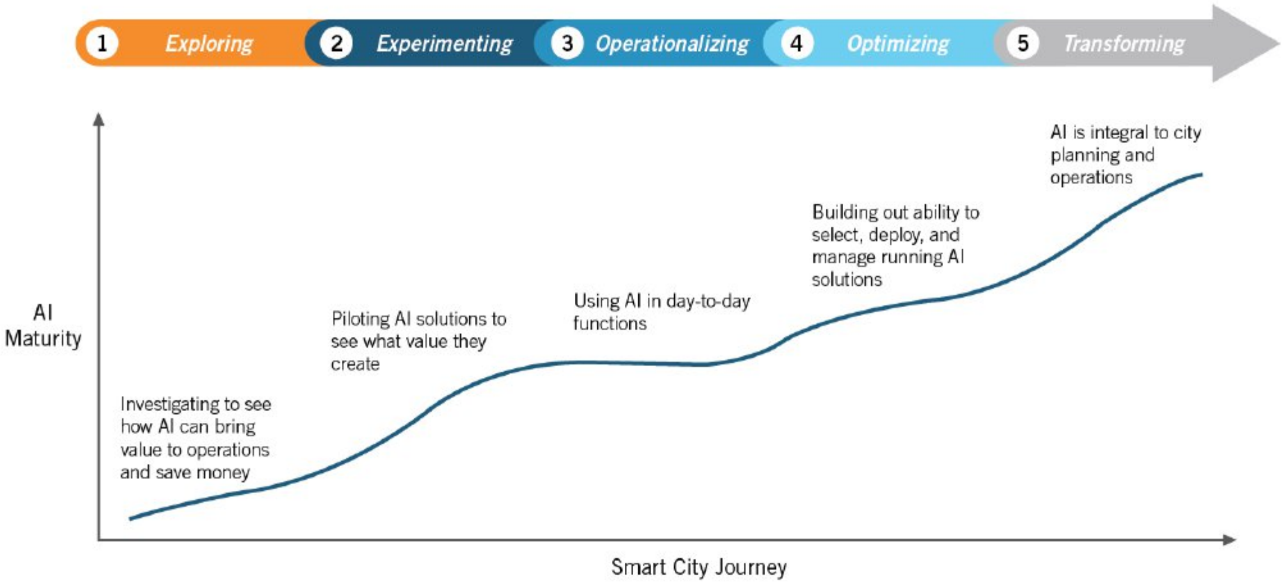
- a strategy defining how they will drive the widespread and rapid adoption of AI and identifying areas to focus attention and resources;
- data to support specific AI technologies and applications;
- technology and access to technical infrastructure to train, deliver, and manage AI models across their lifecycle, such as access to TensorFlow, a machine learning library that helps developers better train neural networks;
- people with the expertise to successfully build and work with AI systems; and
- governance processes to ensure AI solutions are safe and reliable, and operators of AI systems are held accountable for harms.

In the United States, the city of Peachtree Corners in Georgia has invested in Curiosity Lab, a 25,000-square-foot test bed center that provides established companies and start-ups with free access to the resources they need to test and demonstrate new AI technologies, including a 1.5-mile AV test track.[91] The city has also recently partnered with IoT provider IPGallery to build a centralized data platform, thereby enabling the city to better analyze and use the data that comes from various devices and sensors across the city.[92] But Peachtree Corners has neither presented a clear case for how it will apply AI technology systematically and extensively nor evaluated factors for securing trust with citizens, which will impede even the most sophisticated AI solution from achieving its full impact. The lesson from this example is investment in technology, data, and attracting skilled people is not useless, but a lack of progress in strategy and governance delays returns on investment. National governments can and should play a role in accelerating and coordinating the development of AI-enabled smart cities. For example, the federal government can develop a national "Smart City App Store"—a common repository of successfully deployed commercial applications and open-source code—which other cities could adapt and reuse. Every government-funded smart city initiative could contribute to this repository so that cities could more easily find solutions and replicate their projects.

But all cities are not the same. The structural and institutional forms that shape cities vary from country to country—and even within the same country, cities do not have the same policy tools or resources at their disposal. Consequently, cities' responses to AI are going to be varied and local governments will need to make most of the decisions related to deployment based on their specific needs, innovation opportunities, and priorities.[93] Federal agencies that provide funding to states should therefore be able to evaluate progress and base their funding decisions much more on performance. Holding states and their cities accountable for real results will allow federal funds to go farther, achieving better results for the same amount of funding. It will also provide stronger incentives for states to adopt innovative AI approaches.

Policymakers can use the AI maturity model in figure 6 to evaluate cities' development in their AI capabilities. In the first stage, "Exploring" cities are beginning to investigate how AI can bring value to their operations. "Experimenting" cities have begun piloting specific AI solutions to see what value they can create and how. In the next stage, cities have begun operationalizing the use of AI in their day-to-day functions and are creating value. "Optimizing" cities are focused on building out their ability to select, deploy, and manage running AI solutions that deliver the most value. In the final stage, cities are using AI pervasively to push the boundaries of their technology and strategy. In particular, federal agencies can use the AI maturity model to establish short-term and long-term performance targets for cities in each group and hold states accountable to AI-adoption benchmarks.

Figure 6: AI maturity model for smart cities

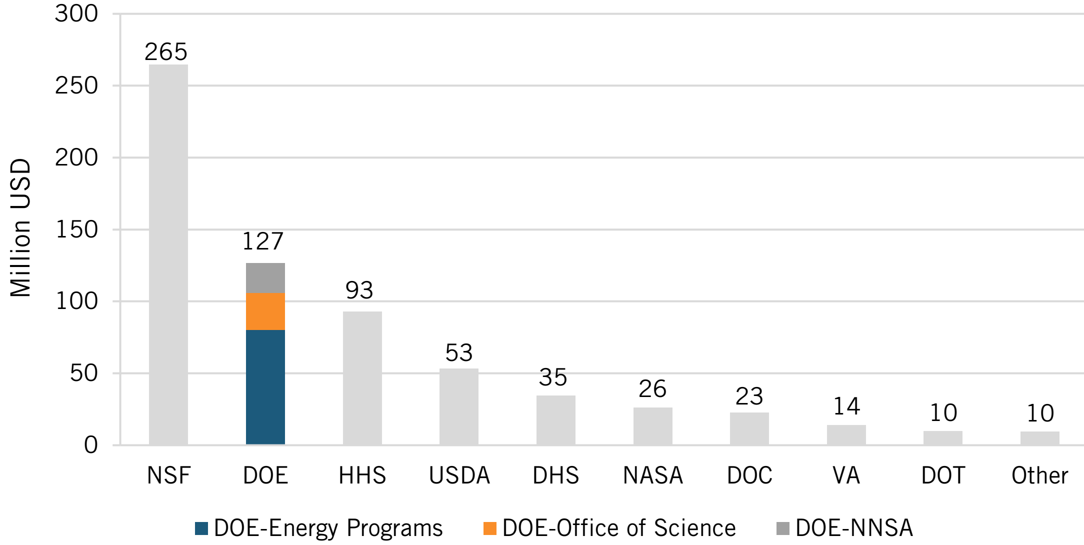


U.S. FEDERAL GOVERNMENT SUPPORT FOR AI AND SMART CITIES

The U.S. government has begun to commit more resources to accelerating AI. The Trump administration identified AI as one of five key "Industries of the Future" and issued Executive Order 13859 on "Maintaining American Leadership in Artificial Intelligence," which directed federal agencies to make government data and computing resources available for AI, prioritize AI research and development (R&D), and provide guidance to federal regulators on how to approach AI.[94] The Networking and Information Technology Research and Development (NITRD) program, an interagency program that tracks and coordinates federal research in information technology (IT), in 2019 launched "The National AI R&D Strategic Plan" to identify R&D priorities and provide guidance to federal agencies.[95] The FY 2020 budget provides $655 million for AI R&D across more than a dozen agencies, and the administration requested $912 million in its FY 2021 budget, a 39 percent increase.[96]

This investment creates a significant opportunity to encourage cities to leverage AI more effectively, but it will go unrealized unless federal priorities are reordered. The portion of federal AI R&D investment devoted to developing AI for smart city applications is likely small, and the share devoted to energy and climate applications is even smaller.[97] For example, the Department of Transportation (DOT) invested only $9.8 million in AI R&D in FY 2020, despite the fact that ITS are a major use case of AI (Figure 7).

Figure 7: Federal FY 2020 funding for AI R&D by agency



Existing AI programs are heavily weighted toward R&D, with very little funding supporting real-world demonstrations of AI, or funding deployment of smart infrastructure. Demonstration projects establish the technical, economic, and environmental viability of technologies in practice, and are often necessary before widespread commercial adoption. Prior ITIF analysis has identified demonstration projects as a critical gap in the federal innovation ecosystem and demonstrated the need for greater investment in demonstration projects to de-risk emerging technologies such as AI.[98] Similarly, deployment of IoT and digitally enabled infrastructure is often a necessary precursor to the development of AI applications, but federal infrastructure funding tends to favor non-digital infrastructure projects (e.g., fixing potholes and repairing roads) over digitally enabled infrastructure investments.[99]

Additionally, existing programs are isolated and tend to support siloed applications (e.g., only smart grids, or only ITS), with few programs supporting integrated energy systems.

The following are key federal programs that support AI and smart city investments.

Intelligent Transportation Systems (DOE, DOT)

Federal research in ITS is split between the DOE Vehicle Technologies Office (VTO) and the DOT ITS Joint Program Office (JPO). In general, DOE programs focus more on vehicle technologies such as batteries and EVs, while DOT focuses more on transportation infrastructure (e.g., roads and bridges), though the boundary between vehicles and infrastructure has become blurred as transportation systems are becoming more intelligent.

DOE VTO

VTO leads DOE's work on intelligent transportation systems. Its batteries and electric vehicles subprogram is pursuing several applications of AI for smart charging of EVs, which include 1) monitoring and predicting EV driver charging needs, 2) communicating vehicle charging intentions to infrastructure (e.g., charging stations and grid operations), and 3) making decisions on optimal charging times and locations based on real-time feedback from charging infrastructure.[100] The energy efficient mobility systems subprogram leads DOE's work in CAVs.

Use cases of AI include simulating and modeling regional transportation systems, monitoring energy consumption of drones for package delivery, optimizing traffic signaling to minimize congestion and fuel consumption, and examining behavioral choices such as why people make modal choices.[101]

DOE has partnered with the United States Council for Automotive Research, the Electric Power Research Institute, and several automotive and energy companies to launch the U.S. Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability (US DRIVE) partnership to coordinate on vehicle research, identify technology challenges, and inform the federal research agenda. In February 2020, DRIVE released a roadmap for vehicle mobility systems analysis that identified machine learning for CAVs as a potential research gap. The partnership is currently reviewing existing uses of AI related to mobility in order to identify future research directions.[102]

DOT ITS Joint Program Office

DOT ITS JPO—funded at $100 million annually—collaborates across DOT administrations to coordinate and plan the agency's ITS technology research program. AI is one of six main elements of ITS explored by DOT.[103] In December 2015, DOT launched the Smart City Challenge prize competition for mid-sized cities, which awarded $40 million in March 2016 to Columbus, Ohio, to implement connected technologies that reduce congestion, improve transportation safety, reduce traffic pollution, and support economic growth. However, the program was narrowly focused on transportation, and was not funded at a sufficient level to meet the needs of other cities that submitted applications. DOT also launched in 2015 the Connected Vehicle Pilot Deployment Program, which seeks to spur innovation among early adopters of connected vehicle applications. DOT selected three pilot sites—in New York City, Tampa, and Wyoming—for building and testing deployments of integrated wireless in-vehicle, mobile device, and roadside technologies. In the final phase of the projects, to be completed by September 2021, the connected vehicle systems will be operational for a minimum 18-month period, and the systems' impacts will be monitored on a set of performance measures.[104]

No transportation infrastructure programs support widespread deployment of ITS infrastructure. JPO focuses primarily on R&D and deployment of first-of-a-kind pilot projects (such as the Smart City Challenge and the Connected Vehicle Pilot program). In FY 2020, the FAST Act authorized $46.4 billion for highway projects and $12.6 billion for other transit. However, most of this funding supports more-traditional physical infrastructure projects—fixing roads and bridges—because cities are simply trying to keep up infrastructure maintenance needs. ITIF has previously recommended that Congress significantly increase funding for ITS to $2.5–$3 billion annually.[105] Smart infrastructure is an essential ingredient for smart cities, and provides the data, communications, and controls that enable AI applications.

Smart Grid RD&D and Deployment (DOE)

DOE Office of Electricity and the Grid Modernization Initiative

Multiple DOE offices are exploring AI applications in the smart grid. The Office of Electricity (OE) leads DOE's work on the electricity grid (transmission, storage, and distribution), including grid components and grid communications and controls. Other offices focus on specific electricity generation technologies, such as wind and solar energy. While these programs tend to focus on electricity generation technology development (e.g., more efficient solar PV cells), they also often include subprograms focused on specific grid integration challenges.[106]

In 2015, DOE launched the cross-cutting Grid Modernization Initiative (GMI) to coordinate grid modernization and smart grid research across the department, in collaboration with the national laboratories and utility partners. The GMI was intended to break out of the technology silos and provide better coordination between OE; the office of Cybersecurity, Energy Security, and Energy Resilience (CESER); Fossil Energy (FE); Energy Efficiency and Renewable Energy (EERE); and Nuclear Energy (NE). That same year, DOE, the national laboratories, and utility partners again collaborated to develop the Grid Modernization Multi-Year Program Plan (MYPP), a multiyear R&D roadmap outlining priority research areas and identifying technology goals to pursue by 2020.[107] The plan identified a number of smart-grid-related AI applications. However, DOE has not updated its Grid Modernization research plan since 2015—despite congressional pressure to do so—leaving open the possibility that future AI applications may be missed, and that smart grid research at DOE will devolve to an uncoordinated approach with individual technology programs pursuing separate research agendas.[108]

Smart Grid Investment Grant Program in the American Recovery and Reinvestment Act

There are no active federal programs that support deployment of smart grid infrastructure. Current federal smart grid programs focus solely on RD&D of smart grid technologies. However, deployment of smart grid infrastructure (such as smart meters) is often a prerequisite for taking full advantage of AI applications for the grid. The 2009 American Recovery and Reinvestment Act (ARRA) included $3.4 billion for the Smart Grid Investment Grant (SGIG) program to modernize the electric power grid. The SGIG program provided funding for deployment of advanced metering infrastructure (i.e., smart meters), distribution automation systems, phasor measurement units for the transmission grid, and customer systems such as smart appliances and building energy management systems.[109] The SGIG program is credited with installing more than 16.3 million smart meters, nearly double the number of smart meters installed before the SGIG program began.[110] However, since the end of the program, utilities have had to finance grid upgrades without federal support, which is an especially large burden on rural electric coops and some of the smaller utilities that have fewer customers who can support rate increases to fund infrastructure upgrades.

Smart Buildings RD&D and Deployment (DOE and GSA)

DOE Building Technologies Office

The Building Technologies Office (BTO) houses DOE's programs in smart buildings/smart appliances, building and appliances codes and standards, and grid-integrated buildings. In 2019, BTO launched a new research initiative to develop GEBs that can provide greater systems-level efficiencies and demand-management services.[111] As part of the initiative, DOE is currently exploring applications of AI in whole-building controls, sensors, modeling, and analytics, as well as applications in advanced lighting and HVAC systems. The National Renewable Energy Laboratory (NREL) is developing a test bed—the Advanced Research on Integrated Energy Systems (ARIES) platform—to understand the impact of new technologies such as EVs, DERs, and GEBs on the grid.[112] The physical platform will be supplemented by a virtual emulation environment powered by NREL's 8-petaflop supercomputer.[113] The new ARIES platform could be used to develop, train, and validate AI tools with smart grids, smart buildings, and smart EV charging applications.

In October 2020, BTO launched a new Connected Communities funding opportunity announcement (FOA), which will provide up to $65 million for communities to demonstrate how groups of buildings, and the DERs to which they connect, can cooperate to collectively manage and optimize their energy performance.[114] The FOA includes the AI-driven Smart Community in Basalt, CO, as an example of the type of connected community project DOE aims to fund.[115] The program is analogous to the DOT Smart City Challenge for ITS (and has similar faults). Like the DOT program, the BTO program for connected communities is an important first step in piloting new technologies, but the funding is far too little to meet the full range of potential applications. And like the DOT program, BTO is focusing on a narrow set of smart city technologies, rather than taking an integrated approach that demonstrates smart grid, smart buildings, ITS, and other smart city technologies in an integrated setting.

General Services Administration Grid-Interactive Efficient Building Pilot Initiative

The General Services Administration (GSA), which manages the federal portfolio of 8,700 owned and leased buildings, has partnered with DOE to pilot GEB technologies on its own buildings and evaluate for efficiency, cost savings, and resilience. The effort is motived by a Rocky Mountain Institute (RMI) 2019 report finding that GEB technologies, if implemented comprehensively throughout GSA's portfolio, could save the government $50 million annually, with a payback time of under four years. The effort could also generate $70 million per year in societal value to other grid users, due to reduced generation capacity and reduced transmission and distribution costs, which could be monetized to benefit all electricity customers.[116] In July 2020, GSA announced it would be piloting four GEB technologies, all of which couple machine learning with sensors and automation to provide real-time demand management.[117]

Crosscutting R&D and Economic Development Programs (DOE and NSF)

DOE AI Technology Office

In its FY 2021 Congressional Budget Request, DOE proposed establishing a new AI Technology Office (AITO) to coordinate AI research throughout the department and with other agencies.[118] According to its mission, AITO "will define DOE's strategy, identify opportunities for AI research, development, and delivery (RD&D), and address gaps within current mission-relevant operations."[119] DOE swore-in the first director of AITO in February 2020.[120] In August 2020, AITO announced the creation of the First Five Consortium, a collaboration between the DOE labs, Department of Defense, and Microsoft to improve response to and mitigation of natural disasters. The consortium is named for the critical first five minutes in responding to a disaster, and will apply AI to address such issues as wildfire prediction and containment; damage assessment; search and rescue; and hurricanes and tornadoes.[121] So far, AITO has focused on coordinating DOE AI research around disaster mitigation and hazard response, and does not appear to be exploring AI applications in energy systems.

NSF Smart and Connected Communities

NSF's Smart and Connected Communities program is one of the few cross-cutting programs that conducts R&D across multiple smart city applications. The program supports multidisciplinary research that spans social and technological research dimensions and engages community partners to inform research questions and develop pilot solutions.[122] In 2019, the program announced up to $43 million to support 35 to 45 projects, which was a sharp increase from the 2018 solicitation that provided $22.6 million to 13 projects.[123]

NIST Smart Cities and Communities

NIST works to develop the foundations and measurement science for cyber-physical systems and Internet of Things. In 2014, NIST launched the Global City Teams Challenge (GCTC), a collaborative platform for cities and industry, academic, and government stakeholders to identify common barriers and develop and deploy emerging smart city technologies.[124] The Smart Cities and Communities Framework series uses input from the GCTC to develop best practices and technical guidance for planning, developing, and implementing smart city technologies.[125] The Framework series addresses cross-cutting and foundational issues such as data standards and privacy, and sector-specific issues such as transportation and utilities, implementation approaches, and case studies.

HOW THE FEDERAL GOVERNMENT SHOULD SUPPORT AI FOR SMART CITIES

Leveraging AI for smart cities will help achieve U.S. energy and climate goals. While city governments will ultimately take the lead on deploying AI smart city applications, there is an important role for the federal government in funding R&D and coordinating activities at a national level. The following recommendations outline the steps Congress, federal agencies, and city governments need to take to advance R&D, demonstration, and deployment of AI for smart cities.

Research and Development

- NITRD should refresh the 2019 National AI R&D Strategic Plan to include a focus on smart city applications. The strategic plan details eight strategies to help guide AI R&D efforts, ensuring federally funded research is prioritized around the advancements critical to using AI to improve the economy, society, and national security. But the strategy fails to prioritize AI for smart cities, which is vital to addressing energy and climate concerns.
- Congress should double investment in R&D of AI with energy applications across the federal government, including DOE programs in advanced grid R&D, grid-integrated efficient buildings, ITS, and energy systems integration; DOT R&D programs in CAVs and other ITS technologies; and crosscutting R&D in NSF's Smart & Connected Communities program. Congress should fully fund DOE's new AI Technologies Office, which should play a coordinating role for federal AI R&D both within DOE and between agencies.
- Congress should fund 10 smart city cooperative research networks at universities across the country that bring together stakeholders and researchers from industry, universities, and the national labs, such as the network of research centers and institutes at the University of Illinois-Urbana Champaign's College of Urban Planning and Public Affairs.[126] This network includes eight research centers including a Great Cities Institute focused on solving urban challenges, an Urban Transportation Center dedicated to innovative transportation research, and an Urban Data Visualization Lab focused on geo-spatial data analysis and complex systems modeling. Together, these centers work closely to share and compound knowledge.

Demonstration

- Congress should direct NITRD to create cross-agency development test beds to help agencies collaborate and validate AI technologies and convert R&D output into innovative and useful capabilities for smart cities. The frameworks for these test beds should be made available to cities and states to encourage their adoption at the state level.
- Congress should provide at least a tenfold increase in annual funding for the GSA Proving Ground to pilot new GEB technologies (currently funded at $1 million annually).[127] GSA should share data on its GEB Initiative to pilot grid-integrated building technologies with cities and the public. If GSA can demonstrate energy savings and performance improvements from AI applications in federal buildings, it can share that information with state and local governments and private sector building owners and operators. Cities and states in turn should evaluate the GSA initiative for potential inclusion of grid-integrated technologies in their own energy savings and climate action plans.
- Congress should provide at least $2 billion to fund a competitive smart cities program. When DOT launched a smart city challenge in 2015, it had almost 80 cities compete for a $40 million grant. In the process, many cities developed detailed plans for how they would invest additional funding to become smart cities. Congress should authorize a new round of funding to make resources available on a competitive basis for up to 10 large cities, 20 medium-sized cities, and 30 small cities to receive grants to invest in smart city infrastructure.[128] In order to qualify for funding, DOT should require participating cities to open-source the code for any applications they develop in a Smart City App Store to share their data to a common data pool.
- City governments should pilot smart building and smart grid technologies on city buildings. Because they generally have more control over their own buildings than other buildings in the public sector, if city governments can pilot and demonstrate energy savings from AI applications on their own facilities, they can then share that information with commercial and industrial buildings managers. The Salt River Project, an Arizona public utility, for instance, is piloting GEB technologies on their facilities, which they intend to eventually offer as a service to large commercial and industrial energy users.[129]

Deployment

- Congress should reserve 5 percent (approximately $2.5 billion) of the Highway Trust Fund allocated to states to be devoted to digital and ITS-based infrastructure projects.[130] Smart infrastructure, and the data it provides, is generally a precondition for the development and deployment of AI solutions.
- Congress should revive the SGIG program to support deployment of advanced metering infrastructure and other smart grid investments. The first SGIG program, funded through ARRA, was responsible for nearly doubling the number of smart meters, and was a key program for other grid modernization investments. However, nearly half of U.S. customers still lack smart meters. Grid upgrades are especially challenging for rural electric coops and utilities serving low- and moderate-income communities to fund on their own without federal support.

- Congress should expand Department of Housing and Urban Development (HUD) ConnectHome pilot program which allows HUD funding to be used to provide digital-literacy training for, and distribute internet-connected devices to, public-housing residents—and to install broadband networks in public housing units. Congress could create similar smart city programs at HUD or other agencies.
- Congress should appropriate funds for planning grants targeting underserved communities. The Department of Commerce's Economic Development Administration's (EDA) Economic Development Planning Assistance Program could support dozens of cities with small grants to identify and assess opportunities afforded by smart city technologies.
- Congress should expand EDA support for regional innovation ecosystems. EDA's i6 program provides communities with funding for smart city start-up accelerators, workforce training, IoT networks, and planning.
- Congress or the Biden administration should establish a national "U.S. Smart City App Store"—a common repository of approved commercial applications and open-source code. The App Store could be housed at DOT or DOE but should encompass the full range of smart city solutions. Every government-funded smart city initiative should be required to contribute to this repository so cities could more easily find solutions and replicate their projects.
- DOE should establish a smart city energy data pool—a collection of common data elements that are useful to addressing energy and climate goals—that cities can contribute to. By establishing a common data pool for energy data from smart cities, complete with technical standards and data governance policies, cities can facilitate the development of scalable applications that contribute to and make use of this data.
- City governments should facilitate open data sharing—within city governments, between cities, and between cities and public and private partners. The Chicago Array of Things partnership between Argonne National Laboratory, the University of Chicago, and the City of Chicago provides a good example of an open data initiative. The Array of Things is a network of interactive, modular sensor boxes that measure temperature, light, carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, sound, particulate matter, and pedestrian and vehicle traffic to better understand their links to health outcomes, transportation safety, and crime. The data is provided to researchers, policymakers, developers, and residents.[131]
- The Department of Commerce, the Department of Health and Human Services, and other relevant federal agencies should develop and pilot "data trusts" to facilitate data sharing in specific application areas among academia, businesses, and government agencies. Data trusts are legal structures that act as independent intermediaries to encourage businesses to collect and share data responsibly. Congress should also fund and task the Department of Commerce to pursue additional innovative models for increasing the availability of data. This should include facilitating the creation of industry-led data councils to identify barriers to data sharing and developing strategies to overcome these barriers.

- City governments should include AI smart city applications in post-COVID-19 recovery plans. Many AI and smart city investments can reduce both city operating expenses (while also accelerating recovery) and growth for city businesses and residents. Smart city projects with the most direct ability to reduce city operating expenses include smart streetlights, smart parking, traffic monitoring, smart buildings, and other energy-saving technologies.
- City governments should include AI and smart city technologies in their climate plans. AI is an important but often overlooked tool in the decarbonization toolkit. For example, in the last couple years, four large U.S. cities—St. Louis, Chicago, Pittsburgh, and Boston—developed citywide building energy benchmarking reports to inform city energy and climate plans.[132] The St. Louis report was the only one that encouraged adoption of smart building technologies (automated building energy management systems, occupancy sensors, and smart thermostats).[133] But the list of technologies included was not complete. And the other cities did not include any AI or smart building technologies in their energy plans.
- City governments should adopt building codes that prepare buildings and parking lots for two-way, automated utility-to-customer energy management. Cities and states should examine building codes for opportunities to enable smart grid and smart building adoption. States are generally responsible for adopting commercial and residential building codes, while local governments are responsible for enforcing them. But some states leave it up to cities. Recent versions of the energy code in California require that certain new and retrofitted equipment and systems be ready for two-way, automated utility-to-customer energy management, so they can potentially participate in demand response programs.[134] NYSERDA has "stretch codes"—voluntary building codes beyond the minimum New York requirement—that include an option for building-to-grid communications (for HVAC and lighting systems) that enable demand response. The federal government can support these efforts through the development of voluntary building codes.

CONCLUSION

Leveraging AI will help cities meet their climate goals and upgrade aging infrastructure, while simultaneously reducing energy expenditures and city operating costs. While city governments will ultimately take the lead on deploying AI smart city applications, there is an important role for the federal government in funding R&D and coordinating activities at a national level. Smart cities offer a strategic opportunity to address infrastructure needs and strained state and local budgets at the same time.

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