MAPPING THE HYDROGEN ECONOMY IN GHANA: THE STRATEGIC CONTRIBUTION OF SMALL MODULAR REACTORS

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Abstract

The conversation about economic development in Ghana is co-evolving with sustainability, technological innovation, and energy security through Nuclear Power.

To maximise Nuclear Power in Ghana, the economic opportunities that lie ahead require a new and deep strategic focus, especially with the emergence of new SMR technologies. Cogeneration allows SMR technology to be deployed to produce hydrogen, water, salt, and heating beyond electricity. In the short to medium term, electricity demand appears to be the key concern in Ghana as driven by population increase and economic growth scenarios. In the longer term, however, the spotlight could shift to the potential of hydrogen as an alternative source of energy.

What are the prospects of nuclear hydrogen in Ghana? What factors may drive these scenarios? What could be the potential contribution to the Ghanaian economy? What recommendations can structure or formalise the future hydrogen economy in Ghana?

The paper attempts an analysis of a hydrogen economy in Ghanaian context. It uses a systems approach to synthesise critical elements that require consideration as Ghana transitions into a hydrogen economy, especially with the emergence of Small Modular Reactors. The analysis further presents a 'phased framework' which could inform policy from several perspectives: technical, social, regulatory, and economic Key insights are also drawn from country policy experiences as well as benchmarks for building hydrogen infrastructure.

1.0 INTRODUCTION

The current global energy landscape is fast evolving. Central to this evolution is the drive towards a net-zero global economy. Efforts to decarbonize energy systems and create resilient economies therefore continue to drive policy choices in many countries. Gradually, the interest in hydrogen as an alternative source of energy is coevolving with the drive to decarbonize energy systems.

At the global level, the deployment of hydrogen sources will play a vital role in achieving net-zero emissions within the next three decades [1]. As demand for hydrogen rises, developing a hydrogen economy is becoming a topical issue globally. Many countries such as the United States of America, Canada, Japan and Germany have introduced hydrogen fuels and demonstrated a commitment towards shaping a sustainable future built on a hydrogen economy [2] [27].

In the advent of hydrogen as an important energy source, a critical understanding of the it's nature and the potential role it can play towards a sustainable and energy secure future cannot be overemphasized. The evolving hydrogen economy requires strategic planning, structuring and mapping to properly leverage its contribution towards a net-zero future.

In Ghana, a very nascent hydrogen economy exists. Further, as a developing country, Ghana is currently pursuing an ambitious Nuclear Power Programme that has the potential to drive economic growth and industrialisaton, scientific and technical innovation and ultimately transform the structure of its economy. A nuclear energy project holds the promise optimizing Ghana's energy system and opening new economic pathways for the future. In addition to, the emphatic drive to increase electricity supply through nuclear electricity, the opportunities that lie in cogeneration through nuclear technology require a strategic and deep focus. This becomes important to ensure that Ghana reaps multiple economic benefits through the deployment of nuclear technology. A long term and visionary economic focus ultimately means that Ghana begins to map its hydrogen economy to evolve with innovation in the global economy and the nuclear space.

This initiative is most timeous given the emergence of Small Modular Reactor (SMR) technology which could offer relatively economically feasible nuclear options for developing and newcomer countries. The potential cogeneration capabilities of Small Modular Reactor (hereinafter referred to as SMR) technology must be tied with the conversation to structure and formalize a hydrogen economy in Ghana.

2.0 SCOPE AND JUSTIFICATION OF PAPER

The paper highlights the emergence of hydrogen as an energy alternative. And also emphasizes the strategic contributions of SMR technology (through cogeneration systems). Given the global context, an attempt is made to map the essential elements that require focus, analysis and development to map a hydrogen economy in Ghana. This effort is predicated on first appreciating the prospects of hydrogen in Ghana, the potential economic contribution to the Ghanaian economy and the role of Small Modular Reactor deployment.

This paper seeks to put the spotlight on Nuclear based hydrogen production as Ghana's Nuclear Power Programme evolves. Again, it attempts to set a foundation for discussions and accelerating the policy conversations that underpin a hydrogen economy for the future, and especially put in context the issues to be addressed by newcomer countries.

A system analysis approach is adopted through extensive literature review to identify the elements that require consideration and focus. Further, a phased framework is used to present how newcomer countries can transition in mapping a hydrogen economy for the future. Finally key insights are drawn from some cases on hydrogen policy planning as well as implications and benchmarks for building hydrogen infrastructure.

2.0 SMALL MODULAR REACTOR DEPLOYMENT IN GHANA

2.1 Ghana's nuclear power program

A lower middle-income country, Ghana declared its intention to pursue a Nuclear Power Programme for peaceful purposes in 2012. Several drivers have influenced this policy direction. These include Ghana's long term economic vision to be ranked among upper-middle income or high middle, limited hydro and gas resources and the drive to diversify energy sources moving into the future [14][15][16] Following a successful transitioning from phase 1 (of the International Atomic Energy Agency's milestones approach of the programme), the president of Ghana, His Excellency Nana Addo Dankwah Akuffo-Addo announced the approval of nuclear technology into Ghana's Energy mix [17].

In line with phase 2 requirements of the programme, key activities such as Site Selection, vendor and technology selection and contracting are required to move Ghana's Nuclear Power Programme forward. In terms of choice of technology, Small Modular Reactors, although relatively less mature could present an opportunity for strategic deployment of nuclear energy in Ghana. Factors such as relatively small grid size and potential for strategic siting and deployment given Ghana's geographical diversity favour SMR deployment in Ghana [12] [18][19].

2.2 Cogeneration opportunities (going beyond electricity)

Cogeneration products such hydrogen show prospects in Ghana as the trend toward energy diversification intensifies. Hydrogen presents a clean fuel alternative to reduce vehicle emissions and improve quality of air. [13]. In the foreseeable future, demand for hydrogen could increase from sectors such as transportation and manufacturing.[7][21][22][23][24].

An assessment of Ghana's potential for green hydrogen production based on wind and solar energy has been conducted. [20]. The commercial potential for green hydrogen production in Ghana is therefore not in doubt [20][35][36][37].

Further, in this evolving energy outlook, the strategic contribution of nuclear hydrogen through Small Modular Reactors cannot be underestimated. SMRs offer a direct way of producing clean hydrogen with the added benefit of being placed where need exists [31]. For large-scale hydrogen production, with no greenhouse emissions, nuclear energy is particularly seen as well suited. With the advent of Small Modular Reactors and its potential advantages such as lower capital costs and fleet economies, newcomer countries, particularly those in developing economies could embrace SMRs and its cogeneration capabilities benefiting from its strategic contribution to their energy systems including the production of carbon-free hydrogen in the future. [27].

3.0 HYDROGEN IN PERSPECTIVE

Hydrogen is the lightest, most basic, and most plentiful of all chemical elements in the universe. However, it occurs only in combination with other elements, primarily with oxygen in water and with carbon, nitrogen and oxygen in living materials and fossil fuels. Although it is not a primary source of energy, it becomes an attractive energy carrier when split from these other elements by using a source of energy [9] [24]. Further, a characteristic worth noting, is that as a carrier, it is not just a clean source of energy but its method of production is clean [2].

Several methods of hydrogen production are under different stages of demonstration. These range from conventional technologies that process fossil fuels and includes the methods of hydrocarbon reforming and pyrolysis with chemical techniques such as steam reforming, partial oxidation and autothermal steam reforming, to methods of production from renewable methods (either from water or biomass) with thermochemical methods such as pyrolysis, gasification, combustion and liquefaction, and major biological processes such as direct and indirect bio-photolysis, dark fermentation, photo-fermentation and sequential dark and photo-fermentation. A second category of renewable technologies regards the methods, which can produce hydrogen through water-splitting processes such as electrolysis, thermolysis and photo-electrolysis, utilizing water as the only material input [38].

It has been technically demonstrated that hydrogen can be used for transportation, heating, and power generation, and it could replace current fuels in all their present uses [4][7]. The hydrogen fuel cell has been heralded as the most promising energy conversion device especially in transportation [2].

The economic infrastructure based on hydrogen energy carrier is called the hydrogen economy, which is composed of three functional steps, production, storage, and transportation, and use in all aspects of the economy. [27]

The figure below shows the essential features of hydrogen economy. [27]

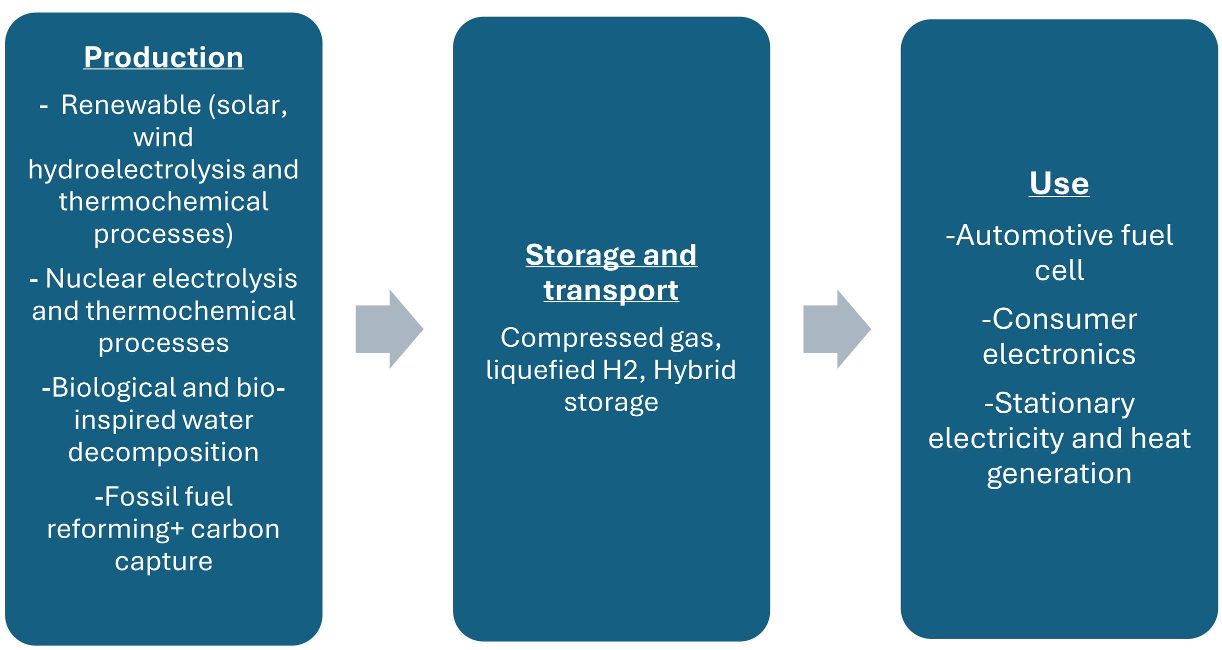

FIG.1. Key features of a hydrogen economy , (Adapted from Ref[27])

The widespread interest in hydrogen rests not only in its long-term social benefits, but also its potential for innovation. Several auto companies have embraced fuel cells as a superior zero-emission technology and are racing to develop the fuel-cell car [6]. Hydrogen is one of the clean fuel options for reducing motor vehicle emissions. Recently, there is already a large hydrogen production worldwide: 50 million tonnes per year. Although current use of hydrogen in energy systems is limited, its future use could increase exponentially, should fuel-cell vehicles be deployed on a large commercial scale [6][8].

4.0 MAPPING THE HYDROGEN ECONOMY IN GHANA

4.1 Demand for hydrogen in Ghana

One potential application of hydrogen in Ghana is its use as a fuel for transportation, particularly in the context of decarbonizing the transport sector. Additionally, hydrogen can be utilized in fuel cell-based power generation systems to provide clean and reliable electricity for off-grid and remote communities [23][29].

Furthermore, hydrogen has potential applications in industrial processes, including steel and cement production, where it can serve as a low-carbon alternative to traditional fossil fuels. By integrating cogeneration systems with hydrogen production facilities, Ghana can maximize energy efficiency and reduce greenhouse gas emissions in key industrial sectors through nuclear technology[24].

4.2 Benefits of hydrogen to the National economy

The economic impact of transitioning to a hydrogen energy system in Ghana can be huge. The Ghanaian economy stands to reap several direct, indirect and induced benefits through a multiplier and cross sectoral effects. These can be seen in the variety of jobs created in several sectors including scientists, technicians, engineers, financial analysts etc. with associated labour incomes and overall contribution the growth of Gross Domestic Product.

4.3 Systems analysis to a future hydrogen economy

In mapping the future hydrogen economy of Ghana, several elements that drive and have linkages to the overall hydrogen energy system can be identified. The elements mentioned are not exhaustive but have been found in literature as critical to structuring and formalising a hydrogen economy:

1, Innovations in transport sector: Adoption of fuel-cell cars [6]
2, Hydrogen Infrastructure: for storage, transportation and distribution [2][6][30]
3, Scientific innovation [2]
4, Cost competitiveness: Economics of hydrogen production [1][11][27]
5, Macroeconomic impacts: benefits to National economy [1]
6, Policy direction: Roadmap to National mainstreaming and complimentary policies not specific to hydrogen [2][6][10][31]
7, Fiscal incentivization: economic levers towards competitiveness including a low and flexible taxation system [2]
8, Market requirements: competitive pricing regime [3]
9, Sustainability and climate requirements- aligning political objectives and legislation of Hydrogen with sustainability and climate targets [3]
10, Technology development requirements- mass market for hydrogen backed by reduced cost of cars and fueling stations [3]
11, Macroeconomic environment -state of economy and long-term scenarios [10]
12, Research and Development programmes [10]
13, Social acceptance [1]
14, Financing and Economic feasibilities – cost mitigation mechanisms to drive investment and reduce risks [1][2][13][30]
15, Regulation and standards - Integrated regulatory frameworks [26][30]
16, Skills and Education [30]

The paper further categorises the issues into a three-part system framework. These are the technical, social and regulatory dimensions. In terms of perspective, the issues are categorized into these dimensions to guide policy discussions towards structuring and formalising a hydrogen economy.

This paper captures all issues directly related to the hydrogen technology and its production as the ***technical dimension***. *The* ***social dimension*** includes all behavioral, social and economic issues that has to be addressed to drive the hydrogen economy and finally, the ***regulatory dimension*** consists of all those issues that optimises the macro-environment (economic, regulatory, legal, political etc.) for the hydrogen economy to thrive.

In line with systems thinking, the interactions and interdependencies between these parts need to be emphasized. This suggests that although the issues have been wholly categorised in these dimensions, the issues often overlap in practice making room to view the issues as **socio-technical**, **techno-regulatory**, or **socio-regulatory**.

These overlaps are very important in appreciating the phased framework later presented in this paper. The figure below illustrates the blocks around which the phased framework revolves.

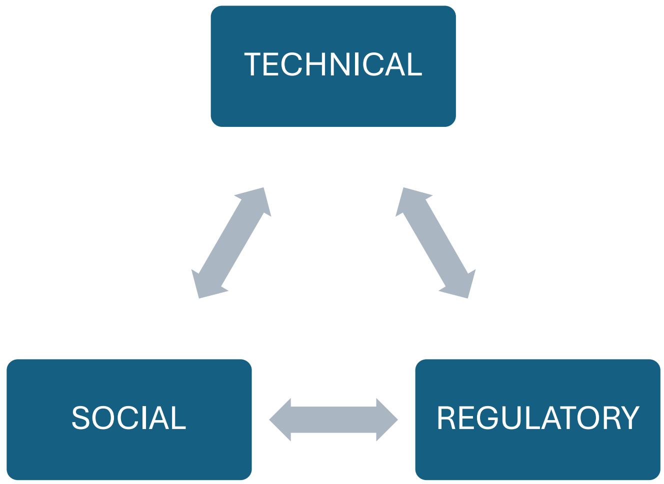

FIG. 2. Systems analysis towards a future hydrogen economy in Ghana

The table below shows the categorization of the key issues under this systems framework

TABLE 1.

Technical dimension	Social dimension	Regulatory dimension
• Innovations in transport sector • Hydrogen Infrastructure: storage ,transportation and distribution • Scientific innovation • Technology development requirements • Skills and Education • Research and Development programmes	• Macroeconomic impacts Assessments • Cost competitiveness • Market requirements • Social acceptance	• Policy direction • Fiscal incentivization • Sustainability and climate requirements • Macroeconomic environment • Financing and Economic feasibilities • Regulation and standards

In terms of overlaps, it could be seen, for example issues like innovations in transport, building infrastructure and skills and education (Human resource requirements which are categorises as technical issues have a link with regulatory dimensions such as policy direction and regulatory standards. This makes such issues techno-regulatory.

5.0 TRANSITION TO THE HYDROGEN ECONOMY (A PHASED FRAMEWORK)

A key question that remains is how to catalyze the transition to a hydrogen-based future sustainable energy system [2]. A phased framework is presented to guide this transition effort. This framework is pivoted on three major blocks which should guide the transition process. These perspectives would guide shaping a strong environment for the hydrogen economy to thrive. Given the key elements identified in literature, the three -phase framework is presented to structure the process for transitioning into the hydrogen economy with the advent of SMR technology. The phases take the view of the short/near term (Phase 1), medium term (Phase 2) and long-term (Phase 3) in terms of time horizons and are continuous in execution and optimisation as shown in the figure below.

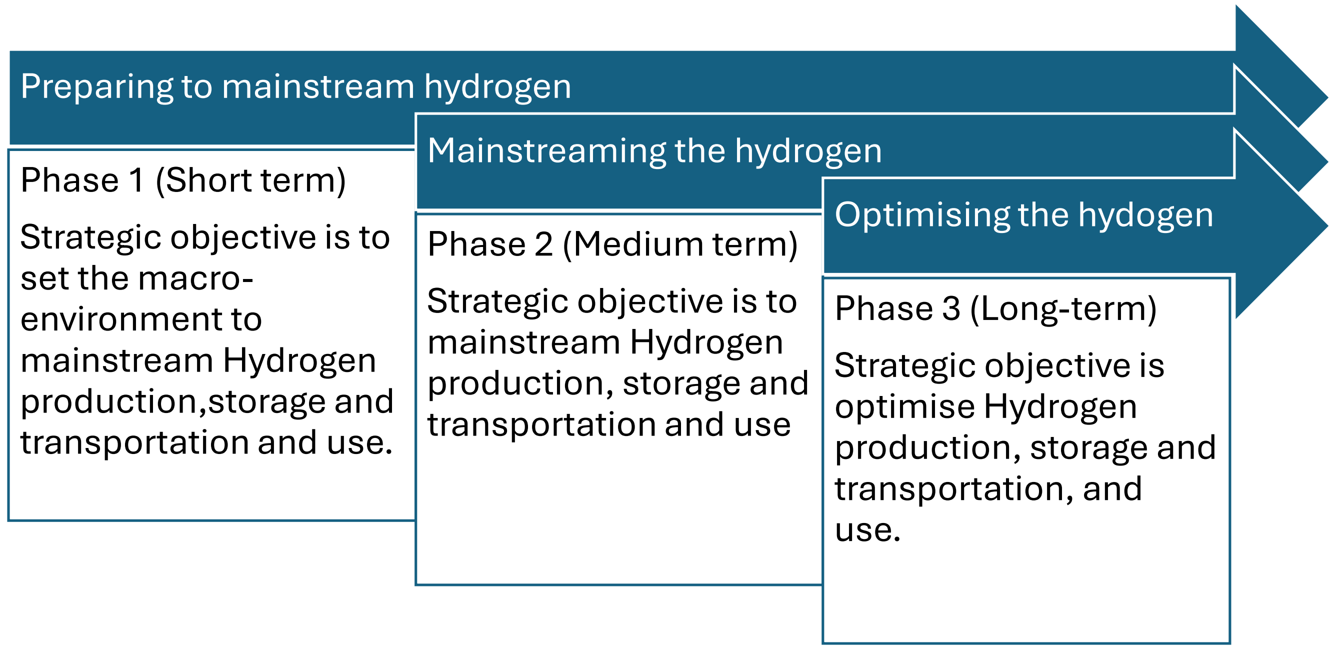

FIG. 3. Phased framework for transitioning into the Hydrogen Economy in Ghana

5.1 Phase 1

These include issues that need to be addressed in the preparatory phases of mainstream the adaptation of hydrogen systems in Ghana. It forms the foundation on which a hydrogen economy thrives, being the first steps to setting the macroenvironment to be conducive for the take-off of the hydrogen economy. This phase will require addressing the key issues such as:

-Policy direction
- Hydrogen Infrastructure
- Regulation and standards
- Sustainability and climate requirements
- Macroeconomic stability
-Skills and Education

5.2 Phase 2

This phase requires address critical issues that usher Ghana into mainstreaming hydrogen in its energy systems. The consist of elements that directly influce the operational phase of a hydrogen economy. Addressing them mitigates risks in the hydrogen economy and catalyses the transition The second phase of this transition will address key issues such as:

- Financing and Economic feasibilities
- Social acceptance
- Cost competitiveness
- Macroeconomic impacts
- Scientific innovation
- Innovations in Transport sector
- Research and Development programmes

5.3 Phase 3

The third phase optimizes the hydrogen economy. This is a phase where most likely, in the longer term, hydrogen has gained mainstream acceptance and use. It includes the key issues that optimizes both the economic and technological environment. The third phase of the transition will address issues including:

-Fiscal incentivization
-Market requirements
-Technology development requirements

6.0 A POLICY FOCUS FOR GHANA (BENCHMARKING EXPERIENCES)

By the beginning of 2021, over 30 countries globally had created hydrogen roadmaps or strategies at a national level.[10]. At continental level, policies and cooperation among various blocs have been identified as a vital tool to facilitate the deployment of hydrogen[30].

In Ghana, the National Energy Transition Plan envisions promoting the use of hydrogen to diversify the fuel mix in Ghana. A key scenario in this plan shows that by 2070 all road and rail mobilities should be electricity and hydrogen fuelled [29].

Although the Ministry of Energy envisions that hydrogen will play a key role in Ghana's energy sector especially through the transport sector by 2050, as at 2024, Ghana has not officially began production. Ghana's potential for producing hydrogen is seen as enormous. However, an omnibus hydrogen policy or initiative has not yet been structured at National level [20][28][29].

To structure a well-functioning hydrogen economy in Ghana, effective and timely hydrogen specific policies will be required. Further, there are other policies that may not be hydrogen-specific but are favourable to the development of a hydrogen economy [6] [31]. The experience of countries and regions can be benchmarked offering some unique policy approaches and initiatives to inform Ghana's policy planning with the right analysis and contextuallisation.

6.1 Canada

Canada's Hydrogen Strategy was developed in 2020 as a call to action intended to catalyse investment in the industry to reduce greenhouse gas emissions, seize economic opportunities, and create new jobs. While the strategy places an emphasis on renewable energy sources as feedstocks for hydrogen, nuclear pathways to producing hydrogen receive less attention. Key recommendations have been made. These include recommendations for:

-policies that support nuclear-based pathways while supporting non-nuclear supporting pathways
-policies that increase end-use demand for clean hydrogen while mitigating investment risks
-promote research and development and evidenced based policy [31]

With regards to nuclear, the federal government's 2018 SMR Roadmap connects partners from different industries across the country as they work to introduce SMRs into Canada's hydrogen future. Nuclear energy is seen as key to producing clean hydrogen; however, continued Research and Development is required for SMRs and their role in the hydrogen economy [31]

6.2 Brazil

Brazil is one of the most competitive places in the world to produce green hydrogen. Although Brazil has been developing hydrogen-related policies for over 20 years so far, only recently has the fuel been looked at from a more strategic standpoint. In 2002, the Ministry of Science and Technology launched the Brazilian hydrogen and fuel cell System Program. In 2005, this program was renamed, becoming the Science, Technology and Innovation program for the hydrogen economy. In the same year, the Ministry of Mines and Energy coordinated the "Roadmap to structure the hydrogen economy in Brazil", a study drafted with the Ministry of Science and Technology, focusing on valuing different technological routes in which the country could have competitive advantages, such as electrolysis and the use of ethanol and other biomass fuel. In 2021, the Brazilian national council for energy policy established hydrogen as a priority area for R and D resources and tasks the ministry of mines and energy, in collaboration with other entities, to prepare guidelines for a National Hydrogen Program. In 2022, the Brazil national program was formally established, and it constituted a committee to manage the program. Given the cross sectoral nature of the subject, the PNH2 management committee provided for the participation of various government entities, as well as created five thematic committees with the purpose of discussing and analysing, developing studies and writing technical reports on their respective topic on:

1, Scientific-technological strengthening
2, Human resources training
3, Energy planning
4, legal and regulatory framework
5, market opening, growth and competitiveness.
The thematic committees were requested to prepare a 3-year plan, the triennial work plan of the national hydrogen program (2023-2025) which will guide the federal government's actions in the development of the hydrogen sector in the years to come [32].

6.3 European Union

The interplay and integration of different policies with a hydrogen policy must be emphasized. In the European Union, a noteworthy area of policy focus is the linkage of a green industrial policy with hydrogen economy development. An empirical example can be found in Europe where In July 2020, *A hydrogen strategy for a climate-neutral Europe* was adopted, demonstrating a clear path for the hydrogen economy's development.to install 40 GW of renewable hydrogen electrolysers by 2030 founded on five objectives: .[33]

1, increasing the EU investment for hydrogen.
2, boosting demand for and scaling up hydrogen production.
3, designing an enabling and supportive legal and regulatory framework.
4, promoting research and innovation in hydrogen and fuel cell technologies.
5, developing international cooperation and
alliances. [33]

On the other hand*, The Green Deal Industrial Plan for a net zero age* recognises the significance of renewable hydrogen as a storage medium, fuel, and feedstock for the net-zero energy transition. First, it addressed the need to develop the necessary infrastructure, described as the *European Hydrogen Backbone*, which consists of gas system operators allowing the advanced existing gas network to transport this energy carrier [33]

6.4 United States of America

In the United States of America's national clean hydrogen strategy and roadmap, the importance of robust and transparent analysis and modelling through collaborations between national laboratories, industry, and academia has been highlighted. All analyses are used to inform R&D activities and real-world data from technical demonstrations are fed back into foundational models to improve assessments in the future. [34]

Again, efficient and effective collaboration has been emphasized. Agencies have already been coordinating with each other, and with industry, states, and numerous stakeholders to execute on hydrogen related activities. Several opportunities exist across agencies, building on activities underway over more than a decade to accelerate progress aligned with the National Clean Hydrogen Strategy and Roadmap [34].

7.0 BUILDING HYDROGEN INFRASTRUCTURE IN GHANA

Producing and commercializing hydrogen fuel sustainably, requires extensive national long-term infrastructure in line with a hydrogen energy policy or roadmap [2]. A hydrogen energy infrastructure is the system needed to produce hydrogen, store it, and deliver it to users. This includes hydrogen production systems (for converting primary-energy sources or other energy carriers to hydrogen), hydrogen storage capacity (needed to match time-varying fuel demands to production output), long-distance transmission systems (if hydrogen is to be transported long distances from the production site to users), local pipeline distribution systems (analogous to a system of natural gas utility pipes), and equipment for dispensing hydrogen to users (for example, hydrogen compressors and dispensers at vehicle refueling stations) [4][7].To build such an infrastructure heavily depends upon investment, which often is the other barrier to achieving a sustainable hydrogen fuel system.[2]

Hydrogen infrastructure should be adequately robust [5]. Such infrastructure must meet requirements of safety, energy efficiency, and cost-effectiveness [4]. Again, a hydrogen fuel delivery infrastructure must ensure the correct balance between production locations and delivery options, considering the availability of feedstocks and the proximity of use centers. Hence, the type and size of market (urban, rural, cross-border) will affect the delivery infrastructure.[4][5].

8.0 CONCLUSION

This paper makes a maiden effort to map a hydrogen economy in Ghana's context. This has become important as the world transitions green and clean technologies for a better and climate resilient economic future. As Ghana pursues a nuclear power programme and with the emergence of Small Modular Reactors, it is important now more than ever, catalyse discussions towards setting up the policy frameworks, strategies and actions towards this hydrogen economy which only is not beneficial to the climate bur will be transformational for the Ghanaian economy.

Through extensive literature review, a variety of issues underpinning the development of the hydrogen economy have been identified. Further, these issues have been categorized through a system framework to put them in perspective and inform policy discussions moving forward.

Further, a phased framework is presented capture the stages or time horizons along which these issues must be addressed as Ghana transitions into a hydrogen economy. In the future with the emergence of SMR technology in the nuclear space.

The policy approaches of some countries have also been benchmarked. Key insights can be drawn:

-Ghana's hydrogen policy must evolve with key strategic objectives such as competitiveness at its heart (the Brazilian case)
-From the outset, it is important to align nuclear energy policy with hydrogen policy in Ghana (the Canadian case)
- Ghana's industrial policy should be adequately linked to its future hydrogen policies and strategies (the European union experience)
- Ghana's hydrogen policy should be backed by robust modeling and tools and effective collaborations between national agencies and institutions (the American experience)

Finally, transitioning to a hydrogen economy in Ghana will require a robust hydrogen infrastructure which meets requirements of safety, energy efficiency, and cost-effectiveness and further ensures the correct balance between production locations and delivery options,

This mapping effort provides a high-level point de depart towards a hydrogen policy in Ghana and further places nuclear hydrogen in perspective as Ghana progresses with its nuclear power programme and begins to consider SMRs as they emerge. Future studies could address key themes such as:

-assessing the economic impact of hydrogen adoption in Ghana (ie. quantitatively)
-analysis of regulatory frameworks required in Ghana to transition into a hydrogen economy
- financial feasibility assessments in projects in the hydrogen economy
- assessing human resource requirements of Ghana's hydrogen economy.

The words of Jeremy Rifkin cannot be truer; "We are on the cusp of a third industrial revolution and a new energy era. Hydrogen is our common future" [24].

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