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Economic and Strategic Significance of Small Modular Reactor (SMR) -Assisted Green Hydrogen Production in the Decarbonization of the Aviation Sector

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ABSTRACT

The increasing demand for energy necessitates investments in energy resources and imports. As fossil fuels currently dominate global energy production, the transition to cleaner energy alternatives is imperative. Nuclear power plants, on the other hand, garner attention due to their consistent base load and low greenhouse gas emissions. Small modular reactor (SMR) technologies have been prioritized in non-electrical applications. This study comprehensively analyzes the economic impact of green hydrogen production by using SMRs on the decarbonization of the aviation sector. In the initial phase, a theoretical literature review was conducted to examine the technological and economic characteristics of SMRs, the correlation between hydrogen production technology and SMRs, and the potential for their integration into the aviation sector. The cost-effectiveness of hydrogen production using SMRs for the aerospace industry was evaluated. Furthermore, the levelized cost of electricity (LCOE) and levelized cost of hydrogen (LCOH) were calculated, considering key parameters and potential price fluctuations. Sensitivity analysis was performed specifically for ACP100, NuScale (VOYGR-4), BWRX-300 and i-SMR designs, and as a result, it was seen that the effect of operating life and reduction rate on LCOH remained below 1%. The most effective parameter has been determined as the lower calorific value (LHV) of hydrogen, which has an effect of approximately 8-9%. Notably, no significant technology-specific differences were observed. Although it was obtained that the LCOH did not fall below \$6/kg even when all parameters were at their lowest, it was concluded that with a 10% change in the parameters, the cost of hydrogen could potentially reach \$10/kg per kilogram. For competitiveness with jet fuel, the LCOH needs to fall below \$4/kg. Within this, it was concluded that when all parameters decrease by 10%, the LCOE value should decrease to \$42/MWh for the scenario and \$33/MWh for the reference scenario. In addition, the main suggestions and points to be considered to guide other researchers working on nuclear energy, hydrogen and aviation are presented in the conclusion section.

Havacılık Sektörünün Karbonsuzlaştırılmasında Küçük Modüler Reaktör (KMR) Destekli Yeşil Hidrojen Üretiminin Ekonomik ve Stratejik Önemi

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ÖZET

Artan enerji talebi, enerji kaynaklarına ve ithalata yatırım yapılmasını zorunlu kılmaktadır. Fosil yakıtlar şu anda küresel enerji üretimine hâkim olduğundan, daha temiz enerji alternatiflerine geçiş çok önemlidir. Nükleer güç santralleri ise baz yük oluşu ve düşük sera gazı salımı özelliği ile dikkatleri üstüne çekmektedir. Özelllikle küçük modüler reaktör (KMR) teknolojileri elektrik dışı uygulamalarda önceliklendirilmiş durumdadır. Bu çalışmada, SMR destekli yeşil hidrojen üretiminin havacılık sektörünün karbonsuzlaşması üzerindeki ekonomik etkisi kapsamlı bir şekilde analiz edilmektedir. İlk aşamada teorik olarak literatür taraması ile SMR'lerin teknolojik ve ekonomik özellikleri, hidrojen üretim teknolojisi ile SMR ilişkisi ve havacılık sektörüne entegrasyon potansiyeli incelenmiştir. Havacılık endüstrisi için SMR'ler kullanılarak hidrojen üretiminin maliyet etkinliği değerlendirilmiştir. Ayrıca temel parametreler ve potansiyel fiyat dalgalanmalarını göz önünde bulundurarak seviyelendirilmiş elektrik maliyeti (LCOE) ve seviyelendirilmiş hidrojen maliyeti (LCOH) hesaplanmıştır. ACP100, NuScale (VOYGR-4), BWRX-300 ve i-SMR tasarımlarına özel olarak duyarlılık analizi yapılmış ve sonucunda, işletme ömrü ve indirgenme oranının LCOH üzerindeki etkisi %1'in altında kaldığı görülmüştür. En etkili parametre, yaklaşık %8-9 etki gösteren hidrojenin alt ısıl değeri (LHV) olarak belirlenmiştir. Özellikle, teknolojiye özgü önemli bir farklılık gözlenmemiştir. Tüm parametreler en düşük seviyelerdeyken bile LCOH'ın 6\$/kg'ın altına düşmediği gözlemlense de parametrelerde 10%'luk bir değişiklikle hidrojen maliyetinin potansiyel olarak kilogramda \$10/kg'a ulaşabileceği sonucuna varılmıştır. Jet yakıtı ile rekabet gücü için LCOH'ın \$4/kg'ın altına düşmesi gerekmektedir. Bunun içinde bütün parametrelerin %10 azaldığında oluşan senaryo için LCOE değerinin 42 \$/MWh, referans senaryo için ise 33 \$/MWh seviyelerine kadar düşmesi gerektiği sonucu elde edilmiştir. Bunun yanı sıra, nükleer enerji, hidrojen ve havacılık üzerine çalışan diğer araştırmacılara da yol göstermek adına hazırlanan başlıca öneriler ve dikkat edilmesi gereken hususlar sonuç bölümünde sunulmuştur.

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INTRODUCTION

As the global population grows, industries develop, and new technologies emerge, the demand for energy continues to rise. To address this energy challenge, substantial investments are made in energy resources, and energy imports, particularly from foreign sources, become crucial. Consequently, energy solutions hold paramount importance for both social welfare and economic growth. Notably, over 80% of the world's energy production relies on fossil-based fuels, underscoring the urgency of transitioning to cleaner and more sustainable energy alternatives in the long term (Bulbul et al., 2023; Hacıbeyoglu et al., 2023; Kapıkıran et al., 2025; Özkan & Demir, 2019).

The growing demand for sustainable aviation fuels and the inherent limitations of conventional jet fuels compel the aviation sector to investigate alternative energy sources. In this context, hydrogen emerges as a significant candidate due to its substantial energy density and the absence of emissions during combustion. The aviation industry's transition to hydrogen energy aligns with its objective of minimizing its environmental impact, particularly CO_2 emissions (Alipour Bonab et al., 2024; Zimmermann et al., 2023). Furthermore, the aviation industry's dependence on limited fossil fuel reserves, volatile pricing, and geopolitical dependence create significant energy insecurity for many countries. Hydrogen production, on the other hand, offers the potential to mitigate this insecurity by enabling diversified resource utilization (Bridgelall, 2025).

One promising method for large-scale and sustainable hydrogen production is the incorporation of SMR into the system. SMRs can provide both high-grade heat and electricity, which is essential for high-temperature steam electrolysis, one of the highly efficient hydrogen production processes. This integration establishes a carbon-neutral framework for hydrogen production, which is relevant for the aviation industry to attain its decarbonization objectives. Notably, the waste heat generated from SMRs can be utilized to fuel processes such as carbon capture directly from the atmosphere and high-temperature steam electrolysis, thereby optimizing energy utilization and ultimately reducing the overall cost of hydrogen production (Slavin et al., 2024). This approach not only enhances the economic viability of green hydrogen but also presents a pathway to produce synthetic transportation fuels when combined with carbon sources, thereby expanding its applicability in the aviation sector (Hansen et al., 2024).

Although various methods (Steam methane reforming, coal gasification, water electrolysis etc.) exist for hydrogen production, the techno-economic analysis of an integrated system combining high-temperature steam electrolysis powered directly by an air carbon capture system and supplied with heat/electricity by a SMR has not yet been adequately investigated. Given that most global hydrogen production still relies on fossil fuels, comprehensive technical and economic assessments are needed to determine the feasibility and optimal design parameters of integrated systems. The continued reliance on existing polluting production processes necessitates the development of innovative, large-scale production methods that align with net-zero emission targets. In conclusion, exploring the synergistic advantages provided by SMRs for both carbon capture and hydrogen production presents a compelling opportunity to substantially reduce production costs and enhance energy efficiency in the clean fuel sector (Slavin et al., 2024)

SMRs are planning to diversify their output to encompass other applications beyond electricity generation due to competition. Consequently, nuclear-hydrogen cogeneration is emerging as an increasingly compelling option for clean hydrogen production (Garrouste, 2024; Slavin et al., 2024). This integration presents significant advantages, as high-temperature steam electrolysis can capitalize on thermal energy generated by reactors in conjunction with electrical power to generate hydrogen with enhanced efficiency and reduced electricity consumption in comparison to other sustainable processes (Remer et al., 2023).

The operational flexibility of steam electrolysis units, particularly their ability to be rapidly turned on and off, enables SMRs to function as adaptable generators, adjusting to fluctuating energy requirements and pricing signals (Garrouste, 2024). This operational model enables nuclear facilities to transition their production from electricity to hydrogen production when renewable energy sources effectively meet grid demand, thereby augmenting the overall system's profitability and stability (Westover et al., 2023). This flexibility enables nuclear power plants to remain economically viable by producing storable and usable clean energy carriers, such as hydrogen, during periods of low electricity demand. This is particularly advantageous in a grid where the share of intermittent renewable energy sources is steadily increasing (Cadogan, 2023).

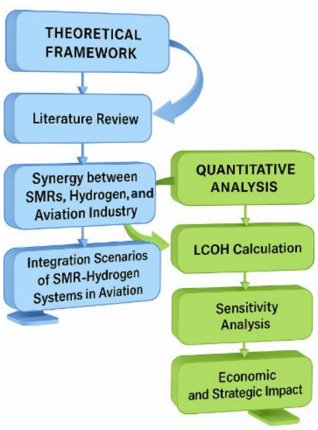
Finally, initial SMR installations at high capital costs, with supports designed for hydrogen production, can reduce industrial carbon emissions by 8% to 14%. It is possible that this rate will increase further as capital costs decrease due to learning effects. (Garrouste, 2024). Only with such significant support ambitious targets of $1 per kilogram will become a reality. These mechanisms could create a competitive market for SMR-sourced hydrogen, allowing its widespread use in various sectors, including aviation.

METHODOLOGY

This multidisciplinary study examines the economic and strategic role of SMR-powered green hydrogen production in the decarbonization of the aviation industry. The study begins by establishing a theoretical framework based on an analysis of existing literature onSMRs, Hydrogen, and Synergy in the Aviation Industry. Subsequently, detailed examinations of potential technologies for SMR and Hydrogen Production, as well as scenarios for the integration of SMR-Hydrogen Systems in the aerospace sector, are conducted. This comprehensive theoretical foundation serves as a solid foundation for the quantitative analyses to be performed in the subsequent stages of the study.

During the quantitative analysis phase, the LCOH calculation, a fundamental cost indicator, will be performed to ascertain the economic viability of SMR-supported and water electrolysis-based hydrogen production. This calculation will be conducted by considering the diverse operational and capital costs associated with various types of SMR. Subsequently, a comprehensive sensitivity analysis will be conducted to evaluate the impact of critical variables on LCOH. Finally, based on the LCOH values and production scenarios derived, the economic integration of this green hydrogen into the aviation industry will be analyzed. Specifically, its potential to contribute to the achievement of decarbonization targets and its competitiveness with existing jet fuel or other sustainable aviation fuels will be assessed.

Figure 1
Steps involved in the proposed methodology

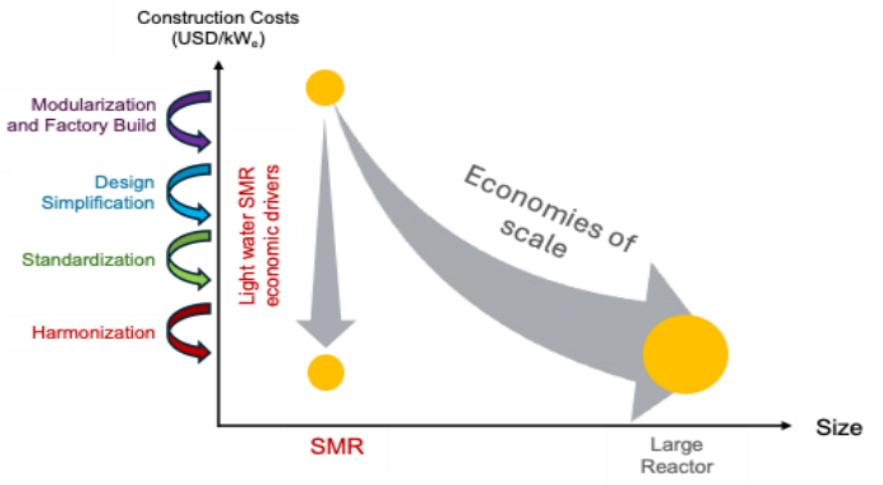


The Synergy of Small Modular Reactors, Hydrogen, and the Aerospace Industry

Technical and Economic Evaluation of Small Modular Reactors

SMRs are a relatively smaller class of nuclear reactors compared to large-scale reactors, characterized by their lower installed power output. SMRs are designed with modularity in mind, enabling factory fabrication, portability, and on-site assembly. These features promise cost reductions and expedited construction times. The electrical capacity of SMRs ranges from ten to several hundred megawatts (MWe), significantly smaller than conventional reactors that typically support capacities exceeding 1,000 MWe. This approach presents financing advantages due to passive safety systems, operational flexibility with load tracking capabilities, and reduced capital expenditures during construction phases (Chalkiadakis et al., 2023). The effects of modularity, standardization, simplification and harmonization, which are the economies of scale elements of investment costs, are presented in Figure 2.

Figure 2
Economies of Scale Impact for SMRs (Butcher et al., 2021; OECD NEA, 2011)



In addition to the structural and economic advantages, SMRs are involved in the global decarbonization of energy supply. They enable their deployment not only in grid-connected environments but also in remote areas or islands where conventional power generation faces challenges. Furthermore, SMRs can furnish process heat or electricity to sectors that are difficult to electrify, such as industry and transportation, where electrification is either challenging or insufficient. Their compact size facilitates their integration with other energy systems, including renewable energy sources, resulting in a hybrid and diversified energy landscape that better accommodates future energy demands (Soloviev et al., 2022).

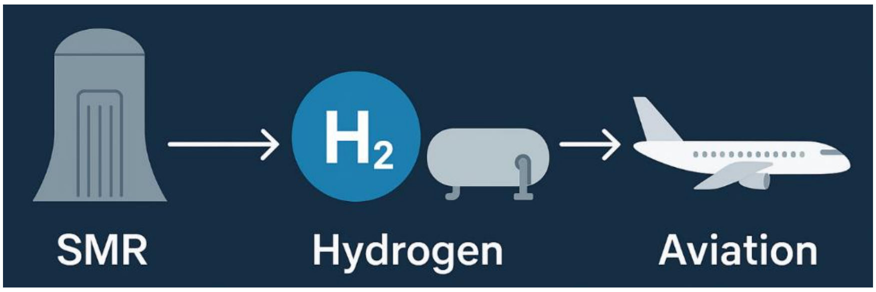
From a technological standpoint, SMR development is helpful for diversifying the energy mix and mitigating greenhouse gas emissions. This endeavor necessitates extensive international collaboration and the establishment of experimental facilities to assess cogeneration applications, particularly those involving heat and hydrogen production for industrial sectors. These platforms complement other nuclear technologies, such as fast reactors and fusion systems, indicating a multifaceted approach to address the long-term global energy requirements sustainably (Steigerwald et al., 2023).

Small Modular Reactors and Hydrogen Production: A Comprehensive Overview

The integration of SMRs with hydrogen production facilities is used for optimizing hydrogen production efficiency. This synergy positions SMRs as instrumental enabling technology for large-scale hydrogen production. SMRs maximize asset utilization by providing a consistent baseload energy supply that can be flexibly allocated between electricity generation and hydrogen production (Chalkiadakis et al., 2023).

Hydrogen clusters are also envisioned, where SMRs are co-located with hydrogen production and consumption regions, including transportation hubs such as industrial plants, airports, and port terminals. This integrated approach not only enhances the economic viability of hydrogen but also promotes the development of the hydrogen value chain, which is of interest for the aviation industry. By reliably delivering hydrogen at scale, SMRs can meet the anticipated surge in demand stemming from the aviation industry's transition to hydrogen-powered aircraft (Walden et al., 2023). Figure 3 depicts the image prepared for SMR, hydrogen production, and aviation applications.

Figure 3
The Relationship between SMR, Hydrogen and Aviation



Additionally, integrated energy systems are being considered, combining SMRs with renewable energy sources and hydrogen production units. These systems aim to harness the complementarity of renewable energy sources with the output of nuclear reactors, optimize hydrogen yields, and provide electricity to the grid or directly to end-use sectors. This integration enhances system resilience and reliability, critical factors for supporting aviation's energy needs and the overall sustainable energy transition (Jacob & Zhang, 2023).

The Importance of Hydrogen in the Decarbonization of the Aviation Industry

Hydrogen is one element in the pursuit of decarbonizing the aviation sector, which is heavily dependent on fossil-based jet fuels and significantly contributes to carbon dioxide emissions. If current trends persist, a substantial surge in aviation emissions is anticipated, underscoring the urgency of transitioning to sustainable energy carriers. While pure kerosene (Jet A-1) is typically employed in gas turbine engines, Jet B type fuel, a mixture of 30% to 70% kerosene and diesel, can also be utilized in certain instances. Conversely, piston engines require fuel with reduced flammability, known as AVGAS, preferred (Yusuf & Mesut, 2025).

Hydrogen, generated through low-carbon processes, presents a promising and environmentally friendly alternative. It can serve as a fuel for aircraft propulsion systems or be utilized in modified jet engines, thereby leading to substantial reductions in greenhouse gas emissions when compared to conventional fuels (Yakovlieva et al., 2024). The environmental advantages of hydrogen in the aviation sector extend beyond the reduction of carbon dioxide emissions. Hydrogen combustion predominantly releases water vapor, which could potentially mitigate the formation of nitrogen oxides (NOx) in comparison to fossil fuels. Nevertheless, challenges persist in the lifecycle emissions associated with fuel storage, infrastructure development, and hydrogen production (Wilson & Lukose, 2025). The current aviation fuel challenges include the extended lifespan of existing fleets and the substantial engine or system modifications necessary for new fuels. This presents hydrogen as a particularly appealing option in the context of future aircraft designs, where propulsion systems could be tailored for hydrogen utilization (Abubakr et al., 2024).

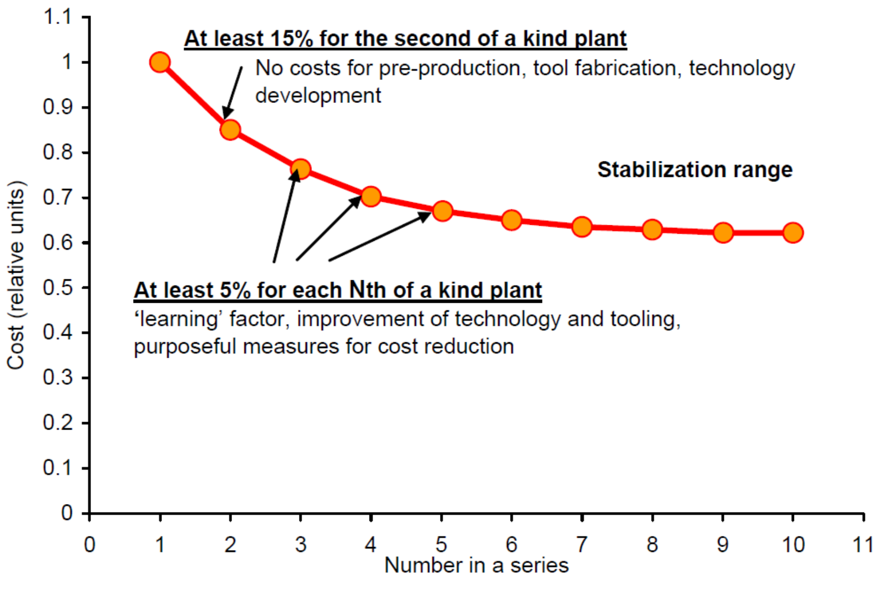
Integration of SMR-Hydrogen Systems in Aviation Infrastructure

LCOH using SMRs

The LCOH serves as a metric for comparative analysis of diverse production methodologies. Studies assessing SMR-driven hydrogen production underscore that costs are significantly influenced by reactor capital expenditure (CAPEX), plant scale, operational efficiency, and the seamless integration of hydrogen storage and transportation infrastructure. LCOH estimates for hydrogen production via SMR exhibit fluctuations based on reactor design, hydrogen storage techniques (compressed gas or liquefaction), and transportation modes (Kim et al., 2022). Various costs will be incurred depending on the SMR technologies employed (Elkhalafy et al., 2024).

Although LCOH offers competitiveness for SMR-produced hydrogen, market factors such as fossil fuel prices and carbon taxes significantly impact its economic viability. For instance, in marine applications, the production cost of hydrogen from SMRs surpasses that of diesel fuel, necessitating substantial carbon pricing to attain viability. While achieving economies of scale through mass production can substantially reduce costs, it necessitates substantial expansion and investment. (Pompodakis & Papadimitriou, 2025). In this context, Figure 4 presents the graph illustrating the mass production and cost implications associated with SMR installation.

Figure 4
Reducing Equipment Manufacturing and Installation Costs in Large-Scale Nuclear Power Plant Production (Agency, 2013)



Hydrogen Demand Forecasts for Aviation

Hydrogen demand for aviation is an emerging field. However, as hydrogen-powered aircraft technologies and certification standards advance, growth is projected to reach 2050. While various scenarios are anticipated, it is believed that hydrogen demand from aviation could represent a substantial portion of total hydrogen consumption. Given the dependable and consistent hydrogen supply capabilities of SMRs, there is a consensus that they can assume a pivotal role in fulfilling demand (Yakovlieva et al., 2024).

To meet the growing demand for hydrogen, airport infrastructure must undergo transformative changes. Comprehensive assessments reveal that hydrogen supply within airports and aviation clusters encompasses not only production but also logistics and utility systems. These systems must be seamlessly integrated with existing fuel handling systems to ensure safe and efficient operation. (Šilhan et al., 2025).

Storage, Distribution, and Refueling Infrastructure

Hydrogen storage technology holds paramount importance for aerospace applications, considering the unique fuel density and energy demands of aircraft. The primary challenges associated with hydrogen storage include maintaining low-temperature liquid hydrogen storage, utilizing high-pressure compressed gas tanks, and employing advanced solid-state storage methods. Furthermore, complementary advancements in storage technology are essential for the successful production of hydrogen using SMRs (Boyko et al., 2022).

Transportation and refueling stations must be meticulously designed to accommodate the distinctive characteristics of hydrogen, thereby guaranteeing safety and optimizing operational procedures. Advancements in hydrogen fueling infrastructure are underway, encompassing the establishment of high-capacity refueling stations at airports. However, their integration with hydrogen production systems, particularly those powered by SMRs, necessitates careful consideration. The aviation sector imposes stringent requirements on fuel purity, accessibility, and the resilience of storage systems, thereby complicating the supply chain (Boichenko et al., 2025). The unit costs for literature are provided in Table 1.

Table 1
Hydrogen Cost Elements for Storage, Distribution, and Refueling Infrastructure

Component	Type / Unit	Typical Cost Range (USD)	Source
Electrolysis (for comparison)	Production cost, \$/kg H_2	3 – 7	(IEA, 2024)
Liquid hydrogen (LH_2) liquefaction	Energy + OPEX, \$/kg H_2	1.5 – 4	(IEA, 2024; NREL, 2025)
LH_2 storage (large cryogenic tanks)	CAPEX, \$/m³ or \$/kg H_2 capacity	0.5 – 3 (annualized \$/kg H_2)	(Nivedhitha et al., 2024)
High-pressure gas tanks (350/700 bar)	CAPEX, \$/kg H_2 capacity	400 – 700	(Shin & Ha, 2023)
Metal hydride / solid-state storage	CAPEX, \$/kg H_2 capacity	Several hundred – thousands	(Nivedhitha et al., 2024)
Transport — tube trailer (compressed gas)	Cost per trailer / \$/kg delivered	Trailer CAPEX: 200k – 500k; delivery cost varies	(NREL, 2025)
Transport — LH_2 cryogenic tanker	Cost per tanker / \$/kg delivered	CAPEX: ~1–3 million; delivery cost distance-dependent	(IEA, 2024; NREL, 2025)
Airport refueling (LH_2 hydrant / dispenser)	Investment, \$/station or \$/kg dispensed	Million-dollar scale (dispenser share 3–5%)	(Hoelzen et al., 2023)
Onsite compression & purification	Delivery + dispensing cost, \$/kg H_2	2 – 5	(NREL, 2025)
Onsite SMR integration (modular reformer)	CAPEX	Small-scale units: several million	(European Commission, 2024)
Delivered hydrogen (at dispenser)	\$/kg H_2	2 – 6 (SMR); +1–2 (LH_2 logistics)	(IEA, 2024)

Hybrid Energy Systems for Airports and Aviation Clusters

Hybrid energy system planning for airports frequently integrates SMR with renewable energy sources to attain carbon neutrality and operational efficiency objectives. These integrated energy clusters employ advanced smart grid technologies and sector coupling strategies to harmonize electricity and hydrogen supply and demand. Control architectures facilitate the dynamic distribution of generated energy between grid export, aircraft refueling, and airport internal operations, thereby optimizing the overall system's performance (Choi & Hong, 2025).

Real-time operational frameworks that incorporate day-night strategies prioritize electricity generation during periods of high demand and maximize hydrogen production during periods of lower electricity demand. This approach guarantees economic efficiency while ensuring reliable supply of aviation fuel. The presence of high-fidelity simulation environments facilitates the testing and validation of these integrated systems, thereby enhancing the readiness of SMR-hydrogen clusters for practical deployment (Jacob & Zhang, 2023). Furthermore, hybrid systems of this nature can stabilize energy supply at airports, decrease greenhouse gas emissions associated with airport operations, and bolster the resilience of aviation energy systems to fluctuations in renewable generation (Gad-Briggs et al., 2022).

RESULTS AND DISCUSSION

As detailed in the method section, hydrogen fuel presents a viable solution to the aviation industry's carbon-neutral fuel requirement. To achieve this, there is a growing interest in nuclear energy, which exhibits minimal greenhouse gas emissions throughout its lifecycle. Consequently, SMR are being considered. In this context, LCOH calculations and sensitivity analysis, which can be derived from the utilization of SMRs, have been elucidated, leading to the identification of potential solutions.

In the initial phase, a study will be conducted to assess the techno-economic viability of SMRs. The cost analysis for ACP100, NuScale (VOYGR-4), BWRX-300, and I-SMR designs is presented in Table 2, encompassing a comprehensive range of technical and economic parameters and assumptions. To illustrate competitiveness, the costs associated with radioactive waste management, decommissioning, and the entire fuel cycle have been excluded from the analysis, with only the fuel cost being included. It is recommended to review the publications conducted in this field if their inclusion is deemed necessary for a different study (Kilic, Yigit, Sobahi, et al., 2025; Kılıç & Variyenli, 2023). Additionally, operating costs have been incorporated based on the nth example of its kind principle, enabling comparisons within the same scale as large-scale reactors.

Table 2

LCOE for SMRs (Kilic, Yigit, & Sreenivasulu, 2025; Kılıç et al., 2025; OECD NEA, 2025)

	NuScale (VOYGR-4)	BWRX-300	I-SMR	ACP100
Overnight Cost ($/kWe)	6596	6596	7395	8194
Interest During Construction Cost ($/kWe)	923	923	1035	1147
Thermodynamic Efficiency (%)	30.8	34.5	32.7	26
Plant Thermal Power (MWth)	1000	870	520	385
Total Capital Cost (B$)	2315	2254	1433	0934
Levelized Capital Cost ($/MWh)	76.71	92.75	86.71	97.24
Levelized O&M Cost ($/MWh) (Scaling factor 0.72)	15.23	15.23	23.32	29.75
Fuel Cost ($/MWh)	9.33	9.33	9.33	9.33
Levelized Cost of Electricity ($/MWh)	101.27	117.31	119.36	136.32
Levelized Cost of Electricity($/MWh) (n of a kind)	70.88	82.11	83.55	95.42

The inputs and formulas employed in the calculation of LCOH are provided in Table 3. Utilizing these data, LCOH was determined for the reference scenario, and a sensitivity analysis was conducted to assess the impact of parameter variations on LCOH.

Table 3

LCOH Reference Scenario: Inputs and Formulas

Parameter	Symbol / Unit	Formula	Description
Project life time	n (years)	Input = 25	Project economic lifetime
Discount rate	r	Input = 0.08	Annual discount rate
Electrolyzer CAPEX	$CAPEX_{(unit)}$ ($/kW)	Input = 1000	Capital cost per kW of electrolyzer
Electrolyzer capacity	P_{el} (kW)	Input = 100,000	Installed electrolyzer capacity
Electrolyzer efficiency	η	Input = 0.70	Conversion efficiency (electricity → hydrogen)
H_2 Lower Heating Value	LHV (kWh/kg)	Input = 50	Energy content of hydrogen
Annual availability	A	Input = 0.9	Fraction of annual uptime
Annual operating hours	$h_{(year)}$	8760 × A	Effective yearly operation time
Annual H_2 production	$H_{2(annual)}$ (kg)	$(P_{el} \times \eta \times h_{(year)}) / LHV$	Annual hydrogen output
Total CAPEX	$CAPEX_{(total)}$ ($)	$CAPEX_{(unit)} \times P_{el}$	Total investment cost
Annual OPEX	$OPEX_{(annual)}$ ($)	$0.03 \times CAPEX_{(total)}$	Operating cost (3% of CAPEX, assumed)
Electricity cost	C_{el} ($/kWh)	Input = Table 3 (LCOE data)	Price of consumed electricity
Annual electricity consumption	$E_{(annual)}$ (kWh)	$(H_{2(annual)} \times LHV) / \eta$	Total yearly power use
Annual electricity cost	$Cost_{el}$ ($)	$E_{(annual)} \times C_{el}$	Yearly electricity expenditure
Capital Recovery Factor	CRF	$r \times (1 + r)^n / ((1 + r)^n - 1)$	Converts total CAPEX to annualized CAPEX
Annualized CAPEX	$CAPEX_{(annual)}$ ($/year)	$CAPEX_{(total)} \times CRF$	Annualized investment cost
Total annual cost	$C_{(annual)}$ ($/year)	$CAPEX_{(annual)} + OPEX_{(annual)} + Cost_{el}$	Combined annual costs
Transport & storage cost	$C_{(TS)}$ ($/kg)	Input = 1	Hydrogen logistics cost
LCOH	LCOH ($/kg)	$(C_{(annual)} / H_{2(annual)}) + C_{(TS)}$	Levelized cost of hydrogen

The results of sensitivity analysis specific to ACP100, NuScale (VOYGR-4), BWRX-300, and i-SMR designs are presented in Figure 5, demonstrating the parameter change effects of ±10%. According to the analysis, the project duration exhibits the least significant impact, with a reduction rate below 1%. Conversely, the H_2 LHV parameter exhibits the most pronounced effect, influencing the unit price by approximately 8-9%. Notably, no substantial technology-specific differences were observed in the sensitivity analysis results.

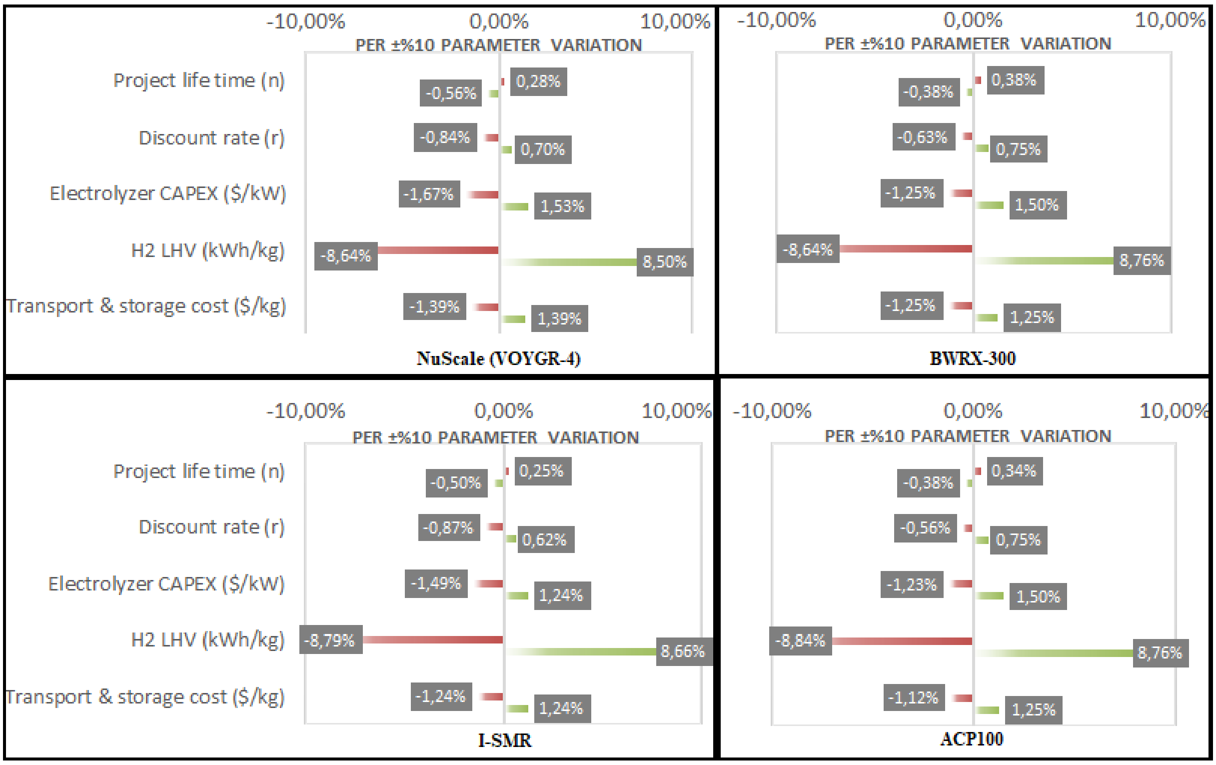
Table 4

Aviation Fuel Price Table and LCOH

Fuel Type	$/gal	MJ/gal	$/MJ	References
Jet A-1	2.42	130.3	**0.0186**	(BTS, 2025)
AVGAS	6.26	120.0	**0.0522**	(Globalair, 2025)
LCOH	**2.23- 6.26 $/kg**	120.0 MJ/kg × density relation		

Figure 5

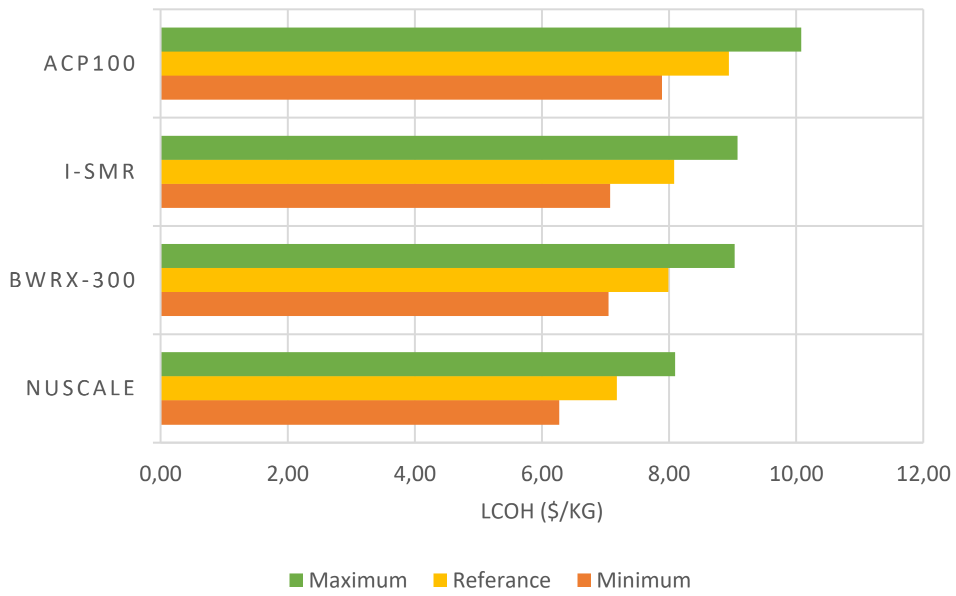
Sensitivity Analysis Results According to SMR Technologies



Subsequently, the maximum and minimum LCOH values, which are complementary to the reference values derived, were derived from the sensitivity analysis results and presented in Figure 5. It is evident that the LCOH value does not fall below \$6/kg even when all parameters are at their lowest levels. Furthermore, it has been concluded that the LCOH value may potentially increase up to \$10/kg due to the impact of the rise in electricity prices and the +10% adjustment in parameters.

Figure 6

Graph depicting Minimum, Reference, and Maximum LCOH values



Finally, unit costs per megajoule (MJ) were determined using the jet fuel prices provided in Table 4. Subsequently, the LCOH range was calculated based on the $/MJ values and its comparison with jet fuel was conducted. Based on this assessment, it was determined that, considering factors such as hydrogen engine efficiency, storage weight and volume, cooling and tank losses, the LCOH value should decrease to $2-4/kg for competitiveness. To achieve this, it was recommended that the LCOE value be reduced first.

CONCLUSION AND RECOMMENDATIONS

With the world's population growing and industries expanding, strategies need to be developed to manage energy resources efficiently and safeguard the environment. This is especially important for countries that rely on fossil fuels. In alignment with the objectives of mitigating carbon emissions within the aviation sector, hydrogen emerges as a prominent alternative, characterized by its high energy density and the absence of any emission potential. SMR possess the potential to reduce hydrogen production costs by augmenting energy efficiency through the cogeneration feature they offer. This integrated system approach stands out as an innovative solution that mitigates dependence on conventional fossil fuel-based hydrogen production while bolstering the economic viability of green hydrogen and supporting the transition to clean fuels within the aviation industry.

In this study, the economic impact of SMR-supported green hydrogen production on the decarbonization of the aviation sector is comprehensively analyzed. Initially, the integration potential of these systems within SMRs, hydrogen production technologies, and the aviation sector was theoretically examined through a literature review. Subsequently, the LCOH was calculated, considering the operational and capital costs associated with various SMR types. Furthermore, sensitivity analysis was conducted to assess the value of this metric. Finally, the economic feasibility of integrating green hydrogen into the aviation sector, its competitiveness with conventional jet fuels, and its contribution to the sector's decarbonization objectives was evaluated based on the LCOH results obtained.

As a result of the sensitivity analysis conducted specifically for ACP100, NuScale (VOYGR-4), BWRX-300, and i-SMR designs, the impact of the project's lifespan and reduction rate on LCOH remains below 1%. The most influential parameter was identified as H_2 LHV, exhibiting an effect of approximately 8-9%. Notably, no significant technology-specific disparities were observed. Although it was observed that the LCOH value did not fall below $6/kg even when all parameters were at their lowest levels, it was concluded that the LCOH value could potentially reach $10/kg with a ±10% change in parameters. For competitiveness with jet fuel, it was determined that the LCOH value should decrease to 4 $/kg. It was concluded that the LCOE value should attain the level of $42/MWh for the scenario where all parameters are assumed to be reduced by -10%, while the reference scenario yields $33/MWh.

The following suggestions for future studies are:

- Utilize technical and economic data with realistic assumptions.
- Do not overlook uncertainties in costs.
- Conduct an accurate evaluation of the effects of variable parameters.
- If there is widespread acceptance of carbon taxes, they should be incorporated into the calculations.

It is beneficial to consider these issues in depth.

Ethical Statement

The author of this article declares that the materials and methods used in his study do not require ethics committee permission and/or legal-special permission.

Author Contributions
Data Collection (CRediT 2) Author 1 (70%) – Author 2 (30%)
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The authors have no conflicts of interest to disclose for this study.

Sustainable Development Goals (SDG)

Sustainable Development Goals: 7 Accessible and Clean Energy, 12 Responsible Production and Consumption

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