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EPRI Insights

Current Events, Industry Forecasts, and R&D to Inform Energy Strategy

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Executive Summary

EPRI collaborates with a global network of energy leaders across industry, government, and academia every day to drive research and development for society.

This insight document extends the benefit of our experts' perspectives through a snapshot of industry events, developments, and forecasts to help inform energy strategy.

Advanced nuclear reactors can provide baseload carbon-free power in a decarbonized grid.

Attributes such as inertia and ability to efficiently vary output in response to changing grid conditions (for example, due to variable renewable energy sources) may result in potentially higher efficiencies, grid stability, and grid security.

However, issues such as regulation, costs, and public perception may impede adding new nuclear assets to the grid. Digital twin technology offers the potential to help offset certain costs by optimizing construction and maintenance sequences.

Continued growth of electric vehicles (EV), supported by a concurrent expansion of charging infrastructure, can play a significant role in global decarbonization efforts.

Increased EV adoption may create new demand challenges for the grid, however, so there is growing recognition of potential grid resilience and reliability issues. Countries around the world are exploring ways to incentivize EV adoption and charging infrastructure.

Equitable access to EV charging infrastructure is a prime consideration, particularly as a potential means of increasing EV adoption and reducing transport sector emissions.

ACRONYMS AND ABBREVIATIONS

ANT: Advanced Nuclear Technology

AR: Advanced Reactor

CLCPA: Climate Leadership and Community Protection Act

CNSC: Canadian Nuclear Safety Commission

DER: Distributed Energy Resources

DOE: Department of Energy

DOT: Department of Transportation

DR: Demand Response

DT: Digital Twin

EU: European Union

EV: Electric Vehicle

GHG: Greenhouse Gas

GW: Gigawatt

GWe: Gigawatt electrical

IEA: International Energy Agency

IIJA: Infrastructure Investment and Jobs Act

LLC: Limited Liability Company

MTCO2e: Mega-tons of CO2 equivalent

MWe: Megawatt electrical

IEA: International Energy Agency

NRC: Nuclear Regulatory Commission

PACE: Property Assessed Clean Energy

PAYS: Pay as you save

SME: Subject Matter Expert

SMR: Small Modular Reactor

U.S.: United States

V2G: Vehicle to Grid

V2H: Vehicle to Home

V2L: Vehicle to Load

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ADVANCED NUCLEAR REACTORS

Advanced nuclear reactors may provide firm, no-carbon power generation to support reliable around-the-clock energy supply on a decarbonized grid.

As energy systems decarbonize, the rise of variable, renewables resources on power grids increases the value of firm generation assets during times of high demand and low renewable output. As fossil fuel assets are retired, nuclear energy may continue to provide a significant portion of baseload carbon-free power.

Traditional nuclear facilities generate energy via fission (splitting atoms to release energy) using reactors which use water for cooling and moderating the rate of reactions. The heat generated is used to create steam to drive a turbine and produce electricity. To capitalize on economies of scale, these plants are typically large (~1 GWe), which often results in high capital costs (both overnight and financing) and longer deployment timelines than other energy technologies.

Advanced nuclear reactors (ARs) refer to reactors with significant improvements over traditional reactors [1]. ARs include designs with non-water coolants and enhanced passive safety features. Small modular reactors (SMR), up to 300 MWe, and microreactors, up to 20 MWe, may reduce capital costs compared to traditional nuclear plants and enable more diverse applications.

Various types of ARs are in distinct technology readiness stages. In terms of non-water-cooled designs, sodium-cooled fast reactors and high-temperature gas-cooled reactors are among the more mature technologies [1]. Molten-salt reactors (often using fluoride or chloride salts as the primary coolant instead of sodium) [2] are still in the development stage.

SMRs using water as a coolant are a promising advanced reactor type, with some designs nearing deployment stage [3]. These reactors are modular: components are factory assembled and transported to a location as a unit. This may result in significantly shorter deployment timelines, reducing project risk and capital costs compared to traditional nuclear plants. Some SMR designs include other AR characteristics, such as passive safety systems [4].

Representative model of small modular reactor pressure vessel.

POTENTIAL BENEFITS OF ADVANCED NUCLEAR REACTOR TECHNOLOGY

Advanced reactors employ a combination of new coolants, fuels, materials, and power conversion technologies that enable greater safety, efficiency, and flexibility of nuclear power.

Enhanced AR safety is the product of a variety of design decisions, including operating pressure, complexity of coolant system, and fuel form. Lower operating pressures may lead to less energetic accident scenarios, making designs at lower pressure potentially safer [1]. AR coolant systems can be as simple as heat pipes, which allows for the possibility of entirely passive cooling.

In terms of fuel, there are a variety of fuel forms with different safety features [2]. Additionally, many AR designs propose partially or totally buried modules, which improve their resistance to external factors.

As renewable energy sources and their intermittency proliferate on electricity grids around the world, the ability to efficiently vary power output in response to changing grid conditions, known as load following, grows increasingly important.

ARs have a great deal of expanded flexibility as compared to the current nuclear fleet (and compared to other energy sources) [3]. Certain AR designs also have a better ability to load follow because they have a higher ramp rate, enabling plants to change power output over a shorter period [4]. Other AR designs have inherent energy storage capabilities, such as molten salt coolants, which can be diverted to thermal storage.

ARs can be coupled with other energy sources, including renewables and fossil fuel energy, to leverage resources and produce higher efficiencies and multiple energy end-products while potentially increasing grid stability and security [5]. **Due to the unique attributes of nuclear (such as inertia), the ability to efficiently vary output may allow advanced reactors to support a high renewable penetration grid.**

ARs can also divert useful heat to alternative processes, with certain designs producing very high temperature water (~800 °C). Heat from ARs can be used for high-temperature industrial processes or desalination, or for lower-temperature needs, like district heating for a community [6] or hydrogen production. This flexibility could be treated as a way of varying plant electrical output or could be the primary plant function.

Some ARs have black start capability. These ARs start from a de-energized state and without support from the grid which means they in the event of a major system blackout. **If needed, ARs can operate independently of the main electrical grid to provide energy for disaster response and recovery, remote communities, and for non-interruptible energy supply for critical operations (for example, hospitals)** [7].

EPRI's Advanced Nuclear Technology (ANT) program is engaged in a variety of projects to support AR deployment and commercialization. These projects include a major update to EPRI's advanced reactors requirements guidance documents, various economic and market evaluations, materials research and reporting, and more.

CHALLENGES TO ADVANCED REACTOR DEPLOYMENT

The economic and policy development environment for nuclear power globally and in the United States is complex, with conflicting drivers that may impede the deployment of new nuclear technology.

Regulation

Ongoing efforts by the AR community, the nuclear community at large, and the U.S. Nuclear Regulatory Commission (NRC) staff have identified licensing issues unique to AR designs. **Stakeholders are working collaboratively to develop alternative approaches for reconciling these issues within the established NRC regulatory process** [1].

NRC has engaged in varying degrees with AR designers in pre-application activities. For example, the NRC approved NuScale Power, LLC's SMR design in 2020, the first SMR design to receive approval [2].

The NRC and Canadian Nuclear Safety Commission (CNSC) signed a memorandum of cooperation in 2019 to share best practices and experiences in reviewing AR and SMR technology designs [3]. The memorandum details how the commissions can collaborate on the development of regulatory approaches to address technical considerations for ensuring the safety of ARs.

Cost

High initial development and capital investment costs can be a key factor in the extent and speed of nuclear deployment [4]. According to NuScale, the company spent over $500 million and over two million labor hours to develop information needed for the NRC Design Certification Application alone [5].

Publicly available cost analyses for SMRs are limited and current estimates may have a significant amount of uncertainty. Additionally, utilities may be hesitant to invest in SMR deployment until they see the technology demonstrated.

SMRs require lower overall capital investments compared to the existing nuclear fleet [6]. The shorter construction duration and scalability of SMRs further potentially reduces initial financing costs.

Public Perception

U.S. communities may benefit from the potential economic impacts of hosting a nuclear power plant, including communities that have retired nuclear sites.

Negative perceptions of nuclear plants exist, however, potentially creating community reluctance to host these facilities. **Building and maintaining public trust may need to be considered as an essential factor in the development and on-ongoing operational process for plants.** Nuclear plant siting also has potential to stimulate local economies in accordance with considerations for equity and environmental justice through consent-based processes [7].

DIGITAL TWINS APPLICATIONS FOR ADVANCED REACTOR CONSTRUCTION

Digital twins use real time data to digitally represent a physical system or asset. Access to predictive models of construction parameters can support time and cost-efficient processes.

Overview

A digital twin (DT) is a digital representation of an asset or process. Data is sent from sensors on an asset to a model, which grows and changes with the system. As the model changes and is refined over time, outputs can be used to provide real-time information to operational personnel to predict performance, monitor health and maintenance needs, and make informed optimization decision.

DTs have already been widely used in the energy industry, including for gas turbine [1], hydropower [2] and cybersecurity needs [3].

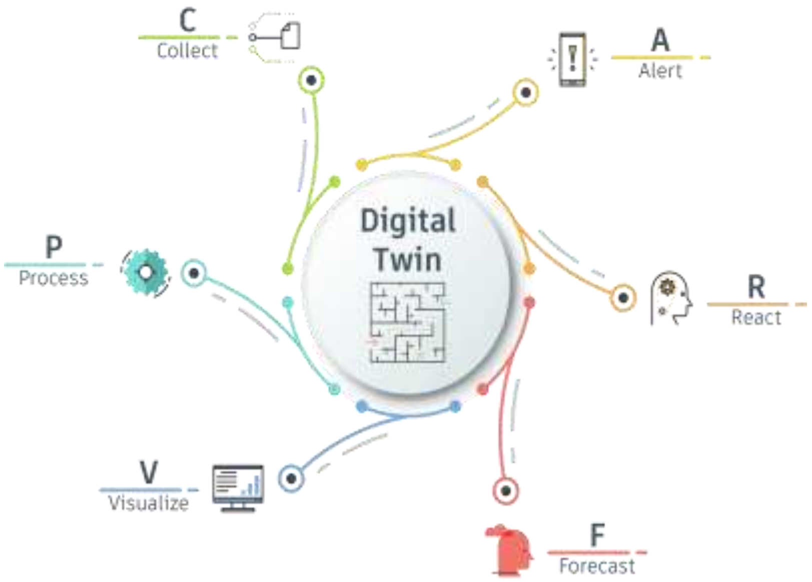
Today's efforts towards digitization and the development of improved sensors, simulations, and models are prompting investigation of DTs for use in many areas, including nuclear.

Potential Benefits

When constructing an SMR or other advanced reactor, optimizing construction sequences can improve efficiency and safety and reduce costs and timelines.

As a reactor is constructed, a digital twin can monitor and optimize schedule- and cost-critical parameters, including health, efficiency, quantities of materials delivered, and status of work products [4]. If an unplanned event occurs or a component is imperfect or damaged, the digital twin can be updated, give an alert, and serve as a source of real time information to all involved personnel.

Decisions informed by real-time data and forecasts from the DT can be made quickly and efficiently and may reduce costs. This is especially useful when individuals involved in the construction sequence are not in the same location. For example, as a component is fabricated in the factory, both design engineers in one location and construction staff at the build site may use the DT to monitor the condition of the component.



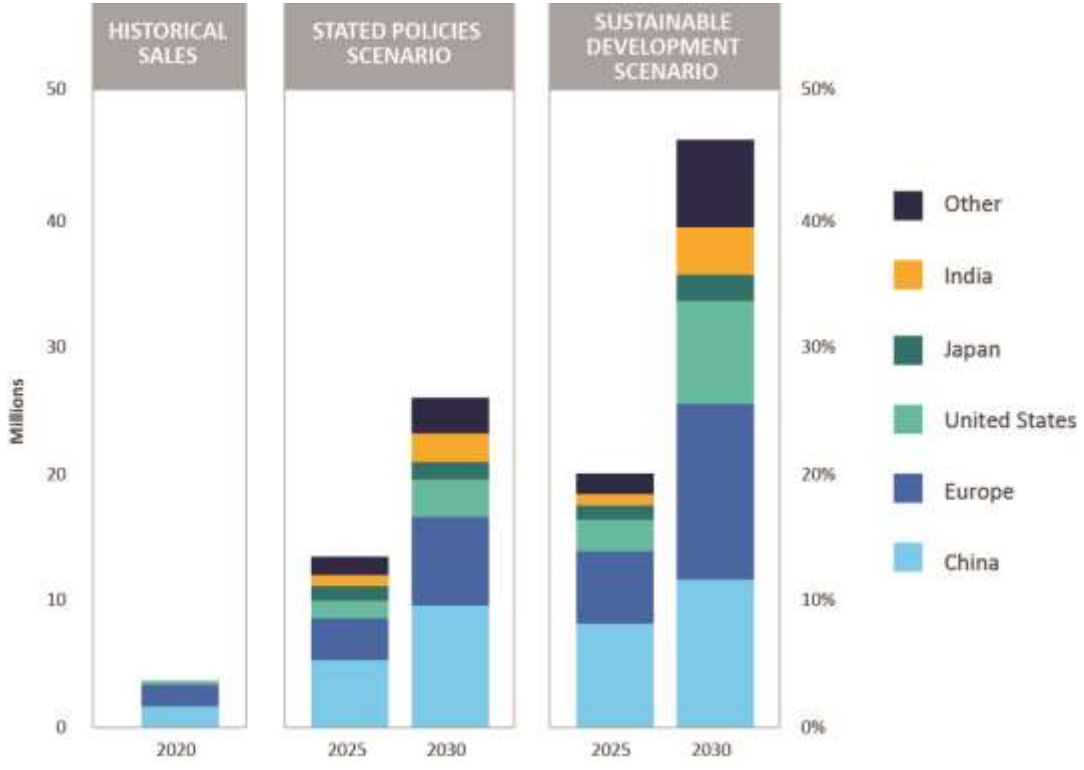
EPRI has been investigating use cases for digital twins across the energy industry. For more information on ongoing DT projects, see the EPRI reports "Quick Insight Brief: Digital Twin Projects at EPRI" (3002020014), "Quick Insight Brief: Elements of Digital Twins and Project Updates" (3002022555), and "Program on Technology Innovation: Digital Twin Applications for Advanced Reactors" (3002023904).

EV CHARGING: OVERVIEW

Transport electrification is a key component of global decarbonization efforts; as automakers continue to increase EV production and sales, the electric sector potentially can help support this growth through infrastructure deployment.

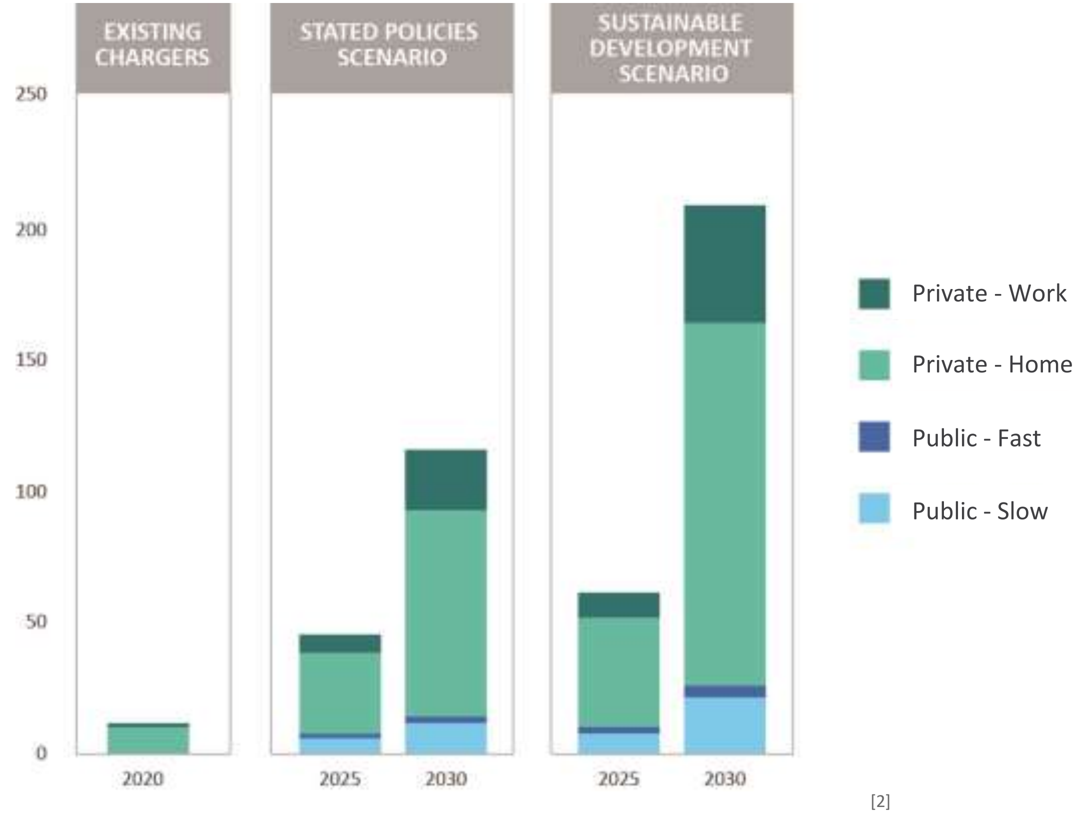
Thirty-seven percent of global end-use CO_2 emissions are emitted by the transport sector [1], underscoring urgency for decarbonizing transport. Although EV sales continue to increase, both sales and charging infrastructure deployment are not on track to meet the UN Sustainable Development Scenario [2]. EV charging infrastructure also can serve as a bridge between the electric sector and transport sector decarbonization. For example, EV batteries may be used as a grid resource through bi-directional power flow back onto the grid [3], providing balancing services, serving as a back-up power source during outages, and potentially saving homeowners money on their electric bills [4].

Global EV sales by scenario, 2020-2030



[2]

Number of electric light duty vehicle chargers by scenario, 2020-2030



[2]

POTENTIAL IMPLICATIONS OF WIDESPREAD EV ADOPTION

EV adoption at the scale necessary to meet international climate targets may increase electricity demand of an already decarbonizing and electrifying grid, heightening concerns about potential grid resilience and reliability.

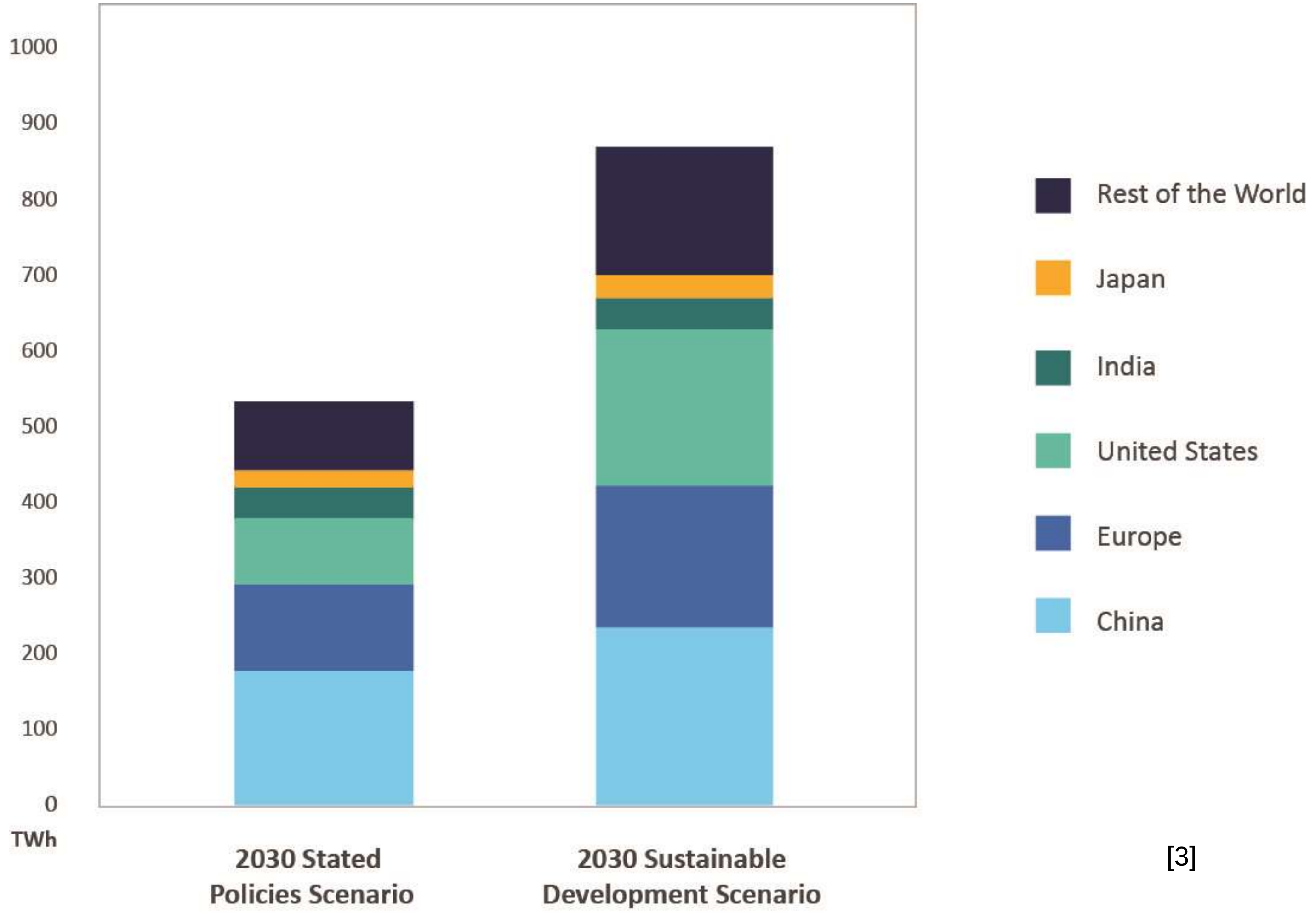
EV charging practices that emphasize coordination may help alleviate potential pressures on the grid (and on customers) from increased electricity demand attributable to growing EV adoption. And, if properly designed, these charging practices may even enhance overall grid resilience.

For example, managing the timing of EV charging, as well as utilizing EV batteries as a grid resource through bi-directional power flow, may provide stability and balancing services to the grid.

Demand for Raw Materials

Demand and prices for raw materials to make EV batteries is increasing as EV adoption increases. For example, the price of lithium carbonate increased 569% between January 2020 and January 2022 [1]. The costs of raw materials have risen from 5% of total production costs of EV batteries to 20% [2]. These rising costs could impact the decades long trend of decreasing EV prices.

Estimated electricity demand (2030) from the global EV fleet



[3]

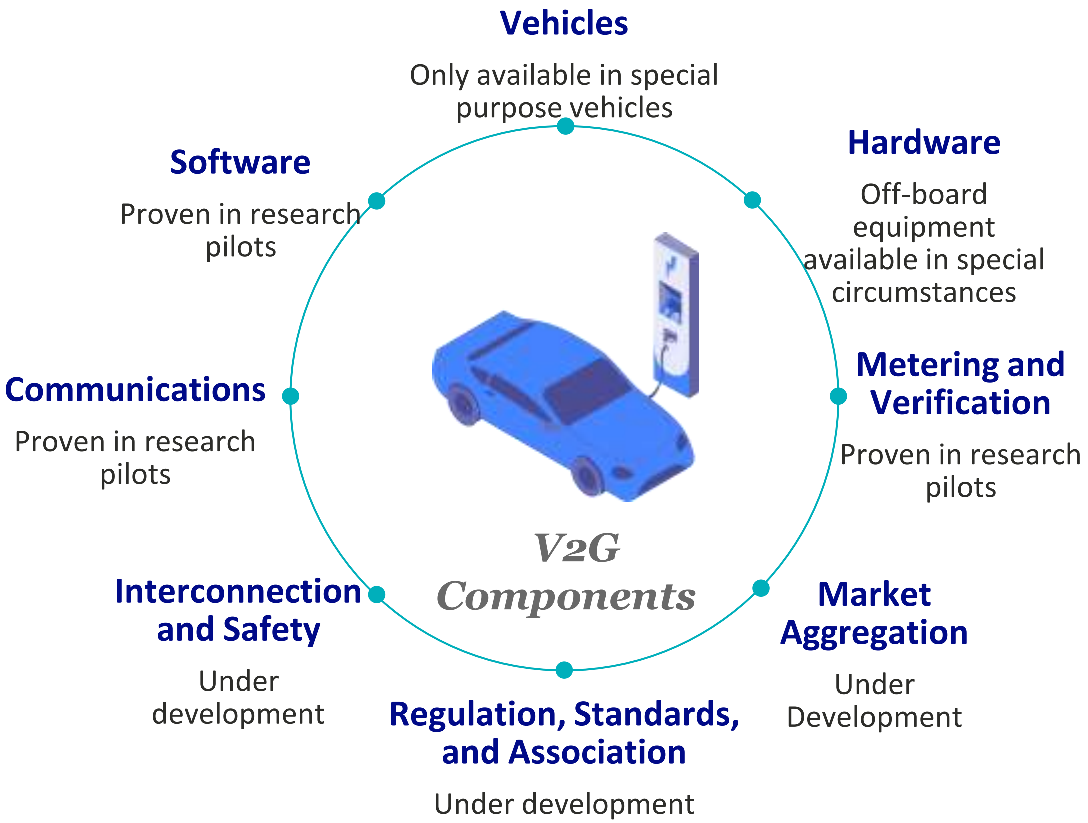
EV CHARGING APPROACHES

Current Primary EV Charging Types

Unmanaged charging	The user charges the vehicle based on vehicle availability and their preferences
Scheduled charging	The user charges the vehicle based on a schedule that occurs within the window of when it is plugged in. For example, the vehicle is charged during the lower cost hours of a Time of Use rate.
Smart charging	The user employs a mechanism to control the vehicle charge rate dynamically or allows another party to do so. The charging is shaped to minimize impacts on user equipment, utility equipment, to provide grid services, or to provide another service.
Vehicle to X (V2X)	The user exports power to a Load (V2L), a Building (V2B), or the Grid (V2G). V2X may be Unmanaged, Scheduled, or Smart. In addition to the services described above, V2X can provide remote power, resiliency, and additional grid services.

Current State of Commercialization of V2G Technology

Using EV batteries as grid resources allows V2G charging to potentially provide balancing services. This added balancing may increase the reliability and resilience of the grid.



Much of V2G charging is still in varying stages of R&D, but over two-thirds of stakeholders surveyed by EPRI see V2G as a viable future revenue stream [1].

SELECT GLOBAL APPROACHES FOR EV ADOPTION & INFRASTRUCTURE

Government policies may play a key role in incentivizing global EV adoption and charging infrastructure deployment, with stakeholders including elected officials, regulators, utilities, and community members.

Norway: Tax Policy

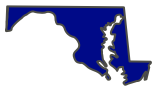
Norway uses taxes as an incentive to buy EVs and as a disincentive to buy an internal combustion engine vehicle (ICEV). This policy began in the 1990s, with different types of taxes being added that disincentivize ICEV purchases: for example, import/purchase taxes, VAT taxes, higher tolls and ferry prices, and higher parking prices [1]. These taxes have helped increase EV adoption in Norway. In September 2021, 77.5% of new car purchases were EVs [2].

China: Industrial Subsidies

One aspect of the Chinese government’s EV policy is subsidizing lithium-ion battery production. China produces 76% of the world’s lithium-ion batteries for a variety of uses: EVs, smart phones, laptops, and other technologies. The Chinese government subsidized the use of Chinese batteries in EVs produced by Chinese manufacturers. By 2019, 50% of EVs sold worldwide used batteries produced by Chinese companies, up from 10% used in 2012 [3].

United States: National Mandates

The U.S. government has enacted EV manufacturing and sale mandates. Current federal mandates require 50% of new vehicles sold in 2030 must be EVs, and the installation of 500,000 public EV chargers [4]. By comparison, EVs made up 5% of new vehicle sales in 2021, and slow charger stock increased by 12% to 92,000 total chargers [5]. To help meet the EV charger goals, U.S. utilities have begun collaborating on a massive coast-to-coast fast-charging corridor [6]. The Inflation Reduction Act of 2022 provides additional means of funding the adoption of EVs [7].



United States: Utility Programs

Some states have incentivized consumers to purchase their own EV chargers. Maryland and several utilities that operate in the state have compiled a list of rebates and incentives for individual consumers. These include installing home EV supply equipment, purchasing new alternative fuel vehicles, and reducing time-of-use rates for residential customers that operate plug-In EVs [8].

Current policies to increase EV adoption may not be sufficient to meet international carbon reduction targets. Previous policies employed for other types of DER can potentially provide valuable lessons as policies develop to bridge that gap.

Net Metering

A net metering policy, previously adopted in several U.S. states, has experienced pushback from some consumers and energy stakeholders [8]. This pushback is rooted in the fact that in many cases, net metering may have stifled solar and solar+ storage system uptake by (1) limiting DER system size, (2) the amount of power that DER can export to the grid, (3) not providing sufficient financial incentives for customers able to provide power back to the grid, and (4) making these technologies available to primarily wealthy households while not providing opportunities for lower-income households to adopt DER [14]. As new policies develop, it may be important to consider how to optimize power flow from EV batteries to the grid, provide adequate benefits commensurate with the value of resilience provided to the grid by EV charging, and help ensure all types of households have access to this technology and its potential benefits.

*NOTE: The policies used in the examples above are not necessarily unique to these countries. They provide a snapshot of how global stakeholders are addressing this issue within different market conditions.

EV CHARGING & EQUITABLE DECARBONIZATION

Equitable access to EV charging infrastructure is a core tenet of many state and federal level investment strategies, with the intent to potentially enable more people to adopt EVs and maximize transport sector emissions reductions.

Deploying EV charging infrastructure equitably potentially means the costs and benefits of infrastructure projects should be proportionally distributed. The U.S. Department of Transportation (DOT) lists the following as equity concerns relating to EV charging infrastructure [1]:

- Affordability
- Accessibility
- Reliability
- Location
- Safety
- Related employment and economic opportunities

In addition to building out EV infrastructure, another potential way to expand access to clean transportation is through electrification of public transit options. In the U.S., electric buses that have been ordered or are in operation rose 112% between 2018 and 2021, from 1,650 to 3,533 buses. The Low Greenhouse Gas Vehicle Technologies Research, Development, Demonstration and Deployment fund under the Infrastructure Investment and Jobs Act (IIJA) may create more opportunities for transit agencies to acquire electric buses [2].

EPRI's Incubatenergy Labs conducted a 2022 pilot project in partnership with MicroGrid Labs utilizing the EVOPT software platform to complete a feasibility study for transitioning from a diesel feel to an electric bus fleet. See EPRI report (3002023032): "Incubatenergy Labs 2021 Pilot Project Report — Microgrid Labs: Zero-Emission Fleet Transition Planning and Simulation".

COMMUNITY ENGAGEMENT, POLICY APPROACHES, & PROJECTS PROMOTING EQUITY

Fair and meaningful involvement of communities in policy decisions also has been identified as paramount to creating an equitable EV charging infrastructure future.

Opportunities exist for stakeholders to work closely with communities to achieve mutually beneficial solutions. Utilities are uniquely positioned to partner with communities because of their close connection(s) to local communities. Solutions may vary based on the differing and unique needs of each community. Avenues for addressing equitable access issues may include state governments, tribal governments, and state public service commissions.

New York

A key tenet of New York's Climate Leadership and Community Protection Act (CLCPA) is deploying 850,000 EVs by 2025. To assist and encourage community participation in the development of the CLCPA, the state is holding public hearings, producing educational webcasts, and engaging in a public comment process.

To help reach CLCPA's goals, utilities have implemented the EV Make Ready Program, which provides reimbursements for EV charger installation projects. The program requires that 30% of funding must directly benefit disadvantaged communities. Projects that directly impact disadvantaged communities are eligible for reimbursement of 100% of their project costs [1].

California

Under California law, 35% of funding for EV charging infrastructure must be funneled into underserved communities [2]. Utility companies in California have increased efforts to expand charging to underserved communities. The percentage of charging ports installed in underserved communities by selected utilities includes:

- 50% of charging ports installed by Southern California Edison's Charge Ready program
- 32% of ports installed in San Diego Gas and Electric's service territory
- 27% of Pacific Gas and Electric's installed chargers [3].

Native Sun Community Development

Indigenous communities are some of the most heavily impacted by the negative effects of fracking, and fossil fuel production. To begin to rectify this, Native Sun Community Development, a native-led nonprofit organization partnered with Xcel Energy, Standing Rock Power Authority, Otter Tail power, and other non-profit organizations. This coalition secured $6.6M in funding from the Department of Energy's Low Greenhouse Gas Vehicle Technologies Research, Development, Demonstration and Deployment fund. This funding will be used to build 120 EV charging stations in Minnesota and South Dakota, creating a network of charging stations that connects 21 indigenous tribes. This project will also include the purchase of 19 EVs and two electric buses [4].

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