

Hydrogen technology in Sub-Saharan Africa: Prospects for Power Plants

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Abstract. Hydrogen as an energy vector could be one of the solutions to the crucial energy crisis in sub-Saharan Africa. A technological review is done in this paper as a first attempt to foster research and development on the subject. It shows the hydrogen technology disadvantages and difficulties regarding its usage in Africa, and explores ways to better tackle them. Concepts are also discussed by showing the benefits of hydrogen introduction in sub-Saharan African countries on their economy through the increase of their electrification coverage and the reduction of electricity shortages witnessed in these countries. Ideas of systems hybridization including hydrogen fuel cells are presented, discussed and adapted to the sub-Saharan context. Methods of overcoming possible risks, technologies that could be adopted now and on-going research on the subject are finally performed.

1 Introduction

Africa is indexed nowadays, as the continent where the level of development is still weak. Apart from South Africa, which now appears as the "Power House" (...), Africa is today the continent least supplied with electric power [1]. However, more than 14% of the world's population resides in Africa with an access to electricity limited to 35% [2]. By 2050, the African population would be around 1.9 billion, which would imply an increase in already unsatisfactory energy demand. Any aspiring industrial nation typically requires about 1 GW of energy for 1 million people, so providing sufficient power to African population alone is a 1900-GW opportunity [3]. While the alternative resources (renewables) are mostly intermittent, the so-called conventional resources suffer from shortages. It requires and/or imposes the need to store the energy thus produced and to offer acceptable technological performances. Most of today's energy storage solutions pose additional constraints, such as increasing installation costs, technological constraints, or environmental problems. The storage of energy thus appears today as a limiting factor to exploitation and deployment of existing and alternative resources. Power plants are the most concerned regarding this issue. One of the solutions for the storage of electricity is the production of hydrogen. Information about hydrogen and fuel cells technology in sub-Saharan Africa context to initiate basis research of hydrogen production using renewables energies is the motivation. Even adopting energy-mix has not considerably help mitigating the environment while tackling energy poverty. It is therefore to explore all the available resource. Hydrogen could be one of the solutions to the crucial energy crisis.

This paper presents the role of hydrogen economy to the Sub-Saharan Africa (SSA)'s energy sector with the objective of boosting initiative, and explores ways to tackle challenges in power systems. Some of the key findings show that only 17% of the SSA's countries are involved in this technology development and initiatives. This paper is useful, as it is a first-hand research hotspot on hydrogen technology in SSA countries, excluding South Africa. Energy systems that are based on hydrogen are fundamentally different to energy systems based on hydrocarbons and electricity. Based on the Levelized Cost of Energy (LCOE) methodology, an analysis on the costs involved to produce large-scale hydrogen is done [4]. This allow an analysis on how hydrogen compares on a cost basis to other energy technologies. Concerning also solar source, results showed that production of hydrogen from solar photovoltaic is about 1.09 €m^{-3} [4] under the conditions of production of 115 Lday^{-1} . Storing renewable electricity through hydrogen might be cost-effective when disregarding certain constraints.

1.1 Interests of hydrogen technology for sub-Saharan African countries

In climate change dynamism, it is sustainable to think of alternative and clean solutions in sub-Saharan Africa such as renewable energy technologies. Hydrogen is identified as a potential alternative fuel as well as an energy carrier for the future power supply. It could help to make the transition away from fossil fuels and towards sustainable energy a reality in Africa. The development of the hydrogen economy will most likely rely on water electrolysis by using large amounts of electric power, which in its turn has to be clean

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generated [5]. It is done through fuel cell, an electrical cell, which unlike storage cells can be continuously fed with a fuel (hydrogen) so that the electrical power is produced sustainably and indefinitely. Hydrogen is then suitable to feed a low temperature fuel cell, such as Proton Exchange Membrane Fuel Cell (PEMFC) or Alkaline Fuel Cell (AFC) or a high temperature Fuel Cell, e.g. Solid Oxide Fuel Cell (SOFC) or Molten-Carbonate Fuel Cell (MCFC). As a recall, a fuel cell operates like a “battery”, except that it does not run down or need electrical recharging. Today, PEMFCs that work at relatively low temperatures (ambient to 70 – 80 °C), are becoming a matured stand-alone or cogeneration (electricity and heat) technology with relatively good electrical efficiencies (40 – 55%) depending on the applications and working conditions [6]. Because PEMFC are made of polymer electrolytes, they indeed work at low temperatures, which have the advantage to start quickly. As matter of fact, in terms of electrical efficiency, PEMFCs are better than SOFCs, even better than concentrated solar power plants (CSP), if solar resource is considered. Also called as the “gas battery” by his pioneer Sir William Grove, the principle, well described in the literature [5,7,8], is renewable when it is produced from renewable energy sources. When it is converted into useful energy in the form of electricity via a fuel cell, the by-product is harmless water vapour.

In the introduction, African countries that already stepped in the hydrogen and fuel cells technology with some major advances were mentioned. In sub-Saharan African countries, it is not yet the case though few are countries to benefit most from early transition to hydrogen fuelled transportation [9]. Although most of these countries have a potential for petroleum resources, none has ever initiate or thought of hydrogen production from steam gasification [10], even though such coal gasification techniques very expensive, might be dangerous, and involves many complex and so-far unsolved problems [5]. Few theoretical and numerical investigations were however performed. Koumi Ngho and Njomo [11] have reviewed several methods of producing hydrogen, especially from biomass that is most available in sub-Saharan African countries. In fact, biomass (forest products and residue, agricultural residue, energy crops, and municipal solid waste) is one of the largest renewable energy resources in Sub-Sahara Africa [12]. The inconvenient of hydrogen production from the biomass is the simultaneous production of other compounds such as carbon oxide (CO) that needs to be converted again into CO₂ [13]. Hydrogen can also be produced from solar water splitting through artificial photosynthesis technique (mimicking photosynthesis) [14]. As a recall, water splitting consists of two parts: first, the water molecule is split into an oxygen molecule, a lost proton and electron. A hydride catalyst drives this reaction, artificially, at least. Scientists are trying to determine the material that will better serve its purpose as the catalyst for this reaction. Second, hydrogen molecule is formed from the lost proton and electron. Therefore, producing hydrogen that way requires a catalyst, which makes it somehow complex

again [15]. Hydrogen production through steam electrolysis was simulated in a tropical weather conditions. Authors found that about 2 tonnes of hydrogen can be produced per day and that the electrolyser installation will require 0.2 ha of land [16]. As for example, 1 MW of solar photovoltaic in sub-Saharan countries will require 2-4 ha [17]; large electrolyser can be integrated on the same site to optimise the land space use. Despite hydrogen production from water, it represents only 4% of the world’s energy demand [11]. Hydrogen remains one of the safe and ecological ways to empower economies, especially for Africa. Though, the International Energy Agency’s Hydrogen Implementing Agreement (IEA-HIA) has established that a lower hazardous limit is 8% vol. of H₂ in air [18]. Meaning that, outdoor H₂-stationary systems are safe since 8% vol. of hydrogen in the whole atmosphere could be hardly reached.

Due to financial and infrastructure limitations, national grids in most sub-Saharan countries cannot fully insure access to electrification in remote areas such as rural and remote regions. However, decentralised energy systems can solve the problem. In the present context, stationary hydrogen/fuel cells systems can be a good candidate. Stationary fuel cells generate electricity through an electrochemical reaction, not combustion, providing clean, efficient, and reliable off-grid power to homes, businesses, telecommunications networks, utilities, and others [19,20]. Many companies around the world are adopting fuel cells for primary and backup power. Stationary fuel cells do not make any noise when operating and have very low emissions, so they can be either installed in an urban or rural environment without pollution concerns. Stationary fuel cell systems also take up much less space in proportion to other clean energy technologies. For instance, a 10-megawatt (MW) fuel cell installation can be sited in about 0.4 ha of land. This is compared to about 4 ha required per MW of solar photovoltaic and about 20 ha per MW of wind [21]. Even for stationary system, this needs to be at large scale to supply many remote areas with energy. Most investigations focus on large systems and utility scale power that is priced at the utility scale prices for the end-user. However, small hybrid systems could be affordable and efficient. If millions of households using electricity are considered, mass production for example of small solar-battery-H₂/fuel-cell systems may become economical, along with government programs and subsidies established for domestic hydrogen production. In fact, Friberg [22] showed that electricity cost from solar-battery-H₂/fuel-cell systems can be reduced by 49% in five years in the India context. Design a system that would be small enough for households and perhaps could be used for electrical demand might make them affordable when produced by millions. This technology economy of scale concept will lead to implement adapted large- and small-scale hydrogen/fuel-cells in sub-Saharan African countries.

Hydrogen is also advantageous by not being susceptible to being depleted, unlike fossil fuel and uranium resources. It is also in favour for decentralization and home solutions, and can contribute

to sustainable development in many other developing countries [23]. The flexibility or the absence of norms and standards on hydrogen technology in Sub-Saharan Africa is an opportunity to establish them according to the local context. The standards required for the installation of hydrogen production technology in sub-Saharan Africa (except South Africa, which adopted an American National Standard [24] and adapted it to the country context) do not exist or are under development, compared to Europe, USA or Asia, for example. In fact, no African country is taking part to the safety development of hydrogen technology [25]. Voluntary standards should already be developed, and technical committees created to facilitate the adaptation and/or adoption of existing standards. Africa offers much space for such technologies installation and development. For example, space for wind energy technology is available in Africa [26].

1.2 Technology state-of-the-art in sub-Saharan Africa

Up to now, hydrogen and fuel cells technology are not widespread in sub-Saharan countries. The major advancement on the subject is about theoretical and numerical, though few applications are being implemented and developed in some countries.

In Nigeria, first interest was to find an appropriate fuel cell technology that feeds into economy and energy market [27]. An integrated assessment for transportation and power sector was then performed [23,28]. The aim was to determine the suitability of their economy for incorporating a hydrogen energy system. Authors concluded, based on economic models, that hydrogen-powered vehicles will not have a significant impact on the transportation sector. This study was limited on transportation sector. However, further numerical study demonstrated the usefulness of hydrogen technology to backup residential energy demand. Douglas carried out a dynamic modelling of a solar PV - battery/fuel cell hybrid system [29]. The example studied allowed to simulate a residential load based on 4 hours of solar radiation on 500 W modules. The battery capacity was 42 Ah and the fuel cell power was 1 kW. The operation consisted of a permanent cycle of charge/discharge of the battery from the solar modules. When the battery was fully charged, the excess of available energy was used to produce and store hydrogen. The hydrogen thus produced was subsequently converted via the fuel cell to generate electricity during peak periods and/or when batteries are empty due to unavailability of solar resource. It has been shown that the batteries allow to supply relatively lower power loads over a long time (233 s) compared to the fuel cell which feeds higher power loads over a shorter time (55 ms for this case). Douglas explained that the low response of the fuel cell is due to the reactants flow conditions within it; at the edges of the electrodes, which would induce an internal resistance. However, the production of electricity via the fuel cell makes it possible to generate a current whose sinusoidal shape was maintained stable, at the output of the inverter. This example opens a path towards the use

of hydrogen production and storage to mitigate the peak load constraints on power grids.

In Mali, a natural hydrogen field was discovered in the village of "Bourakebouyou" in the northern part of the country. The quantity of that pure hydrogen at 98% was estimated at $28 \times 10^6 \text{ m}^3\text{H}_2$ [30]. First pilot plant was launched in 2013 where natural hydrogen fuelled a power generator to electrify the village. Natural hydrogen extracted from the ground is not stored but directly used as fuel for generator. This makes Mali country the first in sub-Saharan Africa to exploit natural hydrogen for electrification. Avoiding hydrogen storage reduces the operating cost and helps to provide electricity at a cheaper price in the village. For the coming years, site owner, firm Petroma (petrochemical of Mali) intend to power the country and the sub-region.

In Cameroon, principal investigations focused only on how hydrogen can be produced. Koumi Ngoh and Njomo firstly reviewed several ways of producing hydrogen while performing an exergy analysis on different methods [11]. Their conclusion led them to propose a production method based on hybrid energy system. They designed a solid oxide steam electrolysis system coupled to a photovoltaic array through a Direct Current (DC) converter and coupled to a parabolic trough collector with an integrated heat exchanger network. The heat exchanger network was optimized using a Generalized Reduced Gradient algorithm to enhance water flow and heat sink [16]. System duality of producing hydrogen from photovoltaic electricity and solar thermal (high temperature) was however costly despite promising theoretical results. The high temperature process shows high purity of produced hydrogen in great amount as mentioned in section 2.

In Ghana, hydrogen technology development was dedicated to household cooking fuels (modified green cooking stoves) to improve women's life in their daily activities. The chosen field was guided by the fact that energy for cooking accounts for almost 95% of the household energy use of the country [31]. Topriska et al. ran dynamic simulation to evaluate the potential of solar hydrogen to cover Ghana's cooking demand estimated at 2.5 kWh/day [32,33]. Results exhibit stove efficiency of 60%, corresponding to 4.2 kWh/day or 0.107 kg H_2 /day, which largely cover the demand. The hydrogen stove were modified in a way to adapting the burner and some security measures taken such as cascading system to lightweight low pressure containers suitable for transportation into houses, or in metal hydride more safer but expensive.

In Benin, Amuzu et al. studied the potential for hydrogen production from biomass [12]. The work carried out was because the population does not have sufficient access to electricity and that the country is seen as the one whose evolution of energy demand will increase in the coming years. Authors have shown that the potential for hydrogen production from the combustion of wood and agricultural residues in the country is over 140000 metric tons/year. Electricity generation from those tonnes of hydrogen was estimated at about 6000 GWh/year. In Western Africa actually, hydrogen energy from the combustion of only 30% of

wood and potential agricultural residues would cover 100% of the estimated annual electricity consumption. Currently, the fuel cell efficiency is about 60% compared to 45% for the diesel internal combustion engine and 22% for the gasoline engine. Assuming fuel cell efficiency equal to that of the gasoline engine, Amuzu et al (2015) have demonstrated that 60% of sub-Saharan African countries can produce 100% of their annual gasoline engines consumption from hydrogen [12]. And if, fuel cell efficiency is estimated to be more than twice the gasoline one, then, 75% of sub-Saharan African countries can totally replace gasoline engines by hydrogen engines. One of the concerns in Benin is also the household's energy need, especially fuel consumption for cooking activities. Charcoal is the main cooking energy source. Although new project was developed in order to improve cooking systems as shown in [34], Éclair cooking stoves might be replaced by green cooking hydrogen based stove as developed in Ghana.

In early November 2021, Namibia selected Hyphen Energy as preferred bidder to develop the country's first large-scale green hydrogen project in the vicinity of the Tsau Khaeb National Park [45, 46]. This site is considered as an ideal location thanks to its extensive combination of solar and wind resources and proximity to the ocean (i.e., a water source) and the port of Lüderitz for export options. Developed in phases, the project is set to ultimately produce 300,000 metric tons per year of green hydrogen, for the domestic and international markets, along with 2 gigawatts (GW) of renewable electricity by 2026 at an estimated cost of \$4.4 billion. Further phases of development in the late 2020s will scale up to 3 GW of electrolyzer capacity and 5 GW of combined renewable power generation for a total estimated cost of \$9.4 billion. The production will serve either as pure green hydrogen or will be converted into green ammonia [46].

In February 2021, the government of Niger[†] has signed an agreement with German company Emerging Energy Corporation (EEC) to develop the hydrogen market [47]. The government has given the green light for the exploration and development of green hydrogen projects. EEC plans to implement an electrolysis technique based on clean energy. This project should help decarbonize oil field operations and refineries. The green hydrogen produced in Niger will also be exported to the international market, particularly to Europe and America. This project is still at an early stage in comparison with most advanced projects in other African countries.

In Mauritania, the Project 'Nour' that already showed in his pre-feasibility studies, the production potential of green hydrogen might become the greatest large-scale (10 GW) facility to provide hydrogen [48].

Senegal has not step in yet concerning hydrogen technology. However, there are researchers who tried to develop some storage system in order to store hydrogen

in a small, lightweight and safe container based Cu-functionalized graphene [35]. Motivation behind this H₂ storing method is for on board automobile application.

Despite basic infrastructures for research such as practical lab equipment, in these countries, there is lack of policy developed to lift up the field. Only about 17% of SSA's countries have initiated or implemented an action to promote hydrogen economy. At regional level, SSA institutions in partnership with German institutions are initiating hydrogen project. SADC Centre for Renewable Energy and Energy Efficiency (SACREEE) and the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) is cooperating with ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) and West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) to produce an Atlas of Green Hydrogen Generation Potentials in Africa [36,37]. Aim of this project, to be ran from 2020 to 2022, is to mapping the hydrogen economy in SSA while contributing to implement the climate change – energy nexus on the continent.

It can be seen from previous statements that, hydrogen technology is not well developed in sub-Saharan Africa except natural hydrogen exploited as power plant (to produce electricity) in Mali and few theoretical works. Therefore, the present paper ultimate goal is to open way into research and development of hydrogen technology, which is another solution for a sustainable access to electricity for all in Africa. Major point to retain is that countries with good potential of renewable energy (solar and wind for example) could use this alternative power systems to reinforce more or sustain their power plants.

2 Concepts and implementation of the hydrogen-technology for Power Plants

Hydrogen technology is being explored to diversify energy fuels, and is considered for power generation in Asia Pacific region. Hydrogen provides a storage solution to the intermittency of power plants in Africa. Hydrogen is a clean and sustainable energy vector and can be produced from many sources [38]: water, biomass and hydrocarbons. The methods of production are also varied, from fossil fuels (steam reforming, partial oxidation and auto thermal reforming) or from renewable sources (electrolysis, thermolysis, thermochemical and biological). Renewable energies such as solar, wind and biomass contribute to cover energy demand, while renewable energy excess is used to produce hydrogen via electrolysis of water. The produced hydrogen is naturally converted into electricity through PEMFC, while another part is mixed to methane or diesel to fuel motors (see Fig. 1). Similar concept was recently demonstrated in a dynamic simulation study dedicated to hybrid energy grid and the produced hydrogen was mixed to natural gas to fuel a

[†] <https://ihsmarkit.com/research-analysis/africa-green-hydrogen.html#:~:text=African%20hydrogen%20production%20has%20the,sunlight%20for%20green%20power%20production.>

micro gas turbine [39]. This promising solution yielded in a saving of about 37.5% in fossil fuel and stabilized fluctuations from renewable energy sources. Mixing produced hydrogen with methane from biomass could also provide fuel to two-cycle engines and hence, help to avoid air pollution in dense cities. In practice, hydrogen fuel cell technology is seen as a two thermodynamic cycle, i.e. creating hydrogen (electrolyser cycle) and generating electricity (fuel cell cycle). In fact, hydrogen addition could improve the engine performance at engine loads and reduce harmful gas emissions [41]. Recently, hydrogen use in a diesel engine has experimentally shown better energetic and pollution performance of the engine due to the improvement of the combustion process and reduction of carbon content [42].

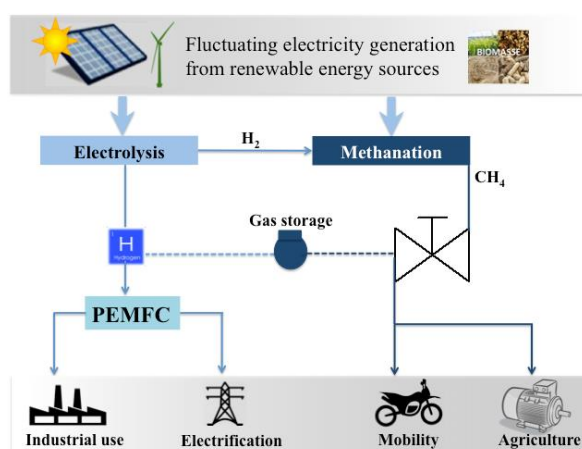


Fig. 1. Concept and implementation illustration of the hydrogen-technology in sub-Saharan Africa

From Fig.1, green hydrogen could directly be turned into electricity with the help of gigawatts fuel cells. Additionally, the produced green hydrogen can be mixed with biofuels from biomass to obtain a gas that can be used in power plants in sub-Saharan countries. Most power plants can benefit of integrating hydrogen into their gas turbines (upgrade of existing power plants). This will contribute producing electricity with lower emissions. As far as it is concerned, only five (05) hydrogen power plant projects are under development around the world, and none of them is based in Africa [49].

2.1 Focus on Power Plants Use

The actual way of storing electricity is through pumped hydro storage (PHS). Hydrogen is a potential option to satisfy the electricity storage since it has 250 times the energy density of PHS [40]. Renewable hydrogen production deployment for electricity storage in the future has started in some African countries. However, the production process for only storage has a low round-trip efficiency compared to other existing storage technologies (pumped hydro, supercapacitor, etc.). Nevertheless, economic challenges, particularly for Africa, currently make alternative solutions (e.g., battery, pumped-storage hydroelectricity) more cost-

efficient. It can also act as long-term storage capacity for hydropower energy, which fluctuates between seasons and across different years. Hydrogen also shows potential in the power sector to stabilise the grid, notably for peak energy use and backup power for the telecom industry (radio masts), and in many other business sectors with high energy consumption and high-power reliability requirements (e.g., hospitals, hotels, supermarkets, shopping malls, offices, and data centres), where ammonia fuelled fuel cell systems could replace mostly imported diesel generators. Moreover, green hydrogen can increase renewable electricity market growth potential substantially and broaden the reach of renewable solutions. In addition, North Africa currently has the most potential for power generation using green hydrogen from fossils, due to existing gas power plant infrastructure. Finally, green hydrogen use could support the continent's path to net-zero, notably in industry (iron and steel industry in South Africa, Morocco, or Mauritania; Nigeria and South Africa; methanol), and mobility (as part of a mix of technologies – fuel cells, electric vehicles, biofuels sectors; in public transports as highlighted by South Africa).

Initial plans are to blend hydrogen in a low concentration with natural gas for injection to avoid major modifications to pipeline networks (higher concentrations may require network modifications such as replacement of steel with polymer pipes or replacement of compressors). Certain newer and more advanced gas turbines are already able to accept fuel blends, which may contain 50% or more hydrogen, and already major turbine manufacturers, are developing gas turbines that could run on 100% hydrogen. While there is a long way to go before hydrogen might fully replace natural gas, the substitution of natural gas with hydrogen will be a very significant step away from fossil fuels and towards a low carbon economy.

2.2 Challenges

From the previous, it remains various significant challenges to be overcome before a true hydrogen-to-power economy in the region can mature and take root.

Currently in sub-Saharan Africa, the production of hydrogen from solar photovoltaic is about 13 €·kg⁻¹ [4]. Recently, there has been a drop in solar and wind power costs [43], and expectations show that this trend will continue. Lowering the cost of renewable electricity and prices for electrolysis devices is the hint to reduce that H₂ production cost.

Transportation of the green hydrogen and/or its conversion to ease the transport from a location to another will not be a good option for the sub-region. Both processes involve a degree of energy consumption and losses during the conversion and transportation process. While existing natural gas power plants can accept a limited concentration of hydrogen, existing pipeline infrastructure will generally need to be retrofitted to accept the injection of more concentrated or pure hydrogen.

The development of a hydrogen technology will require the drafting and implementation of a clear and

comprehensive regulatory framework. For instance, operational, environmental, safety and technical standards need to be implemented in order to ensure consistent standards for utilisation (for instance, blending with natural gas).

2.3 Overcoming issues and adoption

In the power sector, plans are needed to gradually replace natural gas with hydrogen. Pipeline hydrogen injection should be part of the national hydrogen strategy of several countries, and a key element of the wider decarbonisation strategy (to benefit from carbon tax for example). Recent gas turbines can be operated with a mix of hydrogen and natural gas, with a hydrogen share of 5 to 100%. Hydrogen can be cached, transported in gas grids and re-electrified in gas turbines, combined cycles or fuel cell power plants. Actually, General Electric[‡] (GE) has combustion technologies that are capable of operating on a wide range of hydrogen concentrations up to ~100% (by volume) [49]. Emphasis should be put on mixing the actual gas with hydrogen to use in gas power plants.

Conclusion

Faced to the current energy crisis characterized by the future limitations of actual energy systems, sub-Saharan Africa should establish sustainable energy supply strategies. For instance, the creation of “country hydrogen roadmap (CHR)” is mandatory, such as developing national hydrogen energy and fuel cell research and development strategies. CHR could consist of four steps:

- Step 1 – research initiatives and demonstration of intent, where a country engage to identify key stakeholders and develop partners (especially with South Africa).
- Step 2 – Detailed country hydrogen assessment and action plan, where stakeholders come together to discuss and fill up in detail the CHR service-resource pair templates; and to draft a prioritised Action Plan.
- Step 3 – CHR validation and finalisation, where draft of the CHR report that should result from previous steps is presented and validated. This should led to development of cost models and financial models for hydrogen economy.
- Step 4 – Follow up, where the CHR report is disseminated and follow up is undertaken by governments, international institutions in the country, development partners and others where applicable.

Since the crisis is mainly due to the decline in stocks of global fossil fuels, such as oil and coal, and the impact of their combustion on climate change, future strategies should help providing clean and affordable energy without increasing ecosystems' gas emissions. One of

the sustainable solutions to this pending energy crisis is to move towards a global hydrogen economy. Except its disadvantage, which is the cost of the Platinum catalyst required in the hydrogen/fuel cell (PEMFC), sub-Saharan Africa can boost their economy based on the development of such technology. Additionally, Ali and Salman [44] have shown why PEMFC is worth using over other fuel cells in order to move to a hydrogen economy. PEMFC exhibits high power densities, high efficiencies, rapid start-up, long cell and stack life, low weight and cost, contain no corrosive fluids, useful for almost all applications, exhibit most of the basic fuel cell properties [44].

Approaches of producing hydrogen were also reviewed and it came out that the solar way seems promising and simple, when looking to green hydrogen. The overview about the current situation and trends of hydrogen economy is presented in some sub-Saharan countries. The available research on hydrogen technology, processes and simulations are presented as well.

This work also shows that stationary hydrogen/fuel cells system is safe and require less land than solar power plant. Several concepts, adaptable in the sub-Saharan context were presented, and a global summary illustrated in Fig. 1. It is common to read in the literature that hydrogen/fuel cells have the potential to replace batteries completely, but making the technology affordable and cheaper compared to conventional batteries is still far away. At the same time, information about hydrogen technology remains somehow unknown to a broader public in sub-Saharan Africa.

Another aspect is technological risks related. Question raised today is about security for decentralized use, or home applications. Industry uses hydrogen at pressures generally in the range of 200 to 300 bars, while hydrogen vehicles carry hydrogen at 700 bars. Poor maintenance, wear and tear, or vehicle accidents are more important risk-factors in these new configurations. However, well-known security methods exist such as prevention of leaks, gas accumulations and heat (requiring ventilation), overpressures; installation of equipment within a safe distance; restrictions on access to premises; monitoring of several parameters (H₂ content, pressure, etc.) with automatic shut-off and shut-down if threshold is exceeded; regular maintenance and inspection.

To sum up, this technology is likely to play a major role in the future need for green environment and economy of sub-Saharan Africa. However, uncertainties surrounding this possibility, based on renewable sources, appear to be mainly due to lack of research funding and technology development that give it competitive edge on the subject. It is therefore hereby recommended that further research studies on sensitization, management and policy be carried out. This would help tackle institutional barriers such as education, infrastructure for hydrogen research and absence of codes and safety standards.

[‡] https://www.ge.com/gas-power/future-of-energy/hydrogen-fueled-gas-turbines?utm_campaign=h2&utm_medium=cpc&utm_source=google&utm_content=rsa&utm_term=Hydrogen%20to%20electricity&gclid=CjwKCAjwnZaV

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