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Commentary

Hydrogen 1.0: A new age

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ABSTRACT

This perspective type article primarily focuses on a new concept of Hydrogen 1:0 for the global community where hydrogen society is developing with clean hydrogen energy solutions to overcome local and global energy, environment and economy related challenges and provide a sustainable future. In this regard, the article discusses hydrogenization, where hydrogen energy-based solutions, are developed for implementation. It further discusses the economic periods of humanity after the 1950s to see what economic developments are made great impacts and how the future may evolve economically. Moreover, the needs for hydrogen era are discussed in terms of technology, innovation and digitalization. Finally, the "Hydrogen 1.0" is a new age where pioneers in every economic sector are expected to make great contributions.

Introduction

We have been witnessing drastic changes in the way we generate, convert, store, transport, transfer and utilize energy since the industrial revolution started around 1760. The energy equation was primarily considering coals for many sectors where steam engines were introduced. Such engines were heavily using coals. Later, the humanity got into an oil period where petrol became an essential commodity, and later natural gas has got into the energy equation for many countries. These three hydrocarbon commodities have served the humanity in many respects, but caused damages to the ecosystems of all living species, including human beings in the world. In 2020, we were hit by the COVID-19 Coronavirus Pandemic which was a kind of wake-up call for many countries where the energy equation required a carbon-free solution, which was directly addressing hydrogen.

In a recent study, Dincer [1] introduced smart energy solutions which were tailored under eight key categories, namely exergization, greenization, renewabilization, hydrogenization, integration, multigeneration, storagization and intelligization. This is now modified to include nuclearization as illustrated in Fig. 1. It is important to briefly repeat the description of each category with an additional definition coming into the picture for nuclearization as follows.

- Exergization: is defined as the art of using exergy analysis and its specific tools in a conceptually correct manner for better design and analysis, better efficiency, better cost effectiveness, better resources use, better environment and better energy security.
- Greenization: is defined as a new discipline in two ways to help achieve better efficiency, better cost effectiveness, better environment and hence better sustainability: (a) as a process of converting traditional/conventional systems

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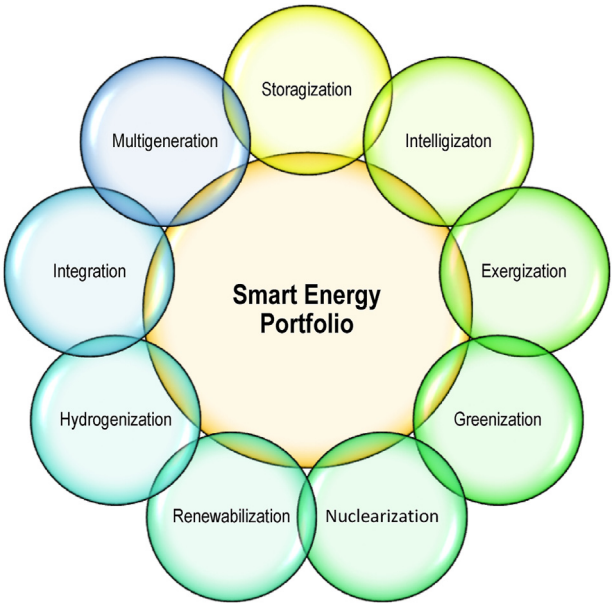

Fig. 1 – Nine branches of smart energy portfolio (modified from Dincer [1]).

with higher environmental damage, less efficiency, more cost, etc. into more efficient, more cost effective and more environmental friendly ones, so-called: greenized systems, and (b) as a unique methodology of developing a new energy framework under Dincer's 3S (Source-System-Service) criterion to achieve greener results than the conventional ones.

- Nuclearization: is defined as a process where nuclear energy options are taken beyond the electricity generation in utility sector and made contributions to potentially all other sectors by providing useful commodities, ranging from freshwater, heat and district heating to hydrogen. There are two unique approaches considered by numerous organizations to more effectively utilize such nuclearization options, namely: (i) through small modular reactors (SMRs) and (ii) via hybridization with renewable energy systems to provide more resilient clean energy solutions.
- Renewabilization: is defined as the process of switching to renewable energy (including solar, wind, geothermal, hydro, ocean and biomass) based systems from conventional fossil fuels based ones.
- Hydrogenization: is defined as the process where hydrogen is deployed as carbon-free fuel, energy carrier and feedstock for all sectors to accomplish hydrogen economy for better sustainability.
- Integration: is defined as a process where energy systems/subsystems are combined and/or hybridized to achieve better efficiency, cost effectiveness, resilience, resources use and environment.
- Multigeneration: is defined as the process of modifying the systems where one can get at least four useful outputs by utilizing the same input(s). Traditionally, we are practically familiar with cogeneration (where two useful commodities are simultaneously produced with the same input) and more recently with trigeneration (where three useful commodities are concurrently produced with the same input).
- Storagization: is defined as the process of implementing energy storage options to offset the mismatch between demand and supply and to operate the systems in a more efficient, effective, resilient and environmentally sound manner.
- Intelligization: is defined as the process where artificial intelligence tools are utilized to better simulate and model, implement, optimize, automate and control, and manage and meter the energy systems and applications. It may also include pattern recognition in smart energy applications.

In closing, this particular perspective article is intended to introduce the "Hydrogen 1:0" concept and discusses various dimensions of it through the needs, players and developments. It also provides smart energy portfolio under nine important categories, namely exergization, greenization, nuclearization, renewabilization, hydrogenization, integration, multigeneration, storagization and intelligization where hydrogenization is taken out to develop the path for "Hydrogen 1:0" age. The world's economic periods are considered to better understand the past and develop right solutions for future along with their impact categories. The needs for hydrogen age are also provided in terms of technology, innovation and digitalization (so-called: intelligization). Furthermore, the specific steps to achieve in hydrogen age are introduced and discussed.

Economic development and hydrogen age

Fig. 2 shows an important graph to illustrate the economic development periods after the 1950s and their economic impact levels. This figure then clearly shows that the first period after the second world war was a comprehensive, labor-intensive period where the economic impact was low. This period continued up until the 1970s. The next period followed the labor-intensive one was a skill-intensive period where more trained people were prepared to join the workforce locally to achieve better quality jobs in shorter time frame with higher efficiency. This period was sort of between the 1970s and the 1980s. This does not mean that skill development activities discontinued, but they rather continued along with additional dimensions. In 1980s the capital-intensive era was more impactful where the economic impact was increased through the investments and capital-based initiatives in many sectors, ranging from industrial to agricultural. Compared to labor-intensive period the economic impact of this period increased by more than three times. The following period was a technology-intensive period which visibly started in the 1990s and helped increase the economic impacts for the developed countries because of the technologies that they developed. Such developed technologies technically helped make those countries really technologically advanced countries and accelerated their economic acivities which resulted in increased welfare and hence lots of profits due to the increased exports of their technological products, services, etc. The next period in the 2000s was innovation intensive one where numerous developed

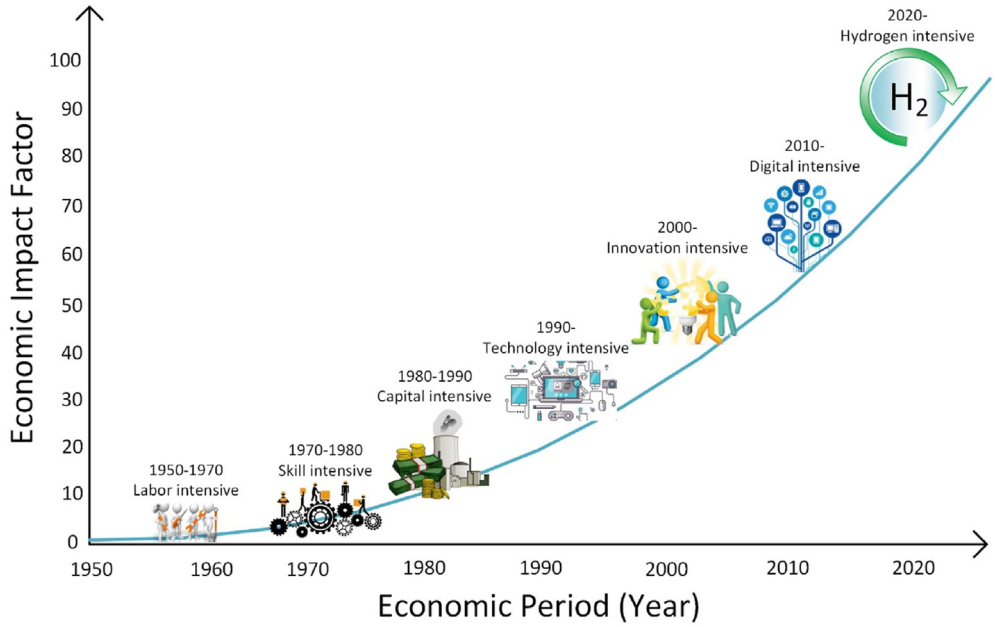

Fig. 2 – An illustration of economic impact factors of various developments after the second world war to clearly indicate economic periods.

countries caught an opportunity to make distinct difference compared to other countries by making their products, services, etc. more innovative and hence leading in the global market by making greater economic impact. The digital intensive period was apparently a common one for the developed countries with digital technologies, products, services, etc. and providing a unique advantage for them in creating their smart materials, smart devices and hence smart products and services. This has also helped in increasing economic impacts after the 2010s by changing the ecosystem with digitalization. In the 2020 the world was hit by the COVID-19 Coronavirus Pandemic which was a historical turning point, as discussed by Dincer [2], by ultimately closing the carbon age, but essentially opening the hydrogen age. Many countries in that year started declaring their strategic plans and road maps accordingly. For example, European Community first introduced their green hydrogen deal. Many other countries, ranging from North America to Far East, began announcing their plans and road maps to move into the hydrogen age with concrete action plans where they mostly announced to make their countries carbon neutral by 2050. This was something remarkable progress for the humanity to achieve the biggest transition ever to the hydrogen-intensive era/age where higher economic impacts are expected to create a better world with better energy solutions, better resiliency, better environment and better sustainable development. This will also help better achieve the sustainable development goals of the United Nations. Further to note that hydrogen period needs three key periods incorporated into its domains, as illustrated in Fig. 3, through technology, innovation and digitalization. This means that the success of hydrogen era will depend heavily on technologies developed, innovations made and digitalization achieved. That's why it is a kind of integrated economic period where all these three domains have to be synchronized for a clear success and a clean future. This will really help countries to make difference if they want to distinguish themselves for a better future where clean air, clean water, clean food and hence clean energy targets achieved.

Here, Fig. 4 is given to illustrate the key requirements of "Hydrogen 1.0" concept in six categories, namely better design, better efficiency, better resources use, better environment, better energy security and better economy. One has to note that everything begins with a design which is expected tobe better than the conventional practices for hydrogen economy. This can literally be extended to cover the entire

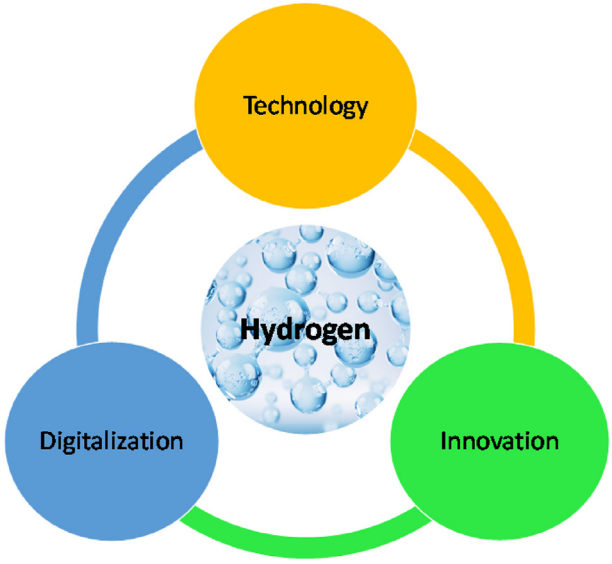

Fig. 3 – The needs for hydrogen age in terms of technology, innovation and digitalization.

Fig. 4 – Hydrogen 1.0 and its six domains to consider.

ecosystem design where the entire spectrum of hydrogen economy is covered from hydrogen production to its utilization including storage, transportation and distribution as well. The design component has to be innovative enough and be part of every respective action ranging from specific system design to the infrastructure building and logistics developments. The design aspects require feasibility studies, thermodynamic (through energy and exergy approaches), economic, environmental impact, sustainability and life cycle analyses and assessments to better design the systems. This kind of analysis/assessment can be enhanced to cover a better design of educational and training practices to create value-added jobs and products and prepare the workforce accordingly for the economic sectors of the hydrogen era. The next domain in the graph is better efficiency where the system efficiency and hence the specific system performance will critically be important for practical operations. Here, one may again consider the hydrogen energy systems in specific and the economic sectors (and hence the hydrogen society) at large to make them more efficient, requiring that both energy and exergy efficiencies are considered for every aspect of these specific component and/or society related systems and applications. In addition, such energy and exergy efficiencies are to be considered for all phases of such systems and applications in an individual or integrated manner. Such efficiencies are direct confirmation of how effectively useful outputs (such as hydrogen) are produced, stored, transported, distributed, converted and used. The next step is better use of resources which is another important action item where all kinds of resources, ranging from natural resources to human resources (capital), are to be considered for better transitioning and achieving the hydrogen economy. As everyone may emphasize, there is a need to use renewable and natural resources in a clean manner to make green hydrogen and hence green hydrogen energy systems and applications. Training and educating human resources to produce right human capital for the hydrogen sectors are of prime importance as well. In addition, better environment becomes the next step to consider. This is something requiring the entire spectrum of hydrogen energy, from source to system and from system to service where the useful outputs are generated for utilization, under 3S concept as introduced by the author in various occasions through publications, presentations and talks/shows. Therefore, the emergence of an environmentally-friendly hydrogen ecosystem requires these achieved in a satisfactorily synchronized manner. It also requires that life cycle assessment studies be implemented to carefully analyze every step where cradle to grave type analysis, for example including comprehensive action plans on goal and scope definition, inventory analysis, impact assessment and improvement study, is performed accordingly. Of course, climate change and/or global warming concerns have played critical role for humanity to help switch the hydrogen economy to basically switch from hydrocarbon-based economy (where the dependence on fossil fuels was essential!) to the hydrogen-based economy. The common question is "Is this going to be easy?" No, it will not be easy. It is obviously expected to be very painful and bring challenges to overcome. It will, however, bring opportunities for human beings to develop and build something new, leading eventually to the hydrogen society. If we look at how many countries have made a carbon neutral pledge, the number is over 130 countries which is a clear indication that the global community is committed to achieve more sustainable future which can only be achieved by implementing the hydrogen economy and fulfill the requirements of the hydrogen age accordingly. The next step is better energy security which is treated as one of the most significant challenges for many countries around the world, including European Community countries where their energy systems/infrastructures depend heavily upon the foreign natural gas coming from Russia. The recent unexpected conflict/war between Russia and Ukraine has changed the energy equation for Europe and energy security actions for their countries to achieve better energy security for them and their planned future. Their energy equation is now restructured to primarily depend on hydrogen energy choices. In Europe, every country is now trying to better develop their hydrogen ecosystem and create better energy security for themselves. This may even be enhanced to cover several more countries, including Turkey, which depends heavily on foreign natural gas, oil and coal. Finally, the last step is better economy in the “Hydrogen 1.0” era. It is general expectation that every choice has to make better economic sense. When it comes to energy, it is even more important to consider. With hydrogen energy we have to develop more feasible solutions where better economy is essentially a primary concern. This means we need more economic hydrogen energy systems and applications for the hydrogen society.

In summary, it is important to note that “Hydrogen 1.0” is not only a concept for the global economy to consider, but rather a set of responsibilities for humanity to rightly engage, develop and implement for more sustainable future.

Closing remarks

In this article, "Hydrogen 1.0" is introduced first time, and the requirements in achieving this hydrogen era is discussed. In addition, the economic periods of the world are discussed through the economic impact indicators by considering economic developments, including the present period of hydrogen. It is also stated that the hydrogen era critically needs three players as technology, innovation and digitalization where there is a strong need to couple and synchronize them in a right way. Furthermore, there are challenges and opportunities simultaneously available for us to tackle with and build a global hydrogen society. So, this is something remarkable, and the history will, in the future, praise those who will make contributions to this hydrogen society building process.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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