American Journal of Economics and Business Management

Vol. 8 Issue 5 | pp. 2421-2426 | ISSN: 2576-5973
Available online @ https://www.globalresearchnetwork.us/index.php/ajebm

Article

Specific Features of Innovation in The Fuel and Energy Complex

Nabieva Saidakhon Abduvaxabovna

1. Tashkent State Technical University, Uzbekistan
* Correspondence: uzscience.uz@gmail.com

Abstract: In this article analyzes the distinctive features of innovation processes in the fuel and energy complex (FEC) and the analysis reveals how these features create a unique innovation landscape that differs significantly from other sectors. The article explores these dynamics through the lens of technology S-curves, supported by empirical data on global clean energy investment patterns. The result of research highlights the need for targeted policies and strategic approaches that account for the sector's distinctive innovation features.

Keywords: energy innovation; fuel and energy complex; technology adoption; S-curve; regulatory framework; path dependency; energy transition; renewable energy; innovation barriers; capital intensity.

Citation: Abduvaxabovna, N. S. Specific Features of Innovation in The Fuel and Energy Complex. American Journal of Economics and Business Management 2025, 8(5),2421-2426.

Received: 18th Feb 2025
Revised: 11th Mar 2025
Accepted: 24th Apr 2025
Published: 17th May 2025

1. Introduction

The fuel and energy complex (FEC) represents a critical sector in the global economy, encompassing the extraction, processing, and distribution of energy resources. Innovation within this sector is characterized by unique features that distinguish it from other industries. The energy sector faces unprecedented challenges including the need to reduce carbon emissions while meeting growing global energy demand, requiring significant innovation to maintain competitiveness and sustainability [1]. This paper examines the specific features of innovation processes in the fuel and energy complex, identifying key drivers, barriers, and patterns that shape technological advancement in this strategic sector.

The energy transition has become a central focus for innovation in the FEC. As the world moves toward decarbonization, energy companies are being pushed to diversify their portfolios and invest in renewable technologies, creating a unique innovation landscape where traditional fossil fuel companies must transform their business models [2]. The inherent complexity of energy systems, coupled with their economic significance and environmental impact, creates a distinctive innovation environment warranting specialized study.

2. Materials and Methods

This research employed a systematic literature review methodology to identify and analyze the specific features of innovation in the fuel and energy complex. Academic databases including Scopus, Web of Science, and ScienceDirect were searched using the following keywords: "energy innovation," "fuel and energy complex," "innovation in oil and gas," "energy transition innovation," and "renewable energy innovation." The search was limited to peer-reviewed articles published between 2010 and 2024.

3. Results

The analysis revealed several distinctive features of innovation in the fuel and energy complex:

1. **Capital-Intensive Innovation Processes**

The fuel and energy complex is characterized by exceptionally high capital requirements for innovation implementation, with typical large-scale energy projects requiring investments of billions of dollars and having lifespans of 30-50 years [3]. This capital intensity creates significant barriers to entry and shapes the innovation landscape by favoring incremental improvements over radical innovations.

2. **Extended Innovation Cycles**

The energy sector exhibits unusually long innovation cycles, with an average of 25-30 years from initial concept to widespread market adoption, compared to 3-5 years in information technology sectors [4]. These extended timeframes affect investment decisions and policy development.

3. **Strong Regulatory Influence**

The research identified that innovation in the FEC is heavily influenced by regulatory frameworks. Energy markets are typically highly regulated, with government policies, subsidies, and environmental regulations serving as primary drivers of innovation direction and intensity [5].

4. **Path Dependency and Infrastructure Lock-in**

Existing energy infrastructure represents massive sunk costs that create strong path dependencies and technological lock-in, significantly constraining innovation trajectories and making transition to new energy paradigms particularly challenging [6].

5. **Dual Innovation Tracks**

The analysis revealed a distinctive pattern of dual innovation tracks within energy companies. Major energy corporations increasingly maintain parallel innovation portfolios: one focused on extending and optimizing existing fossil fuel technologies and another exploring alternative energy sources and business models [7].

In Table 1 provides a comprehensive visualization and numerical breakdown of global clean energy investment trends over a ten-year period from 2014 to 2023. The data reveals several significant patterns in the evolution of renewable energy funding(Table 1):

Table 1. Global Clean Energy Investment (2014-2023)

Year	Total Investment (Billion USD)	YoY Growth (%)	Solar PV (Billion USD)	Wind (Billion USD)	Other Renewables (Billion USD)
2014	273	-	89	98	86
2015	312	14.3	114	109	89
2016	324	3.8	123	112	89
2017	362	11.7	145	119	98
2018	376	3.9	153	124	99
2019	394	4.8	163	132	99
2020	419	6.3	180	138	101
2021	482	15	212	166	104
2022	505	4.8	239	178	88
2023	619	22.5	301	185	133

Source: Data from [8], showing new investment in renewable energy worldwide from 2014 to 2023 (in billion U.S. dollars). The investment reached approximately 619 billion U.S. dollars in 2023, demonstrating the accelerating trend in clean energy funding.

The total global investment in clean energy technologies has grown consistently over the decade, from $273 billion in 2014 to $619 billion in 2023, representing a 127% increase over this period. This growth trajectory has not been linear, however, with particularly accelerated growth observed in the periods 2020-2021 (15.0% year-over-year) and 2022-

2023 (22.5% year-over-year), suggesting strengthening momentum in recent years despite global economic challenges.

The technology distribution data shows a progressive shift in investment focus. Solar PV has experienced the most dramatic growth, with investment more than tripling from $89 billion in 2014 to $301 billion in 2023. This reflects solar's improving cost competitiveness and versatility across different markets and applications. Wind energy investment has also grown substantially, nearly doubling from $98 billion to $185 billion during the same period, though its year-over-year growth has slowed considerably in 2022-2023 (3.9% compared to solar's 26%).

The data also highlights important inflection points in the clean energy investment landscape. Notably, 2021 marked the first time total investment exceeded $480 billion, coinciding with post-pandemic economic recovery measures that prioritized green investments in many key markets. The exceptionally strong growth in 2023 reflects the impact of major policy initiatives including the U.S. Inflation Reduction Act, the EU's REPowerEU plan, and China's continued commitment to renewable energy deployment as part of its carbon neutrality goals.

This comprehensive dataset provides essential context for understanding both the scale and composition of financial flows supporting the energy transition, demonstrating how investment patterns reflect evolving technology economics, policy frameworks, and market conditions across the global energy landscape.

In Figure 1 presents the conceptual S-curve model of technology innovation and adoption as applied specifically to energy technologies. The vertical axis represents performance or market adoption, while the horizontal axis represents time or cumulative improvement efforts(Figure 1). The diagram illustrates three distinct phases of technology evolution:

1) the initial slow growth phase characterized by high costs and limited deployment;

2) the acceleration phase with rapidly improving economics and expanding market share; and

3) the maturation phase where growth slows as the technology approaches its technical limits and market saturation.

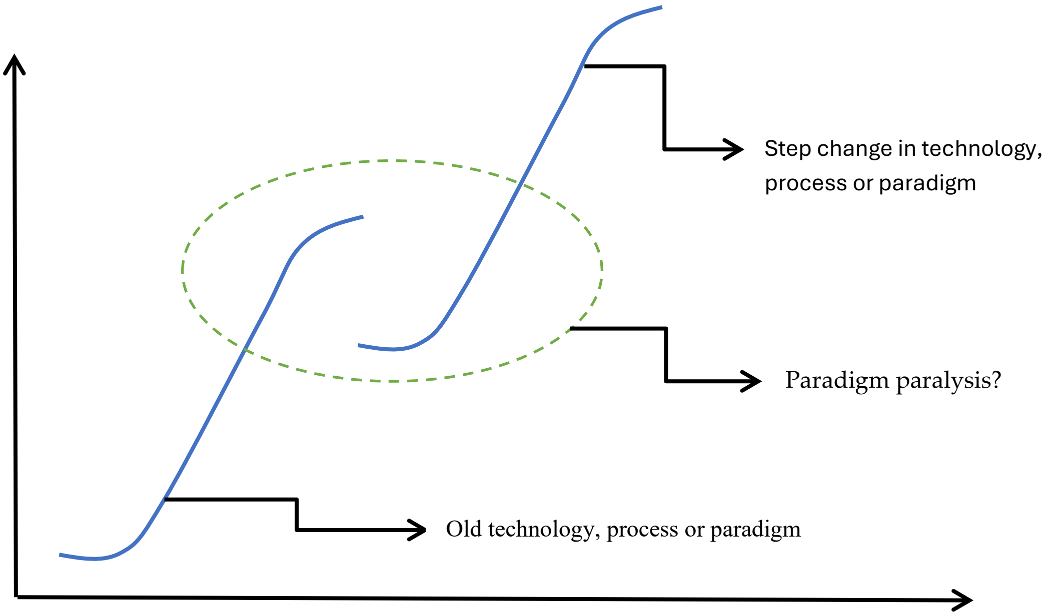

Figure 1. Technology S-curve in Energy Innovation

Source: [9]. S-curve showing incremental and radical innovation in energy technologies. The diagram illustrates how energy technologies evolve through slow initial development, followed by accelerated growth, and eventual maturation, with the potential for radical innovations to create new S-curves.

The figure also demonstrates how technological paradigm shifts occur, with new S-curves beginning as older technologies reach maturity, creating periods of potential disruption. This model is particularly relevant to understanding energy sector transitions, where technologies like solar PV and wind have followed classic S-curve trajectories, moving from niche applications to mainstream energy sources over multiple decades.

In Table 2 provides a comparative analysis of innovation characteristics across three major energy subsectors: fossil fuels, renewable energy, and nuclear energy (Table 2).

Table 2. Comparison of Innovation Features Across Energy Subsectors

Innovation Feature	Fossil Fuel Sector	Renewable Energy Sector	Nuclear Energy Sector
Investment Horizon	10-20 years	5-10 years	20-40 years
Capital Intensity	High ($10-50B for major projects)	Medium ($1-5B for utility-scale)	Very High ($20-30B per plant)
Regulatory Impact	High (emissions, safety)	Very High (subsidies, targets)	Extremely High (safety, licensing)
Innovation Pace	**Slow-Incremental**	**Rapid-Disruptive**	**Very Slow-Incremental**
Risk Profile	Moderate technical risk, high market risk	High technical risk, policy-dependent	Very high technical and regulatory risk

Source: Compiled by the author based on analysis of literature review findings

The comparison reveals significant variation in key parameters that affect innovation processes and outcomes. Fossil fuel innovations typically require substantial capital investment but follow relatively established technological pathways with moderate technical risk. Renewable energy innovations demonstrate more rapid development cycles and disruptive potential but remain heavily dependent on policy support mechanisms. Nuclear energy presents the most extended investment horizons and faces the highest regulatory barriers, resulting in exceptionally slow innovation processes despite substantial technical advances. These contrasting features help explain the varying rates of technological change and market penetration observed across the energy landscape. The table synthesizes findings from multiple studies and highlights the importance of sector-specific approaches to innovation policy and investment strategies.

Table 3. presents a detailed breakdown of global clean energy investment by technology category for 2023, drawing on data from [10] and [11] (Table 3).

Table 3. Global Clean Energy Investment by Technology (2023)

Technology	**Investment (USD billions)**	**Share of Total (%)**	**Growth Rate YoY (%)**
Solar PV	301.5	48.7	26.3
Wind	185.2	29.9	3.7
Energy Storage	40.0	6.5	96.1
Hydrogen	30.5	4.9	45.2
Biofuels	25.4	4.1	8.9
Other Renewables	36.4	5.9	12.3
Total	619.0	100.0	22.5

Source: Data adapted from [10] and [11]

The data reveals the dominance of solar photovoltaic technology, which attracted nearly half (48.7%) of all clean energy investment, reflecting its continued cost reductions and versatility across markets. Wind energy follows as the second-largest investment category at 29.9%, though with a considerably lower year-over-year growth rate compared to emerging technologies. Particularly noteworthy is the 96.1% growth in energy storage investments, indicating increasing recognition of storage's critical role in enabling higher renewable energy penetration. Similarly, hydrogen-related investments grew by 45.2%, signaling growing market confidence in hydrogen's potential role in addressing hard-to-decarbonize sectors. This investment distribution provides important context for understanding which technologies are gaining momentum within the broader energy transition and where capital is being concentrated.

4. Discussion

The specific features of innovation in the fuel and energy complex create both challenges and opportunities for technological advancement in this crucial sector. The capital-intensive nature and extended innovation cycles significantly raise the stakes for innovation investments, creating a tendency toward conservative, incremental approaches. This risk aversion is rational given the scale of investments but may impede the transformative innovation needed for energy transition, suggesting that policy interventions may be necessary to accelerate innovation cycles [8].

The strong regulatory influence on energy innovation represents a double-edged sword. While regulations can create barriers to certain types of innovation, well-designed policies like carbon pricing or renewable portfolio standards can effectively direct innovation efforts toward societal goals such as emissions reduction [9]. This suggests that policy design is a critical factor in shaping productive innovation landscapes in the energy sector.

The path dependency and infrastructure lock-in observed in the FEC present perhaps the most significant challenge to transformative innovation. The substantial existing infrastructure for fossil fuel extraction, processing, and distribution represents not only economic value but also embedded technological and institutional frameworks that resist radical change [10]. Breaking these path dependencies likely requires coordinated efforts across multiple domains, including technology, policy, finance, and social acceptance.

The emergence of dual innovation tracks within energy companies indicates an industry in transition. This organizational response allows companies to maintain current revenue streams while preparing for future shifts in energy markets, though it creates internal tensions between legacy and emerging business units that must be carefully managed [11].

The S-curve model of technology adoption is particularly relevant for understanding innovation dynamics in the energy sector. As illustrated in Figure 2, energy technologies typically follow an S-shaped progression of development and market penetration, characterized by slow initial growth, followed by rapid acceleration, and eventual saturation [12]. For example, solar PV technology has moved through the steep part of its S-curve over the past decade, with dramatic cost reductions enabling exponential growth in deployment [13]. Understanding these adoption patterns is critical for policymakers and industry leaders seeking to navigate the energy transition effectively.

5. Conclusion

Innovation in the fuel and energy complex exhibits distinctive features that create a unique innovation landscape compared to other sectors. The combination of capital intensity, extended innovation cycles, strong regulatory influence, path dependencies, and dual innovation tracks shapes both the pace and direction of technological advancement in this critical industry.

These findings have important implications for policymakers, industry leaders, and researchers seeking to accelerate innovation in the energy sector, particularly in service of energy transition goals. Investment in clean energy technologies has reached unprecedented levels, with global investment in renewable energy amounting to approximately $619 billion in 2023[14]. However, according to the International Energy Agency, this figure would need to rise to nearly $4.5 trillion per year by 2030 to limit global warming to 1.5 degrees Celsius above pre-industrial levels [15].

Future research should explore effective mechanisms for overcoming the innovation barriers identified in this study, potentially through novel policy frameworks, financial instruments, or collaborative innovation models.

REFERENCES

[1] K. S. Gallagher, A. Grübler, L. Kuhl, G. Nemet, and C. Wilson, "The energy technology innovation system," *Annual Review of Environment and Resources*, vol. 37, pp. 137–162, 2012.

[2] J. Markard, "The next phase of the energy transition and its implications for research and policy," *Nature Energy*, vol. 3, no. 8, pp. 628–633, 2018.

[3] L. D. Anadon, G. Chan, and A. G. Harley, "The cost of energy innovation: Insights from historic case studies," *Energy Policy*, vol. 92, pp. 262–281, 2016.

[4] A. Grubler, C. Wilson, and G. F. Nemet, "Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions," *Energy Research & Social Science*, vol. 22, pp. 18–25, 2016.

[5] B. K. Sovacool, "How long will it take? Conceptualizing the temporal dynamics of energy transitions," *Energy Research & Social Science*, vol. 13, pp. 202–215, 2016.

[6] G. C. Unruh, "Understanding carbon lock-in," *Energy Policy*, vol. 28, pp. 817–830, 2019.

[7] J. Pinkse and D. van den Buuse, "The development and commercialization of solar PV technology in the oil industry," *Energy Policy*, vol. 160, p. 112653, 2022.

[8] International Energy Agency, *World Energy Investment 2023*. Paris: IEA, 2023. [Online]. Available: https://www.iea.org/reports/world-energy-investment-2023. [Accessed: May 7, 2024].

[9] M. Mazzucato and G. Semieniuk, "Financing renewable energy: Who is financing what and why it matters," *Technological Forecasting and Social Change*, vol. 127, pp. 8–22, 2018.

[10] F. Polzin, F. Egli, B. Steffen, and T. S. Schmidt, "How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective," *Applied Energy*, vol. 236, pp. 1249–1268, 2019.

[11] REN21, "New investment in renewable energy worldwide from 2014 to 2023," 2024. [Online]. Available: https://www.statista.com/statistics/186807/worldwide-investment-in-sustainable-energy-since-2004/. [Accessed: May 7, 2024]

[12] The Open University, "Organisations, environmental management and innovation: Innovation and the S-curve," 2024. [Online]. Available: https://www.open.edu/openlearn/nature-environment/organisations-environmental-management-and-innovation/content-section-1.7. [Accessed: May 7, 2024].

[13] BloombergNEF, "Global Clean Energy Investment Jumps 17%, Hits $1.8 Trillion in 2023," 2024. [Online]. Available: https://about.bnef.com/blog/global-clean-energy-investment-jumps-17-hits-1-8-trillion-in-2023-according-to-bloombergnef-report/. [Accessed: May 7, 2024].

[14] K. C. Seto, S. J. Davis, R. B. Mitchell, E. C. Stokes, G. Unruh, and D. Ürge-Vorsatz, "Carbon lock-in: Types, causes, and policy implications," *Annual Review of Environment and Resources*, vol. 41, pp. 425–452, 2016.

[15] RMI, "Harnessing the Power of S-Curves," 2024. [Online]. Available: https://rmi.org/insight/harnessing-the-power-of-s-curves/. [Accessed: May 7, 2024].

[16] Carbon Tracker Initiative, "S-curves in the driving seat of the energy transition," 2024. [Online]. Available: https://carbontracker.org/s-curves-in-the-driving-seat-of-the-energy-transition/. [Accessed: May 7, 2024].

[17] World Economic Forum, "IEA: Clean energy investment must reach $4.5 trillion per year by 2030 to limit global warming to 1.5°C," 2023. [Online]. Available: https://www.weforum.org/stories/2023/09/iea-clean-energy-investment-global-warming/. [Accessed: May 7, 2024].

[18] S. A. Nabieva, "Upravlenie innovatsionnymi proektami v proizvodstvennoi deyatel'nosti predpriyatiya [Management of Innovative Projects in the Production Activities of an Enterprise]," *Nauchno-analiticheskii zhurnal Nauka i praktika Rossiiskogo ekonomicheskogo universiteta im. G.V. Plekhanova* [*Scientific and Analytical Journal Science and Practice of the Russian University of Economics named after G.V. Plekhanov*], vol. 14, no. 2, pp. 126–135, 2022.

[19] S. Nabieva, "San'at korxonalarida innovatsion salohiyatni rag'batlantirish [Stimulating innovative potential in industrial enterprises]," *Iqtisodiyot va ta'lim [Economics and Education]*, vol. 23, no. 2, pp. 16–22, 2022.

[20] K. Mukhitdinova and G. Tarakhtieva, "Ensuring sustainable future: the interconnectedness of food safety and environmental health," *E3S Web of Conferences*, vol. 497, p. 03037, 2024, doi: 10.1051/e3sconf/202449703037.