13th INTERNATIONAL CONFERENCE ON HYDROGEN PRODUCTION

ICH2P-2022 ONLINE CONFERENCE

December 11-14, 2022

Hydrogen for a Green Future

CONFERENCE PROCEEDINGS

Editors: Ibrahim Dincer | Tahir A. H. Ratlamwala | Khurram Kamal

PREFACE

The International Conference on Hydrogen Production (ICH2P) is one of the key events initiated by Professor Ibrahim Dincer and his colleagues to highlight the state-of-the-art research going on in the area of hydrogen energy. It provides a unique opportunity for scientists, researchers, academicians, and engineers to present their research and findings in the area of hydrogen energy ranging from production to the storage and use of hydrogen in different applications such as fuel cells, power, and transportation. ICH2P does not cover only the recent trends in the area of hydrogen energy but also projects the future of hydrogen energy in the upcoming era.

Pakistan Navy Engineering College (PNEC) - National University of Sciences and Technology, Pakistan is honoured to organize the 13th conference this year on hydrogen production in collaboration with National Hydrogen Association, Turkey, International Association for Hydrogen Energy (IAHE), and Ontario Tech University.

In closing, we are thankful to our esteemed keynote speakers, invited speakers, and all the participants for making this conference a successful one.

Tahir Abdul Hussain Ratlamwala

Conference chair

TABLE OF CONTENTS

ANALYSIS OF THE ENERGETIC, ECONOMIC, AND ENVIRONMENTAL PERFORMANCE OF HYDROGEN PRODUCTIONS

Elena Barbera[a], Andrea Mio[b,d], Alessandro Massi Pavan[b,d], Alberto Bertucco[a,c], Maurizio Fermeglia[b,d]*

a. Department of Industrial Engineering (DII), University of Padova, Italy
b. Department of Engineering and Architecture, University of Trieste, Italy
c. Centro Studi "Levi Cases" for Energy Economics and Technology, University of Padova, Italy
d. Center for Energy, Environment and Transport Giacomo Ciamician, University of Trieste, Italy
e. Corresponding author e-mail: amio@units.it

ABSTRACT

In this work, process simulation is used to calculate material and energy balances for several different hydrogen production processes. Process simulation outcomes are then used to estimate three key performance indicators: the energy return of energy invested, the levelized cost of hydrogen and the life cycle assessment. We compared several hydrogen generation processes, each denoted by a unique colour code: (i) green hydrogen, produced by electrolysis of water using electricity from renewable sources, (ii) grid hydrogen, produced by electrolysis using grid electricity, (iii) grey hydrogen, produced from natural gas using steam reforming and (iv) blue hydrogen, like grey one, but coupled with carbon capture and storage. In conclusion, the most sustainable hydrogen production method is the green hydrogen, produced by water electrolysis.

Keywords: hydrogen production, process simulation, EROEI, LCA, LCOH.

INTRODUCTION

Human energy use has increased rapidly over the last few decades, putting growing strain on the energy industry. Per capita, primary energy use differs among countries and regions, and the global average has significantly increased from 2000 to 2019, of about 42%, passing from 122073 to 173340 TWh. Recent reports of IPCC [1] and EIA [2] indicates that a strong reduction in the usage of fossil fuels must be achieved in order to meet the 2030 greenhouse gases emission targets. Since energy production from renewable sources are not dispatchable due to their fluctuating nature, great attention is given to energy storage and energy carrier systems. Hydrogen is one of the most suitable energy carriers for several applications, mainly in heavy transportation and logistics.

Decisions in the energy sectors should be based on indicators able to summarise different aspects of the sector under study. Among the others, this paper focuses on the Energy Return on Energy Invested (EROEI) [3], that relates the amount of net energy stored in the hydrogen produced to the total invested energy. It has recently been proposed as a benchmark tool by the international energy agency (IEA) in the guideline methodology for the net energy analysis [4]. Another key performance indicator, specific for hydrogen, is the Levelized Cost of Hydrogen (LCOH), which considers the cost of hydrogen production process and is calculated as the ratio between the net discounted costs over the amount of produced hydrogen [5]. Inputs to LCOH include cost of capital, investment costs and plant lifetime. These two indicators focus on hydrogen productions in terms of energy consumption and economic analysis, however, they are insufficient for determining the overall environmental effect of the activities under consideration. We carried out a complete Life Cycle Assessment (LCA) study to achieve this goal.

In this paper we demonstrate how to use process simulation for the estimation of the performance indicators described above. Specifically, we compare different methods of production of hydrogen each one defined by the appropriate colour code: (i) green hydrogen, produced by electrolysis of water using electricity from renewable source, (ii) yellow hydrogen, produced by electrolysis using grid electricity, (iii) grey hydrogen, produced from natural gas using steam reforming, and (iv) blue hydrogen, like grey one, but with carbon capture and sequestration (CCS).

MATERIALS AND METHODS

Process simulation is used to perform material and energy balances, physical property estimations, design/rating calculations, process optimization, heat integration and economic analysis evaluation for a given hydrogen production process. The simulation starts with the definition of the problem and its objective. The process model consisting of process flow configuration and accompanying equations is then developed. Since in process simulators, constants and equations are already built-in to the system, it is only necessary to select the unit models, thermodynamic models and method of solution. Additional data is collected if data gaps were identified and required for the model: these may include stream data, equipment data/specification and operating data. The equations are solved and the results are then analysed if further improvements can be made. The process is repeated until the it is finally optimized [6].

The following processes have been simulated using Aspen plus™ 12.0: (i) water electrolysis (Figure 1), (ii) methane steam reforming (Figure 2 left) and carbon capture and storage (Figure 2 right). Material and energy balance data coupled with cost estimation obtained by process simulation software are used to calculate the following performanceindicators: EROEI, LCOH and LCA.

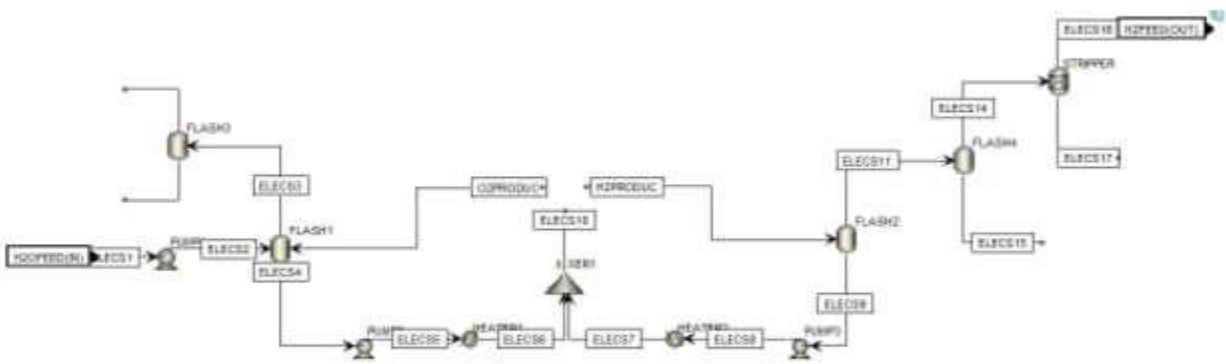

Figure 1. Water Electrolysis process flowsheet within Aspen Plus™..

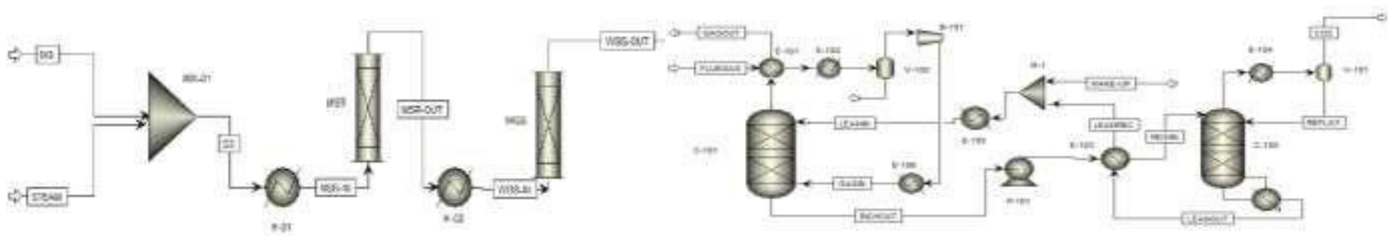

Figure 2. Methane steam reforming process flowsheet (left and MEA carbon capture process flowsheet (right) within Aspen Plus™..

The equation for the calculation of EROEI is:

$$EROEI = E_{out}/E_{in} \tag{1}$$

where E_{out} is the available energy that the process stores in the hydrogen (140 MJ/kg) and E_{in} is the total energy that is provided and consumed during the production and operations periods of the plant and is made up of three contributions: E_{cap} is the capital energy embodied in the materials and used for construction and decommissioning of the plant; $E_{o\&m}$ is the energy needed for operating and maintaining the power plant; E_f is the energy needed for procuring and distributing the fuels, which includes also the energy used for extracting, refining and transporting the fuels from the production well to the power plant. All terms are expressed in GWh for consistency: the EROEI is thus dimensionless [7].

The LCOH is calculated as follows [7]:

$$LCOH = \frac{COST_{Initial} + \sum_{t=1}^{N} \frac{COST_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{Q_{ht}}{(1+r)^t}} \tag{2}$$

Where $COST_{Initial}$ [€] is the initial capital investment, $COST_t$ [€] is the cost at year t, r [%] the discount rate, and Q_{ht} [t] the hydrogen production. *$COST_{Initial}$ is equal to the TPC and $COST_t$ is evaluated from OPEX and* $s_{o\&m}$.

The LCA procedure employs material and energy balances over the entire life cycle of the product system, taking into consideration the extraction of raw materials, manufacturing, use phase, end-of-life and the transportation between life cycle stages [8]. The results of life cycle assessments are depicted by means of several impact categories, which are able to represent the entire range of ecological burdens associated with the product system, avoiding shifting the impact among environmental compartments. The LCA procedure involves the implementation of four main phases: goal and scope; Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and interpretation.

RESULTS AND DISCUSSION

Material and energy balance data coupled with cost estimation obtained by process simulation software are used to calculate the performance indicators. EROEI, LCOH and LCA are calculated using the methods explained above. The following common data were used for all the processes considered: L=20 years, ε_c = 0.656 €/kWh, Q_{H2} = 1000 kg/h, HHV_{H2} = 39.4 kWh/kg, discount rate = 7.3%.

The estimated indicators are reported in table 1. EROEI and LCOH shows that the best technology in terms of energy and cost impact is the hydrogen produced by electrolysis using energy from photovoltaic modules.

Table 1: EROEI and LCOH values for the different hydrogen colours considered.

Quantity	SMR – Grey H_2	SMR & CCS – Blue H_2	Electrolysis – Green H_2	Electrolysis – Grid H_2
E_{out} [GWh]	4559.59	3933.01	6706.492	6706.49
E_{cap} [GWh]	1017.251	1318.601	552.114	552.114
$E_{o\&m}$ [GWh]	956.216	791.161	220.846	220.846
E_f [GWh]	315.761	300.001	335.325	220.608
EROEI	1.99	1.63	6.05	6.75
LCOH	2.15	3.23	5.12	5.49

As far as LCA results is concerned, Climate Change (CC) is strongly reduced using green hydrogen in comparison with the other ones. Water-related impact categories are mainly affected by raw-material extraction for construction of renewable technologies and electricity distribution network. Air-related impact categories are driven by emissions during fossil fuel combustion, therefore green hydrogen exhibits the best performances.

CONCLUSIONS

Four hydrogen production processes have been simulated and the results of the simulations are used for the estimation of the indicators of interest; EROEI, LCOE, and LCA. The integration of indicators' evaluation with processsimulation produces a double benefit: (i) we extended the scope of process simulation by considering up-to-date indicators of impact on energy, economy and environment and (ii) process evaluation may be performed at design time. The values of the key performance indicators shown in Table 1 indicates that the best route for producing hydrogen in terms of global impact is the green hydrogen, based on electrolysis of water.

REFERENCES

1. https://www.ipcc.ch/report/sixth-assessment-report-cycle/ AR6 IPCC 2021 report. Accessed on December 7, 2021.
2. https://www.iea.org/reports/net-zero-by-2050 IEA (2021), Net Zero by 2050, IEA, Paris, Accessed on December 7, 2021.
3. Hall, C.A.S.; Lambert, J.G.; Balogh, S.B. 2014. EROI of different fuels and the implications for society. Energy Policy, 64, 141–152.
4. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf in the Annual Energy Outlook 2021, Accessed on December7, 2021.
5. Minutillo M., Perna A., Fprcina A., Di Micco S., Jannelli E. 2021. Analyzing the levelized cost of hydrogen inrefueling stations with on-site hydrogenproduction via water electrolysis in the Italianscenario. International Journal of hydrogen production, 46, 13667 – 13677.
6. Mio A., Barbera E., Massi Pavan A., Danielis R., Bertucco A., Fermeglia M., Analysis of the energetic, economic, and environmental performance of hydrogen utilization for port logistic activities, submitted to Applied Energy (2022).
7. Fan, J. , Yu, P., Li, K., Xu, M., Zhang, X., 2022, A levelized cost of hydrogen (LCOH) comparison of coal-to-hydrogen with CCS and water electrolysis powered by renewable energy in China, Energy, 242, 123003.
8. EC-JRC. ILCD Handbook - General guide for Life Cycle Assessment. 2010.