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Energy Policy Guiding Principles

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Policymakers at every level of government have important responsibilities to ensure our national, economic, energy, and environmental security. The U.S. energy system is now stressed by rapidly increasing power demand to support emerging artificial intelligence applications and undergoing rapid technological changes which must be carefully managed to provide abundant, low-cost energy while supporting our national economic and environmental goals.

Responsive energy policies are required to successfully integrate the use of low-emission electricity generation, transportation, and manufacturing; advance storage and distribution technologies; and manage greenhouse gas emissions. It is important that policymakers consider the long-term impacts of energy choices made, including their economic and societal costs.

In this report, ASME recommends five principles for guiding policy decisions regarding energy systems and the use of our national energy resources, as well as recommendations to prepare the future energy workforce.

Principles for Guiding Energy Policy

The ASME recommends that the five following principles be applied to the development of U.S. energy policy:

1. ***The goal of the United States energy policy should be to provide energy that is affordable, reliable, and sustainable.***

2. ***All decisions regarding energy generation, distribution, and usage in the United States should be based on an integrated systems approach.***

3. ***Energy efficiency, and not just the generation and movement of energy, is part of a sound national energy policy.***

4. ***Federal, state, and private investments in energy technology should be complemented by policies that support the ability of these technologies to be deployed into the market.***

5. ***Substantial and sustained investments should be made to expand and diversify the STEM workforce to support existing and emerging technologies.***

(1) The goal of the United States energy policy should be to provide energy that is affordable, reliable, and sustainable.

Affordable Energy

The cost of energy impacts both U.S. economic competitiveness and standards of living. Energy costs cascade through all sectors of the economy. For example, approximately 40 percent of the operational costs of a data center are energy[i]. Similar numbers are seen in major industries classified as "energy-intensive": food, pulp and paper, basic chemicals, refining, iron and steel, and nonferrous metals (such as aluminum and nonmetallic minerals such as cement). In steelmaking, energy accounts for 27 percent of total costs[ii], while in cement-making, energy accounts for 40 percent of the total cost. Energy accounts for approximately 30 percent of the costs of many agricultural staples[iii].

The average U.S. household also faces significant energy costs – spending $1,623 on electricity[iv], $3,120 on gasoline[v], and $2,094 on heating fuel in 2022[vi]. Cost increases for essential commodities are particularly challenging for those living on fixed or lower incomes. In 2023, one out of four U.S. households reported experiencing energy insecurity, defined as difficulty paying energy bills, reduced spending on necessities such as food or medicine to pay energy bills, or keeping their homes at unsafe temperatures to reduce energy costs[vii].

Reliable Energy

Reliability is traditionally defined as the dependable delivery of electricity and other energy sources such as natural gas and gasoline to meet industrial and consumer demand. To be reliable, a system must not only be mechanically durable and dependable, but also be able to withstand extreme weather events, be shielded from both physical and cyber-attacks, and be able to withstand other potential disruptions. The complexity of energy systems means that they can never be failure-proof. Therefore, reliability must be complemented by resiliency, or the ability of an energy system to rapidly recover from events that may compromise power delivery. Recent extreme weather events demonstrate the challenges of quickly achieving the combination of mechanical reliability and resiliency needed to deliver electricity and the consequences of non-resilient systems.

The 2021 power outage in Texas demonstrated how near record low-temperature storms can stress-test large parts of a region's power generation infrastructure, resulting in 246 deaths and more than $130bn in direct economic damage. Similar challenges have been encountered after other extreme weather events, including the extended blackout in southern Louisiana after Hurricane Ida (2021) which caused 18 deaths[viii].

The most extreme U.S. case of power failure after an extreme weather event occurred in Puerto Rico in 2017 after Hurricane Maria. Damage to power lines and other electrical infrastructure left large parts of the island without power for 11 months. Fully restoring power after storms in the continental U.S. is also time consuming, especially as hurricanes impact locations not considered hurricane prone. For example, Hurricane Helene in 2024 caused six million customers across several states to lose power[ix]. In many cases a full recovery was delayed by months due to damage not only to electrical lines but also flooding of substations. The delays in recovery reflect not only the physical effort required to repair infrastructure but also the long lead times and complex supply chains needed for critical components. As climate change leads to increased extreme weather events, the challenges of maintaining reliable and resilient energy systems are expected to increase and hardware, planning, workforce, and energy system improvements are necessary.

Sustainable Energy

The concept of sustainability requires addressing a broad range of environmental and resource challenges.

Greenhouse Gas Emissions: The largest concern is the global impact of greenhouse gas (GHG) emissions, especially CO2, from the use of fossil fuels in electricity generation, transportation, home, and industrial heating. In 2022, U.S. electricity generation caused 1.5 billion tons of CO2 emissions, while the transportation sector caused 1.78 billion tons of CO2 emissions. Other sectors, such as home heating, industrial processes, and agriculture account for another 2.9 billion tons of CO2 emissions. The well-documented greenhouse effect, where these gases contribute to the trapping of heat in the lower atmosphere, is rapidly changing the Earth's climate. There is a scientific consensus that a global temperature rise of more than 1.5°C will lead to severe environmental, economic, and public health consequences. Calendar year 2024 is the first with a global mean temperature of more than 1.5°C above the 1850-1900 average.

Meeting the current global target of keeping average temperature increase below 1.5°C will require significant changes in all economic sectors to minimize greenhouse gas emissions[x]. This includes not only CO2, but also methane, which is more potent as a GHG[xi], and accounts for 11 percent of global temperature change. This creates a two-fold challenge for the U.S. electricity system, as it must adopt low-GHG technologies such as renewable energy, nuclear power, and fossil-fuel consumption integrated with Carbon Capture, Utilization, and Storage (CCUS). At the same time, the U.S. electrical system must expand both to allow electrification of transportation, home heating, industrial processes, and to support economic and population growth.

Pollution: Reducing greenhouse gas emissions is not the only sustainability challenge encountered in energy systems. Air pollution from combustion gases, including particulates, organic compounds, carbon monoxide, nitrogen oxides, and sulfur oxides, has substantial environmental and public health impacts. Energy production also contributes to water pollution and creates solid waste such as coal ash. The energy system depends on a range of extractive industries, including coal and uranium mining, production of oil and natural gas, and the production of rare earth metals used in energy storage. Extractive industries, such as heavy metals for batteries, have a significant impact on pollution, and in some countries have a long history of unsafe labor conditions, creating challenges for national energy infrastructure development requirements. Meeting these challenges in all forms of energy generation and use, including renewable, fossil, and nuclear energy requires the development of new policies and technologies.

Other Concerns: Energy production often requires water, putting it in direct competition with agriculture and even human consumption. Finally, energy production and transmission have impacts on wildlife, such as loss of birds to wind turbines, above-ground pipelines interfering with migration routes, and the environmental damage associated with petroleum spills during extraction and transit. In this context, minimizing the impact of any energy technology over its life cycle – such as recycling of wind turbines, solar panels, and batteries – and not just the time and point of use, should be factored into new policies and regulations. Every energy technology has environmental and social impacts; while technological development can often reduce these, it cannot eliminate them entirely.

(2) All decisions regarding energy generation, distribution and usage in the United States should be based on an integrated systems approach.

Energy systems entail technological, organizational, and regulatory complexity. This complexity is most evident in the U.S. electrical grid, defined as the generation and transmission infrastructure for electricity[xii]. The grid uses a combination of fossil (natural gas and coal), nuclear, and renewable (wind, solar, hydro, geothermal, and biomass) sources to generate electricity. In 2024, 60 percent of U.S. electricity was generated by fossil energy (43.6 percent natural gas, 16.1 percent coal, with a small share from other fuels), 21 percent from renewables (10.1 percent wind, 5.7 percent hydroelectric, 7.3 percent solar, with the remainder biomass and geothermal), and 18.1 percent from nuclear[xiii]. The percentages differ locally based on both the availability of renewable energy resources, and policy decisions for infrastructure.

Each of these technologies has different operating characteristics and economic drives. Coal, geothermal, nuclear, and hydroelectric power can provide a stable and efficient "base load." Wind and solar are weather-dependent resources. Natural gas, biomass, and, to a lesser extent, hydroelectric can "load-match" to meet changing demands. A complex distribution system, with more than 11 million miles of transmission lines, seeks to match generation with demand at both local and national scales while maintaining a steady 120 volts and 60 Hz frequency.

<u>U.S. electricity generation</u> is equally complex organizationally, with more than 2,000 independent utilities. Of these, 168 are investor-owned for-profit entities, 812 are cooperatives, and 1,958 are publicly owned. However, more than two-thirds of U.S. electricity customers receive their electricity from investor-owned utilities[xiv]. While these utilities are responsible for both electricity generation and transmission, other companies, known as independent power producers (IPPs), often generate electricity that utilities purchase and distribute. In many areas, groups of utilities are coordinated through Independent System Operators (ISO) or Regional Transmission Organizations (RTO) that operate transmission systems or coordinate generation, distribution, and transmission over large geographical regions.

<u>Finally, the U.S. electrical grid</u> exists within a complex regulatory structure. In seventeen states, power generation is deregulated. At the federal level, the sale and transport of electricity and natural gas is regulated by the independent Federal Energy Regulatory Commission (FERC). The U.S. Department of Energy (DOE) has limited regulatory responsibilities. The DOE's focus is on technology development and deployment, providing technical advice, and overseeing financial assistance programs. Due to the potential for pollutant formation in electricity generation, the Environmental Protection Agency (EPA) also has a large regulatory impact. Power generation and distribution are also regulated at the state and sometimes local level by industry and other environmental regulatory bodies.

This complexity is compounded by the fact that the electrical grid is only part of the U.S. energy system. The production, refining, transportation, and distribution of oil and natural gas for use in transportation, electricity generation, heating, and other uses are intertwined with the electricity system. As hydrogen becomes an increasing part of the U.S. energy system, its production and transportation will be similarly linked to the energy sector. As policy makers seek to create an affordable, reliable, and sustainable energy system, they must consider how this technical, organizational, and legal complexity impacts decisions. The growing adoption of wind and solar energy illustrates this complexity. These technologies become more accessible when increased transmission capabilities allow electricity to be moved to areas of higher demand, and when storage technologies allow electricity to be used when demand is higher. Lack of transmission, distribution, and energy storage has already resulted in load-balancing issues, forcing curtailment of solar deployments in California and wind turbines in the Midwest due to insufficient transmission capacity to deliver electricity to high-demand regions.

Despite the benefits to accessibility and reliability, there are significant organizational and regulatory challenges to expanding energy infrastructure for transmission, distribution, and storage due to the large costs for utilities and independent power producers. Addressing these complexities poses regulatory challenges across federal, state, and local levels.

A critical challenge at the local and state level is permitting. Adding additional electrical production and transmission, and adding supporting infrastructure such as pipelines, often requires approval from multiple levels of government and typically from multiple states and municipalities. These approval processes traditionally operate over a timeline beyond the terms of individual elected officials, meaning the pace of deployment of new energy technologies also stretches over years. Once deployed, these systems then have operational lifetimes that may outlast the careers of individual engineers. The result is that the U.S. energy system requires long-term stewardship from both engineers and regulators.

The adoption of new technologies exists alongside changes in electricity demand. Total electricity production in the U.S. has remained level for the past 20 years[xv]. Even as the U.S. has grown more energy-efficient on a per capita basis, a growing population and economy, and movement of population within the United States, has stressed this system. The growing adoption of electrical vehicles (EVs), the AI-driven growth of data centers, and increasing electrification of manufacturing all create increased demand.

The complex nature of these challenges requires policymakers to take a systems approach, where no aspect of electricity generation and use, or other consumption of energy, is considered in isolation. Instead, policy makers need to consider how changes will cascade across the energy system, and how to prepare not only for technological change, but organizational and regulatory change.

(3) Energy efficiency, and not just the generation and movement of energy, is part of a sound national energy policy.

Energy efficiency

Efficiency reduces the need for additional generation capacity and mitigates transmission needs. Energy efficiency can be viewed as getting more useful output from a process compared to the amount of energy invested in making the product.

Electricity

There is no "zero impact" environmental or safer technology for power generation. Every power generation technology has both negative and positive attributes and costs. Negative impacts include such aspects as the emissions from mining, manufacture, construction, transportation, maintaining and decommission of structures, systems, and components of the electrical generation facility, while some positives include "black start" power generation, backup power and storage battery manufacturing[xvi]. Power costs are a significant portion of both U.S. industrial and agricultural costs and thus a significant strain on household finances[xvii].

Energy efficiency concepts need to be applied to overall life-cycle analyses of all products, not just the generation and movement of energy. Expanding efficiency through heat pump technology, advances in insulation, architectural designs, and cogeneration (production of electricity or mechanical power and useful thermal energy [heating and/or cooling]) from a single source of energy is achieved with the continued advancement of technology, from fundamental research through the demonstration of new technologies. Advanced metering systems can help us understand energy usage and employ distributed energy systems for balancing loads.

Rising Energy Demand

Energy efficiency savings are being offset by new sources of energy demand. Residential, commercial, and industrial sectors have implemented energy efficiency programs. However, bitcoin mining, growth in electric vehicles, and artificial intelligence data centers have outpaced the savings[xviii]. An integrated approach is required to reduce energy consumption while expanding energy storage capacity and new sources of energy generation. Systems designed to maximize cooling efficiency through technologies such as liquid cooling and waste heat recovery have demonstrated the potential for reducing energy consumption. Systems engineering and consideration of life-cycle costs can reduce the amount of wasted energy in data centers by a factor of six in existing commercial systems, and as much as a factor of 30 in next-generation systems as a metric for data center energy efficiency. The Power Usage Efficiency, or PUE, allows for the direct comparison of data center efficiency.

Increased use of combined heat and power technologies are one way to improve energy efficiency and reduce air pollution in lieu of peaking plants that ramp on and off but are not as efficient. Base-load power plants, such as large cogeneration and nuclear power plants, operate more efficiently and reliably when operated at a steady state. Cogeneration facilities improve energy efficiency and plant reliability and improve economics when used to meet off-peak demand. Some potential uses of heat recovery technologies and co-generation are desalination, hydrogen production, and district heating systems.

While not every technology offers opportunities for improved energy efficiency, the basic principles of clear metrics for energy efficiency as well as consideration of life cycle energy impacts can be applied across the entire range of economic sectors that use energy. This includes home energy efficiency, the efficiency of private and commercial vehicles, and industrial processes.

(4) Federal, state, and private investments in energy technology should be complemented by policies that allow these technologies to reach the market and support the development of a robust energy economy.

Need for Transformative Energy Systems

Technology support should include investments in fundamental research, improvement in existing technologies, and exploration of new generation and enabling technologies such as smart grids, energy transportation, and energy storage. New transformative energy systems are needed to reach the goal of reliable, affordable, and sustainable energy to support the needs of the global market. These goals require energy research and development programs that progress from the fundamental research led by federal agencies such as the National Science Foundation (NSF) and the Department of Energy's Office of Science, as well as through applied research led by the DOE's technology-focused programs and adopted into regulatory systems. The Advanced Research Project Agency-Energy (ARPA-E) supports high-risk/high-reward technology investments that may not fit into these conventional categories.

Significant research and funding in renewable and clean energy technologies have been the most publicized successes of energy programs. Technology investments in fossil fuels and nuclear power generation have also led to improvements in efficiency, reliability, and sustainability. For example, unconventional oil and gas exploration technologies resulted in a massive switch from coal to gas energy applications, resulting in lower energy costs and lower emissions. Pollutant removal technologies such as carbon capture storage and use (CCS/CCU) also help reduce greenhouse gas emissions but have not yet reached commercial scale deployment. The Regional Hydrogen Hubs, funded through the Infrastructure Investment and Jobs Act (IIJA) in 2021, will help accelerate large-scale production and use of hydrogen, and continued research investments in renewables, fossil energy, nuclear energy, fusion, and hydrogen will lead to additional efficiency and production gains. There is a significant return on investment for this type of research, which also supports workforce development for existing and emerging energy industry applications.

Cost of Getting New Technologies to Market

Innovative ideas for new or improved energy technologies can be readily studied at laboratory and bench scales to evaluate their promise for further development into a deployable energy system – as equipment and financial support needs are small at these scales. Practice has shown that a prototype at a scale representative of a commercial system must be built and operated successfully to further advance the technology toward deployment in the marketplace. Development costs and technical risks are large for demonstrating advanced energy technologies. Private investors will not usually fully fund such endeavors. Aggressive federal, state, and private investments, complemented by policies that reduce investment and deployment risks, are needed to enable new technologies to successfully pass through the demonstration phases to reach the market.

Permitting new technologies

Challenges remain with permitting new energy technologies. A study[xix] by Lawrence Berkeley Laboratories (LBL) on renewable energy project development showed that local ordinances, interconnection to the electric grid, and local opposition were the leading causes of project cancelations. The study also reported that project developers who engaged with local communities before finalizing project plans were more likely to complete an installation and avoid local opposition.

Infrastructure

Permitting and regulatory reforms are needed to help remove barriers of entry for new energy technologies and infrastructure. The permitting process is lengthy, expensive, and often requires approvals at the federal, state, and local levels. Energy planning for the future requires a portfolio approach to investments that enhances all energy technologies and is sometimes referred to as an "all of the above" strategy.

A key example underscoring the need for permitting reform is the persistent challenge of advancing carbon capture, storage, and utilization (CCS/CCUS) technologies. Despite federal grants and tax incentives supporting maturation of CCS/CCUS technologies, it continues to encounter significant permitting obstacles. Developing a carbon capture facility typically necessitates securing multiple permits and requires twice the physical footprint of a conventional power plant. The storage of the carbon requires either a Class VI permit from the EPA which takes at least four years, or a state may acquire "Primacy approval" and be able to issue Class VI permits itself. As of January 2025, only North Dakota, Wyoming, and West Virginia had primacy. The CO2 pipelines needed to transport the captured carbon have yet to be permitted and installed. In October 2023, after two years of pursuing permits across five states, the Heartland Greenway pipeline project was cancelled due to opposition at local and state jurisdictions. Given the project's breadth, it required permits in each state and from every local jurisdiction and private landholders to transport the carbon to a storage facility in Illinois. At the federal level, there is not a lead agency responsible for carbon pipelines, and projects could require permits from 11 different agencies. Other infrastructure for energy transportation such as electric transmission or hydrogen face similar permitting and regulatory approval challenges.

(5) Substantial and sustained investments should be made to expand and diversify the STEM workforce to support existing and emerging technologies.

The U.S. economy depends on an internationally competitive work force to maintain energy and economic security. The design, deployment, and maintenance of energy technologies in the future will require a highly trained workforce. Half a million energy sector workers may retire in the next 10 years. If personnel with power plant and energy distribution experience retire and leave the workforce without having qualified successors, our nation's ability to design, construct, operate, and maintain our energy systems will be compromised. For instance, the more than 30-year hiatus in constructing new nuclear power plants led to a significant loss of construction expertise and disrupted the development of a workforce pipeline for emerging professionals in nuclear energy.

Personnel needed for the present and future energy workforce include engineering and science disciplines, trades skilled in manufacturing and erecting large pieces of equipment, managers skilled in planning and delivering energy on a national scale, economic and planning experts, and communicators who can assist in negotiating and completing the many agreements needed to deploy new technologies across the U.S.

Strategies for educating and preparing the future workforce are needed throughout the U.S. The rapid rate of technology change makes the energy industry an appealing area to the current generation of people entering the workforce[xx]. Unless older workers currently employed are updated to fit into the new technology sectors, they may lose their employment due to outdated skills or the closing of their current industry site. The loss of their spending power will lead to lay-offs in non-energy sectors, causing an additional drag on the economy.

Many stakeholders such as federal, state, and local governments, businesses and industries, educational and private sector organizations, and technical societies, are involved in workforce initiatives. These stakeholders should all work together to address the workforce issue. The federal government should provide leadership in the workforce sector given the funding support discussed above. In addition to educational policy, a review of the federal government's policies on trade, taxation, regulation, and fiscal and monetary policy should be undertaken to support the workforce and economic development initiatives.

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Conclusion

Modernizing our national energy strategy requires a balanced focus on affordability, reliability, and sustainability, while embracing the principles of energy efficiency and integrated systems approaches. Policymakers must invest in innovative technologies, streamline regulatory frameworks, and address critical workforce challenges to ensure a resilient and secure energy future. By fostering collaboration among stakeholders and advancing sustainable practices, the United States can be a global energy leader, meeting the economic, environmental, and societal demands of the 21st century.

This report was developed by the Energy Public Policy Task Force of the ASME Committee on Government Relations.
For more information, visit: https://www.asme.org/government-relations

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