Allocation of Hydrogen Produced via Power-to-Gas Technology to Various Power-to-Gas Pathways

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Abstract

The global energy sector is growing fast which requires a quicker shift to renewable energy to maintain the rise in the global temperature. Unlike conventional power plants, electricity from renewable sources cannot be adjusted easily to match consumer power demand because renewable resources are intermittent short-term seasonal power sources. Accordingly, a rapid increase in surplus power is expected in the future. Instead of losing the surplus power or exporting it for low returns, storage and utilization in other sectors urgently need to be explored. Power-to-Gas technology offers a possible solution for optimal use of energy surplus and helps managing the intermittent and weather-dependent renewable energies like wind, solar, or hydro in a storable chemical energy form. The main concept behind Power-to-Gas technology is to make use of surplus electricity to decompose water molecules into their primary components: hydrogen and oxygen. Power-to-Gas is not only a storage technology; its role can be extended to other energy streams including transportation, industrial use, injection into the natural gas grid as pure hydrogen, and renewable natural gas. The goal of the current study is to investigate the feasibility of four specific Power-to-Gas pathways in Ontario, Canada. The pathways examined are Power-to-Gas to mobility fuel, Power-to-Gas to industry, Power-to-Gas to natural gas pipeline for use as hydrogen-enriched natural gas, and Power-to-Gas to Renewable Natural Gas (i.e., Methanation). The study quantifies the hydrogen volumes at three production capacity factors 67% (16 h/day), 80% (19 h/day), and 96% (23 h/day)upon utilizing Ontario's surplus electricity baseload. Five allocation scenarios (A-E) of the hydrogen produced to the four Power-to-Gas pathways are investigated and their economic and environmental aspects considered. Allocation scenario A in which hydrogen assigned to each pathway is constrained by a specific demand is based on Ontario's energy plans for pollution management in line with international efforts to reduce global warming impacts. Scenarios B-E are about utilization of the produced hydrogen entirely for one of mobility fuel, industrial feedstock, injection into the natural gas grid, or renewable natural gas synthesis, respectively. The study also examines the economic feasibility and carbon offset of the PtG pathways in each scenario. The amount of surplus baseload electricity for 2017 of each capacity factor is converted to hydrogen via water electrolysis. Accordingly, the total hydrogen produced is approximately 170 kilo-tonnes (kt), 193 kt, and 227 kt, respectively. Results indicate that the Power-to-Gas to mobility fuel pathway in scenarios A and B has the potential to be implemented. Utilization of hydrogen produced via

Power-to-Gas technology for refueling light-duty vehicles is a profitable business case with an average positive net present value of $4.5 billions, five years payback time, and 20% internal rate of return. Moreover, this PtG pathway promises a potential 2,215,916 tonnes of CO2 reduction from road travel. In the scenario to utilize Ontario's surplus electricity to produce hydrogen via the PtG technology for industrial demand, results indicate that supply could achieve 82%, 93%, and 110% of the industrial demand for hydrogen at the three capacity factors, respectively. Nevertheless, hydrogen production through PtG is still costly compared to other available cheaper alternatives, namely hydrogen produced via steam methane reforming. Power-to-Gas for industry projects should, however, be part of government incentives to encourage clean energy utilization. In addition, although using hydrogen-enriched natural gas or renewable natural gas instead of the conventional natural gas could offset huge amounts of carbon, their capital and operational costs are extremely high, resulting in negative net present values and very long payback time.

Biographies

Azadeh Maroufmashat is a postdoctoral fellow in Chemical Engineering, University of Waterloo. She obtained her B.Sc. degree in Mechanical Engineering in 2007 and her M.Sc. and Ph.D. in energy system engineering in 2010, and 2015, respectively, all from Sharif University of Technology, Tehran, Iran. During her PhD, she was a visiting scholar at the University Waterloo. Now she is working on different projects related to the modeling and optimization of different energy conversion and storage systems at University Waterloo as a postdoctoral fellow. Her research interests lie at the intersection of energy system modeling, optimization and policy recommendations and her research contributions have been to the optimal integration of sustainable energy generation and storage technologies with the current energy system. She has investigated the technical, environmental, and economic aspects of urban energy system modeling (a Micro-grid application), and power-to-gas as a feasible energy storage technology and a low-carbon sustainable energy alternative for transportation and for the hydrogen economy. Her future research will be to addressing climate change issues in large scale energy system modeling. She has a number of advising experiences; as examples of successful mentorship, the teams that she co-advised, was the Grand prize winner (2016) and honorable winner (2018) of the Hydrogen student design contest, held by the Department of Energy (DOE) of the United States.

Michael Fowler is a Professor and is cross-appointed to the Department of Mechanical and Mechatronics Engineering at the University of Waterloo. Professor Fowler's research focuses on electrochemical power sources in vehicles, specifically degradation analysis and control of batteries in hybrid and plug-in hybrid power trains. His interest takes him into the modelling of fuel cells and requires simulating the performance and reliability of fuel cells and batteries. Professor Fowler's research group is interested in performance evaluation, diagnostics, and forensics associated with fuel cell stacks, single cells and batteries. His study of fuel cell failure mode and reliability also encompasses the extensive development of polymers due to their function as the fuel cells' electrolyte, gas diffusion layer and blending of polymers for conductive bipolar plates. His expertise in fuel cell technology has landed him the position of co-faculty supervisor of competitive vehicle team design projects; ChallengeX and EcoCar where he has supervised the development of two fuel cell vehicles, and two plug-in hybrid vehicles. Professor Fowler assists these teams with their design, construction, implementation and testing of hybrid vehicles. He also supervises other award-winning student teams in the design of Green Energy Systems.

Ali Elkamel is a Professor of Chemical Engineering. He is also cross appointed in Systems Design Engineering. Prof. Elkamel holds a BSc in Chemical Engineering and BSc in Mathematics from Colorado School of Mines, MS in Chemical Engineering from the University of Colorado-Boulder, and PhD in Chemical Engineering from Purdue University – West Lafayette, Indiana. His specific research interests are in computer-aided modelling, optimization and simulation with applications to energy production planning, carbon management, sustainable operations and product design. Professor Elkamel is currently focusing on research projects related to gas production and processing, integration of renewable energy in oil and gas operations, and the utilization of data analytics (Digitalization), machine learning, and Artificial Intelligence (AI) to improve process and enterprise-wide efficiency and profitability. Prof. Elkamel activities include supervising post doctorate and research associates, advising graduate/undergraduate students and participation in both university and professional societal activities. Professor Elkamel is also engaged in initiating and leading academic and industrial teams, establishing international and regional research collaboration programs with industrial partners, national laboratories and international research institutes.