Journal of Energy and Power Engineering 18 (2024) 127-138
doi: 10.17265/1934-8975/2024.04.001

America's Energy Future Balancing Renewable and Non-renewable Resources for a Sustainable Tomorrow

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Abstract: With an emphasis on renewable and non-renewable energy sources, this article examines America's energy future's complicated and changing landscape. To lower carbon emissions and fight climate change, the United States, which has historically relied on non-renewable resources like coal, oil, and natural gas, is moving increasingly toward cleaner, renewable energy sources like solar, wind, and hydropower. Nevertheless, energy intermittency, grid upgrading, and the requirement for dependable storage systems are still obstacles. Nuclear energy, frequently viewed as a distinct entity, is equally essential to transitioning to a low-carbon economy despite its reliance on finite resources like uranium. The essay examines how the US may handle this energy transition by employing both renewable and non-renewable resources in the short, medium, and long term to balance energy security, affordability, and economic growth. Future innovations that capture thermal, wave, and tidal energy from the ocean, such as ocean energy, are also intriguing additions to a sustainable energy mix.

Key words: Renewable energy, non-renewable energy, energy transition, solar energy, wind power, nuclear energy, carbon emissions, grid modernization, energy security, ocean energy.

1. Introduction

The USA (United States of America) is at the forefront of its energy strategy and policy as it transitions to a cleaner, more sustainable energy landscape. U.S. federal, state, and municipal governments set the country's energy policy. It covers topics including building codes, distance requirements, and commuting policies that pertain to production, distribution, consumption, and modes of use of energy. Public participation, court rulings, regulations, legislation, and other strategies can all be used to address energy policy.

In the past, coal, natural gas, and oil were the US's primary nonrenewable energy sources. These fossil fuels have been the backbone of the country's energy output, industrial growth, and transportation network for over a century. Calls for a switch to renewable energy sources have been sparked by the environmental costs of current energy sources, which include carbon emissions that fuel climate change and contamination of the air and water. Reducing the nation's greenhouse gas emissions, lessening the effects of climate change, and creating new commercial opportunities in the clean energy sector all depend on this reform. The switch from nonrenewable to renewable energy sources is depicted in Fig. 1.

The EPA (Energy Policy Act) addresses energy production in the United States, including:

- Energy efficiency,
- Renewable energy,
- Oil and gas,
- Coal,
- Tribal energy,
- Nuclear matters and security,
- Vehicles and motor fuels, including ethanol,
- Hydrogen,
- Electricity,

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- Energy tax incentives,
- Hydropower and geothermal energy, and
- Climate change technology

The above are all topics covered by the EPA.

For instance, the Act offers financial guarantees to organizations that create or employ cutting-edge technologies that prevent greenhouse gas emissions. The amount of biofuel that must be used with gasoline sold in the US is increased under another clause of the Act.

As alternatives to conventional fossil fuels, renewable energy sources like geothermal, hydropower, solar, and wind have grown in popularity recently (see Fig. 2, which depicts numerous renewable energy sources). These resources, without the harmful environmental effects of fossil fuels, provide the potential for a cleaner, more sustainable energy source that can satisfy the country’s future energy needs. However, to fully realize this potential, it is urgent that we address issues like intermittency, the need for energy storage technologies, and the updating of the power infrastructure.

The cost of moving from non-renewable to renewable energy sources is a complex issue with varying estimates. Here are several examples:

- Infrastructure Costs: Building renewable energy infrastructure such as solar farms, wind turbines, and hydropower plants can be costly upfront. These installations require significant investment in land, materials, and technology, especially if they are to be built on a large scale to replace non-renewable sources.
- Grid Modernization: Renewable energy sources, like wind and solar, are intermittent and require modernization of the existing grid infrastructure to ensure consistent power supply. This includes costs for energy storage solutions (e.g., large battery storage systems) and smart grids capable of managing variable energy inputs.
- Energy Storage Systems: To store excess energy from renewable sources, especially for times when generation is low (like nighttime for solar energy), there is a need for advanced storage systems. Building and maintaining these storage systems, like lithium-ion batteries or emerging technologies, adds to the overall cost of transition.
- The Energy Potential: The full potential of energy must be realized.
- Cost Estimate: With differing estimates, the cost of switching from non-renewable to renewable energy sources is a complicated matter. Here are a few instances:

The investment in renewable energy infrastructure includes the cost of building solar farms, wind turbines, geothermal plants, and other renewable energy facilities. This investment is anticipated to reach billions to tens of millions globally over the next several decades.

- Grids Power Modernization: Significant upgrades must be made to the current power grids to manage the intermittent nature of renewable energy sources and ensure efficient electricity distribution.
- Ongoing Research and Development: The urgency of our transition to renewable energy technology necessitates continuous funding for research and development, ensuring we achieve cost-effectiveness and efficiency.
- Training and Job Transition: As the energy sector shifts away from fossil fuels, new jobs in the renewable energy sector will need to be created, and workers will need to be retrained. There are factors that influence the costs.
- Energy Potential: Energy needs to reach its maximum potential.

The cost of moving from non-renewable to renewable energy sources is a complex issue with varying estimates. Here are several examples:

- Investing in renewable energy infrastructure includes the cost of constructing wind turbines, geothermal plants, solar farms, and other renewable energy installations. Over the ensuing decades, this cost is expected to increase from billions to tens of millions worldwide.
- Modernizing Power networks: Major improvements must be made to the current power networks to handle the intermittent nature of renewable energy sources and guarantee effective electricity distribution.

• The ongoing need for Research and Development: Continuous funding for research and development is crucial to ensure the cost-effectiveness and efficiency of our renewable energy technology, especially given the urgency of our transition.

• Job Transition and Training: As the energy sector moves away from fossil fuels, people will need to be retrained and new jobs in the renewable energy sector will need to be created.

As overall summary, even though the switch to renewable energy involves significant upfront costs, it is crucial to always keep in mind the long-term benefits and cost savings. This change can lead to a cleaner environment, improved public health, enhanced energy independence, and a plethora of new commercial opportunities. Furthermore, the steadily decreasing costs of renewable energy sources are making them more and more competitive with fossil fuels, reinforcing the importance of considering the bigger picture.

It is also critical to remember that the cost of switching to clean energy is expected to be significantly lower than the cost of doing nothing to combat climate change.

Furthermore, the abrupt disappearance of non-renewable energy sources is not expected, nevertheless. Although the percentage of fossil fuels in the U.S. energy mix is expected to decline over the next few decades, coal, oil, and natural gas will still play a role in meeting the country's energy demands during the transition era. As the country develops its renewable energy infrastructure, these sources—natural gas in particular—are seen as "bridge fuels" that can provide stable electricity.

Additionally, advancements in CCS (Carbon Capture and Storage) technologies could allow for the continued use of some fossil fuels while minimizing their detrimental environmental impacts [1-3].

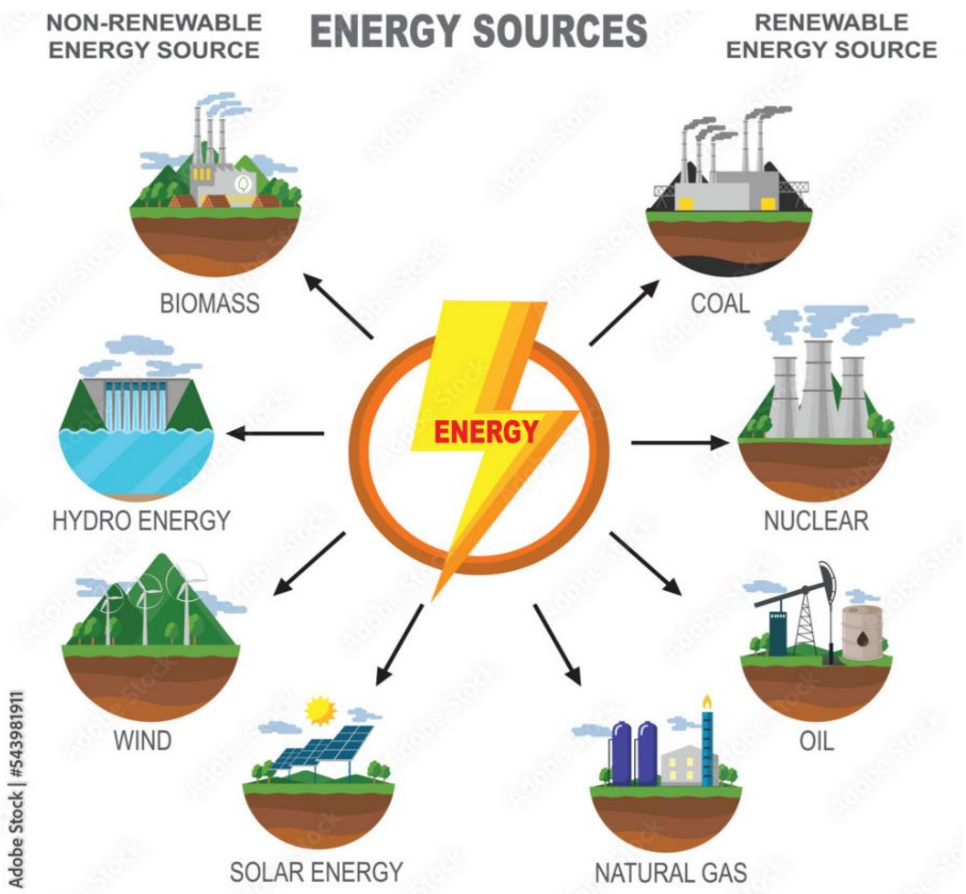

Fig. 1 None-renewable to renewable of energy source.
Source: Courtesy of Adobe Stock.

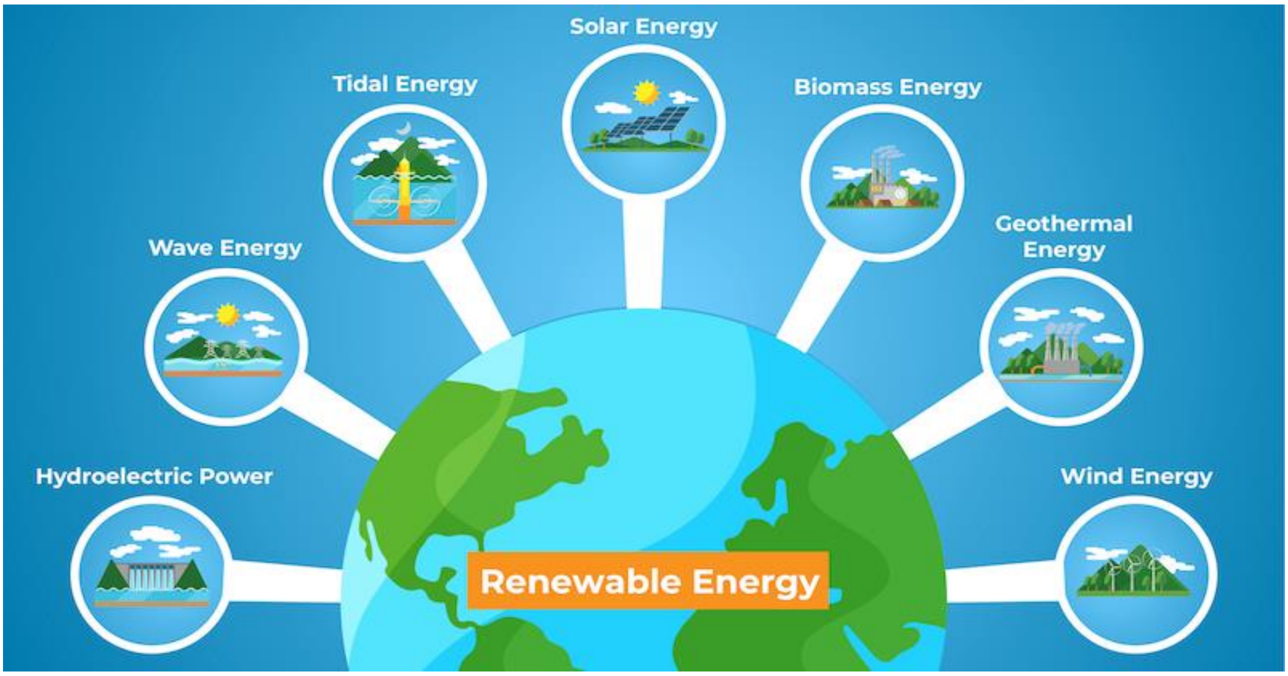

Fig. 2 Various renewable energy source type.
Source: WTS Energy.

This article will look at the current state of renewable and non-renewable energy sources in the US and the opportunities and issues associated with each to ensure a balanced, sustainable energy future.

Examining various energy sources' short, medium, and long-term roles may help us better understand how the United States may manage the difficult transition to a low-carbon energy system while maintaining energy security, affordability, and economic growth. By doing this, we will offer a comprehensive plan that integrates renewable and non-renewable resources to meet the nation's energy needs sustainably and responsibly.

Although there are challenges along the way to a sustainable energy future, the US can set the global standard for creating an energy system that strikes a balance between economic growth and environmental stewardship with careful planning, innovation, and investment.

Future generations will be influenced by the energy choices made today as the country works to lower its carbon footprint and achieve the objectives outlined in international climate agreements.

2. Navigating the Energy Transition: Balance Low-Carbon Goals with Energy Security, Affordability, and Economic Growth through a Strategic Short, Medium, and Long-Term Approach

Moving to a low-carbon energy system while maintaining energy security—which calls for energy storage as shown in Fig. 3—affordability and economic growth is a significant problem for the US.

Meeting these objectives requires a comprehensive, phased strategy that takes into account the evolving roles of different energy sources over the short, medium, and long terms. Natural gas and other non-renewable energy sources will play a pivotal role in the near future, particularly as a "bridge fuel" to mitigate the intermittent nature of renewable energy sources, ensuring a stable energy supply.

Reducing carbon emissions in the medium term will require the quick development of renewable energy sources like solar and wind. Grid modernization and the creation of large-scale energy storage systems will be essential to integrate these intermittent energy sources

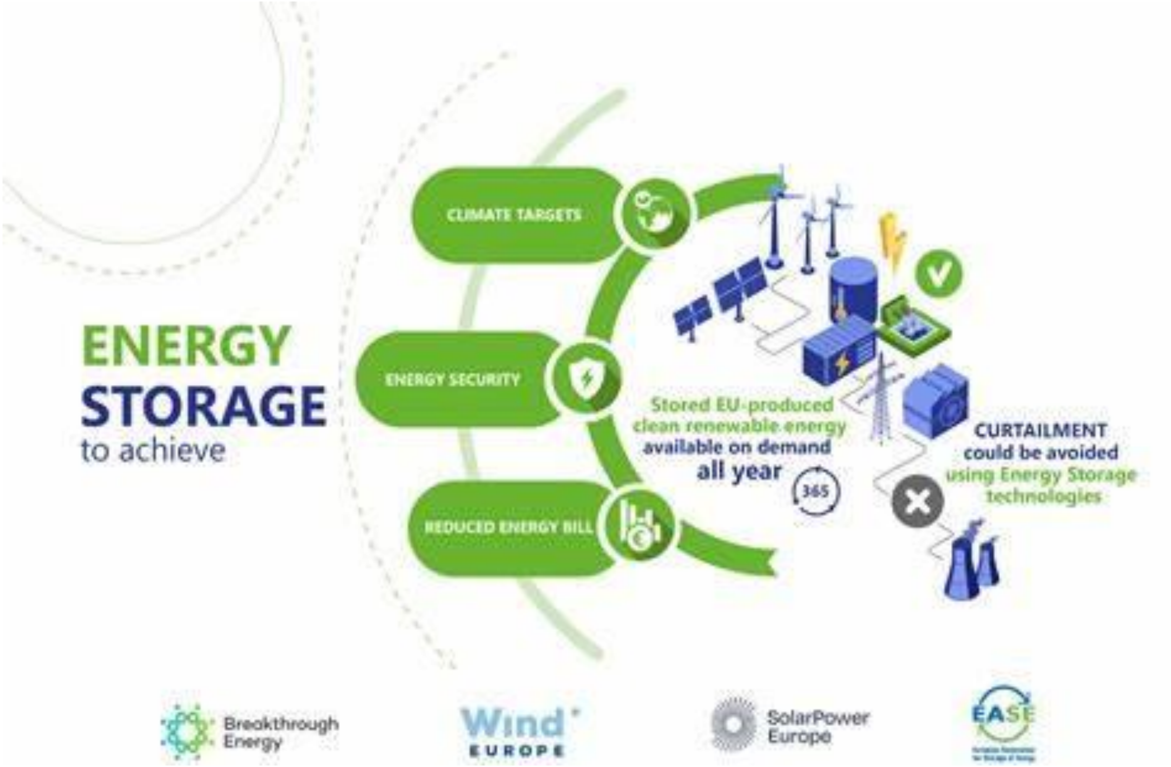

Fig. 3 Energy security requires energy storage.
Source: ExxonMobil Corporation.

into the national grid and guarantee a steady and dependable energy supply. Laws and incentives promoting energy conservation and putting clean energy infrastructure in place will also accelerate this shift.

Looking ahead to the long term, the U.S. must aim to fully decarbonize its energy system by increasing reliance on renewables, supported by advanced technologies such as next-generation nuclear power and energy storage innovations. This period will also require the scaling of electric vehicle adoption, industrial decarbonization, and continued investments in emerging energy technologies.

By carefully managing the transition across these phases, the U.S. can achieve a low-carbon future while preserving energy security and promoting sustainable economic growth.

3. Non-renewable Energy Sources: Backbone of the U.S. Energy Supply

As illustrated in Fig. 4 artistically, for decades, the United States has relied heavily on non-renewable energy sources such as coal, natural gas, and oil. These fuels have powered industrial growth, transportation, and much of the electricity generation across the country. However, despite their importance, non-renewable resources pose significant challenges, including finite supply, environmental impact, and price volatility.

List of high-level sources of none-renewable energy source are listed below with their holistic description as.

3.1 Oil

Oil has long been the dominant energy source for transportation in the U.S., accounting for about 35% of the country's energy consumption. The U.S. remains one of the largest oil producers in the world, yet it still imports a substantial amount to meet domestic demand. The volatility of global oil prices and the environmental concerns associated with its extraction and burning (such as air pollution and greenhouse gas emissions) make the future of oil uncertain. As EVs (electric vehicles) (i.e., Fig. 5 an EV automobile) become more widespread, oil's role in transportation could diminish over the next few decades.

Fig. 4 Artistic none-renewable energy source.

Fig. 5 An EV automobile illustration.

3.2 Natural Gas

The NGA (Natural Gas Act) requires the DOE (Department of Energy) to decide if exporting LNG (liquefied natural gas) to a country lacking a free trade agreement with the U.S. is in the "public interest". Applications to export LNG to countries that have free trade agreements with the U.S. are automatically deemed to be in the public interest. In January 2024, DOE announced a temporary pause on the review of LNG export applications while the department reviews and updates the public interest determination process.

Natural gas has gained prominence as a cleaner alternative to coal, playing a significant role in electricity generation and heating. It has lower carbon emissions than coal and oil, making it an attractive option for bridging the gap toward renewable energy sources. The advent of hydraulic fracturing (fracking) has significantly increased the availability of natural gas, positioning the U.S. as a leading producer. However, concerns over methane leaks, water contamination, and seismic activity continue to draw criticism from environmentalists.

3.3 Coal

Coal, once the cornerstone of American energy, has experienced a steep decline due to environmental regulations, competition from cheaper natural gas, and the rise of renewable energy. While coal remains a significant source of electricity in certain regions, its future is bleak due to its high carbon emissions and the growing demand for cleaner energy solutions. The continued decline in coal use aligns with the U.S.'s goals to reduce greenhouse gas emissions in line with international climate agreements.

3.4 Nuclear energy

Nuclear energy is often classified in a category of its own, neither fully renewable nor entirely non-renewable. It has characteristics of both, which makes its classification somewhat complex.

(1) Arguments for Nuclear as a Non-Renewable Source

Nuclear energy relies on uranium, a finite resource that must be mined from the earth. Like fossil fuels, uranium reserves are limited, and while they are more abundant than some fossil fuels, they will eventually deplete. Additionally, traditional nuclear reactors use a fuel cycle that does not replenish itself, meaning the fuel (uranium or plutonium) cannot be regenerated once consumed.

(2) Arguments for Nuclear as a Renewable Source

Some experts argue that nuclear energy has renewable-like qualities because it generates large amounts of energy with minimal greenhouse gas emissions. Moreover, next-generation nuclear technologies, such as breeder reactors and thorium reactors, could theoretically make the nuclear fuel cycle more sustainable by reprocessing spent fuel or using more abundant materials like thorium. If developed and deployed on a large scale, these technologies could extend the life of nuclear energy resources significantly, blurring the line between renewable and non-renewable.

In conclusion, currently, nuclear energy is generally considered a non-renewable resource because it depends on finite uranium supplies. However, it is often grouped with renewables in terms of its low-carbon footprint and potential future innovations that could make its fuel cycle more sustainable.

4. Renewable Energy: The Path toward Sustainability

Renewable energy sources like solar, wind, hydropower, and geothermal are gaining traction as key players in America's energy future. These sources offer clean, sustainable energy that can help reduce greenhouse gas emissions, mitigate climate change, and decrease dependence on imported fuels. The expansion of renewables also promises job creation and economic development in new energy sectors. Fig. 6 artificially, shows different types of renewable energy sources.

List of examples of these different renewable of energy source are highlighted as:

4.1 Solar Energy

Solar power has emerged as one of the fastest-growing renewable energy sources in the U.S. Technological advances, coupled with decreasing costs of PV (photovoltaic) panels, have made solar energy more accessible than ever. Solar installations, ranging from residential rooftop systems to utility-scale solar farms, are becoming a significant part of the U.S. energy portfolio. While solar energy is intermittent and dependent on weather conditions, advancements in energy storage systems are helping address these challenges, allowing solar energy to be a more reliable part of the grid.

4.2 Wind Energy

Wind energy is another critical component of the renewable energy landscape, particularly in states with vast wind resources such as Texas, Iowa, and Oklahoma. Onshore and offshore wind farms are expanding rapidly, driven by technological advancements that have increased turbine efficiency and lowered costs. As wind power becomes more integrated into the national energy grid, it plays a crucial role in reducing carbon emissions. However, the intermittent nature of wind, similar to solar, requires investment in energy storage and grid modernization to ensure reliability.

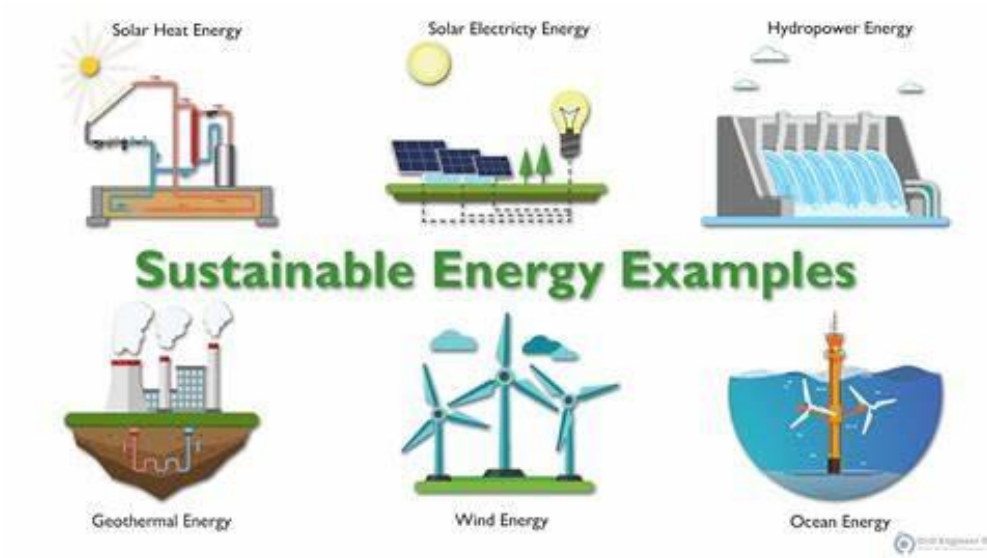

Fig. 6 Sustainable energy sources.

4.3 Hydropower and Geothermal Energy

Hydropower remains the largest source of renewable energy in the U.S., accounting for about 7% of total electricity generation. The energy derived from flowing water is both reliable and sustainable, although there are limits to further expansion due to environmental concerns and geographic constraints. Geothermal energy, while currently contributing a smaller share of electricity generation, has significant potential in certain regions. Its ability to provide baseload power (consistent energy output) makes it an attractive option for enhancing energy reliability alongside intermittent renewables.

4.4 Ocean Energy

Ocean energy refers to the renewable energy harnessed from the ocean’s movements, including tidal, wave, and thermal energy. Tidal energy is generated from the rise and fall of tides, while wave energy captures power from surface waves. OTEC (ocean thermal energy conversion) uses the temperature difference between warm surface waters and cooler deep waters to generate electricity. Ocean energy has significant potential as a sustainable and abundant energy source, although it is still in the early stages of commercial development compared to other renewable energy technologies like solar and wind.

5. Challenges and Opportunities in the Transition to a Mixed Energy Future

The U.S. energy future will likely depend on a mix of both renewable and non-renewable resources (Fig. 7). While the transition to renewable energy is underway, there are several challenges that must be addressed to ensure a smooth and equitable shift [4-8].

Tope-level concerns through these challenges and opportunities are in the transition through a mixed energy future energy forms are listed as follows.

5.1 Energy Storage and Grid Modernization

The intermittent nature of solar and wind energy presents a significant challenge. Energy storage systems, such as batteries, are critical to ensure a stable supply of electricity when the sun is not shining, or the wind is not blowing. Additionally, the U.S. energy grid was not designed for large-scale renewable integration. Modernizing the grid as illustrated in Fig. 8, to handle distributed generation and accommodate new technologies will require substantial investment [9, 10].

Electricity grids are sensitive to a variety of macro and micro events, and emissions data with high temporal granularity will enable monitoring and analyzing the influence of periodical activities, seasonal patterns and disruptions on the grid, and on its impact on climate.

5.2 Policy and Regulation

Government policy plays a critical role in shaping the future of the U.S. energy system as it demonstrated in Fig. 9, where financial, policy and energy regulation drive each other. Federal, state, and local regulations can either accelerate or hinder the adoption of renewable energy technologies. Policies that incentivize clean energy production, reduce carbon emissions, and promote research and development in new energy technologies are essential for achieving long-term sustainability goals [11-14].

The EPRA (Energy Permitting Reform Act of 2024) presents a crucial opportunity to accelerate and streamline the energy infrastructure permitting process that is vital for the U.S. to ensure affordable, reliable energy while reducing emissions.

5.3 Economic Considerations

The transition from non-renewable to renewable energy must be economically viable for both consumers and industries.

According to study done by Yale School of the Environment, converting the entire U.S. power grid to 100 percent renewable energy in the next decade is technologically and logistically attainable, and would cost an estimated $4.5 trillion.

The estimate represents the cost of replacing all fossil fuels and nuclear power with hydroelectricity, biomass, geothermal, wind, and solar. The price tag would drop to $4 trillion if nuclear were allowed to remain part of the energy mix [15].

It is also important to consider that the costs associated with renewable energy technologies are falling, but investment in infrastructure, storage, and grid updates is still required. Furthermore, the energy transition presents an opportunity for job creation in the clean energy sector, but it also poses challenges for workers in traditional fossil fuel industries who may face job displacement.

6. Recommendations for a Sustainable Energy Strategy

A balanced and sustainable energy future for the United States requires a multi-faceted approach that leverages the strengths of both renewable and non-renewable energy sources while prioritizing environmental sustainability and economic growth.

6.1 Invest in Renewable Energy Research and Development

Continued investment in solar, wind, and energy storage technologies is critical for improving efficiency and reducing costs. Public-private partnerships can accelerate innovation and commercialization of advanced energy solutions.

6.2 Modernize the National Grid

To support the integration of renewables, the U.S. must invest in a smart, resilient, and modernized energy grid. This includes expanding transmission infrastructure and deploying smart grid technologies that enable efficient energy distribution and storage.

6.3 Promote Energy Efficiency

Reducing energy demand through efficiency measures in homes, businesses, and industries is one of the most cost-effective ways to cut carbon emissions and lower energy costs.

6.4 Support Workforce Transition Programs

As the energy industry shifts away from fossil fuels, it is important to provide training and support for workers transitioning into new energy sectors such as renewable energy, energy storage, and grid modernization.

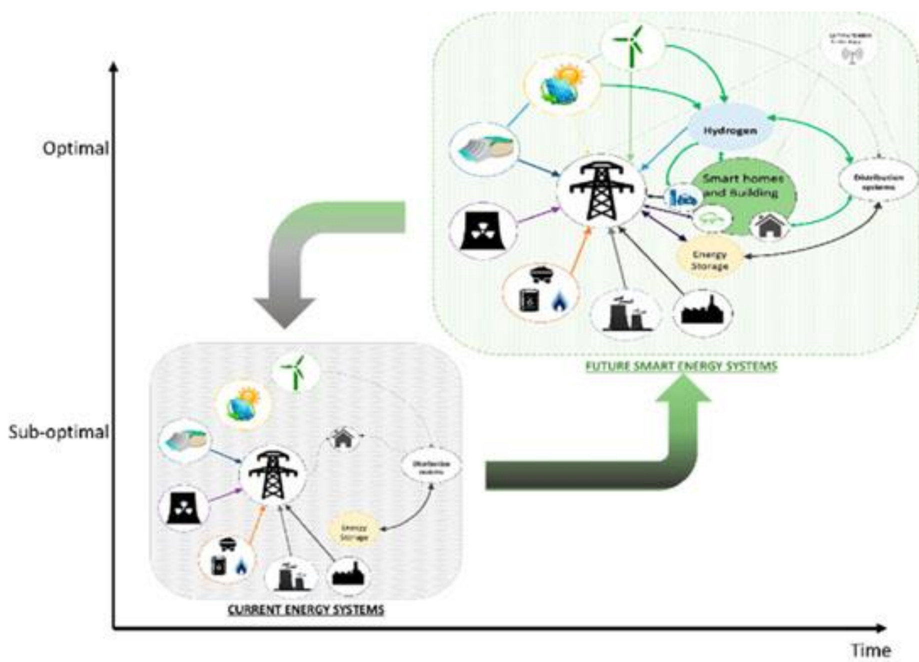

Fig. 7 Mixed energy future illustration.
Source: US Department of Energy.

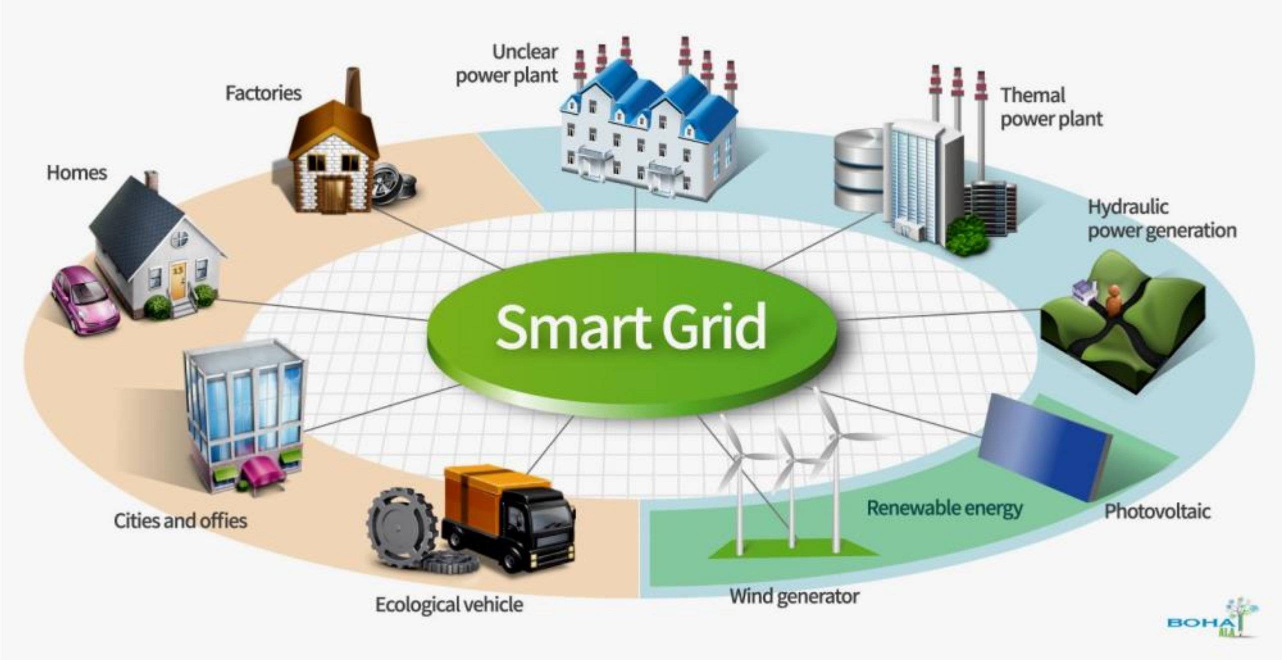

Fig. 8 Smart grid artistic illustration.
Source: US Department of Energy.

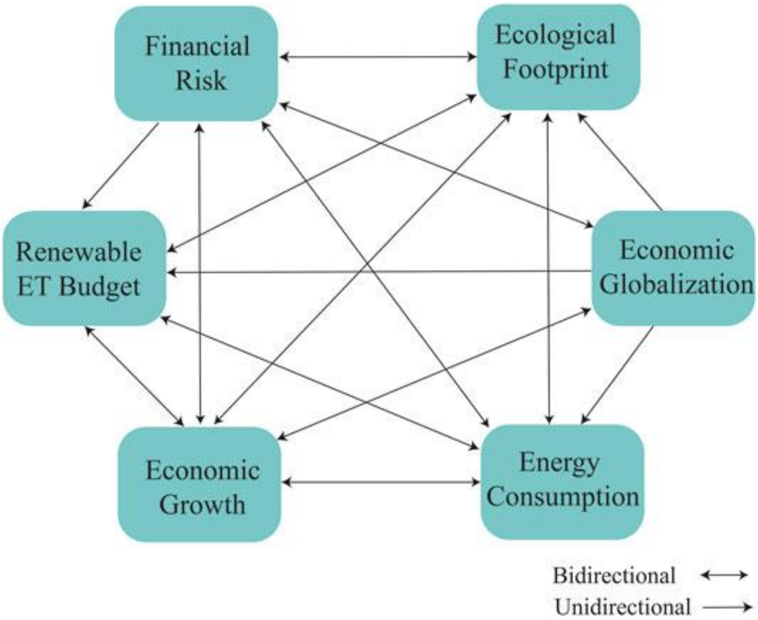

Fig. 9 Financial, policy and energy regulation driving each other, bidirectional and unidirectional.
Source: US Department of Energy.

7. Conclusion

America's immediate future depends on balancing renewable and non-renewable energy sources. In the long term, the United States needs to invest in renewable energy, update the system, enact laws that promote environmental sustainability and economic growth, and define the standard for cleaner, more resilient energy globally.

Grids and storage only receive 60 cents of every dollar spent on renewable energy. For the power sector to be safely decarbonized, grid and storage investments must rise even faster than sustainable electricity generation, and the investment ratio must revert to 1:1.

Efforts to strengthen the resilience of electrical networks are crucial because many of them are currently at risk due to an increase in extreme weather events.

Furthermore, a well-rounded strategy that effectively blends renewable and non-renewable energy sources will be required to guarantee the United States has a safe and sustainable energy future. Historically, non-renewable resources like coal, natural gas, and oil have served as the cornerstone of the American energy infrastructure. However, a move to cleaner alternatives is necessary because of their limited supply and adverse environmental effects. These fossil fuels will continue to be essential in the near future, particularly as "bridge fuels" that provide consistent electricity as renewable technologies grow. However, investments in CCS (carbon capture and storage) can mitigate the environmental impact of these sources throughout the transition phase.

Renewable energy sources—such as solar, wind, hydropower, and more recent options like ocean energy—are crucial to reducing greenhouse gas emissions and ensuring a sustainable energy supply. However, these sources have limitations, including unpredictable behavior and reliance on favorable environmental conditions. To solve these issues, the national grid must be modernized, and energy storage technologies, such as better batteries, must be funded. Integrating renewables into the electrical grid will be made more accessible by increasing resilience and dependability and enabling a more flexible energy system to meet demand as renewable capacity increases.

Nuclear energy is a key component of the clean energy mix due to its consistent baseload output and low carbon footprint. Even while nuclear energy depends on finite resources like uranium, advances in reactor technology, such as breeder reactors and the potential use of thorium, offer a path to more sustainable nuclear fuel cycles. As a result, nuclear energy is a unique weapon in the battle for a low-carbon energy system, aiding in the transition from more traditional non-renewable sources to more modern renewable technology.

Emerging technologies like ocean energy, which produces power using thermal, wave, and tidal energy, are promising additions to the renewable portfolio. Although it is still in its infancy, ocean energy is a mostly untapped resource that has the potential to strengthen and expand America's clean energy mix.

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