Yrjö Majanne*, Venla Vilhonen, Sami Repo, Matti Vilkko

Green Transition, Systemic Approach to Green Hydrogen Based Power2X Value Chain

Abstract: Green hydrogen based Power2X value chain consists of renewable electricity production, electrolysis-based hydrogen production, end product production such as methane, methanol and ammonia, and final use of these end products combined with energy transmission and storing in different forms. Different stages of the value chain have different operational and regulative requirements, which must be brought together to make the whole system operable. This paper presents some results how operational characteristics and physical locations of value chain units effect on the operation and costs of the whole energy system. Analysis is based on simulation and scenario work carried out in Business Finland financed HYGCEL project.

Keywords: Green transition, Hydrogen, Energy systems, System dynamics

*Corresponding Author: Yrjö Majanne: Tampere University, E-mail: yrjo.majanne@tuni.fi
Venla Vilhonen: Polar Night Energy,
E-mail: venla.vilhonen@pne.fi
Sami Repo: Tampere University,
E-mail: sami.repo@tuni.fi
Matti Vilkko: Tampere University,
E-mail: matti.vilkko@tuni.fi

1 Extended Abstract

Transition from fossil carbon to carbon free/neutral energy system is an enormous project. In 2023 the global energy consumption was 182 230 TWh, of which 140 000 TWh, 76 %, was fossil origin. In Finland the total primary energy consumption was 366 TWh, of which 110TWh, 30%, was fossil origin. Thus, getting rid of fossil energy is not a fine tuning of the existing energy system, but it means a revolution in the whole society, how energy will be produced and consumed.

Electrification of energy consumption as much as possible by renewable and low carbon electricity will be in a key role in the energy transition. Where direct electrification is not feasible, hydrogen and its' derivatives will be utilized.

One main challenge in green transition is the variable nature of renewable electricity production. Main sources of new installed renewable electricity will be wind and solar power. Because of the giant scale of the new electricity production capacity required to replace fossil energy, the share of variable renewable energy will dominate the electric power systems in future.

As well known, power production and consumption in electric power system must be equal in every second. In order to help to keep the electric power system stable, EU has imposed a delegated act of the Renewable Energy Directive (RED) which states that in green hydrogen production, the renewable electricity consumption of electrolyzers must follow the contracted electricity production in one hour time window. This will enter into force from 2030. Before that the balancing time window is one month.

This requirement implies that green hydrogen production will be variable as well as renewable electricity production. This will have several impacts on the whole Power2X value chain. Electrolyzers must be operated at frequently varying operation points, which must be taken into account in process and automation design. Also the dimensioning of the electrolyzer capacity must be optimized based on the generation profile of the contracted electricity producer and desired total production capacity. The full load hours of the designed electrolyzer plant will be around 4 000 hours, which means poor investment efficiency. However, with estimated investment costs of electricity battery storages and electrolyzers, it is more economic to invest in over capacity of electrolyzers instead of required battery capacity to smooth the fluctuations in electricity production.

Hydrogen production and production of synthetic methane or methanol has sectoral interconnections which must be considered. In hydrogen production app. 30 % of supplied electric energy is converted to heat, which can be applied in heating applications, e.g. in district heating. This will improve the operation economy of the hydrogen production but must be included in the operation design of the process. In hydrogen methanation, CO2 is needed as another raw material besides hydrogen. CO2 will be captured from flue gases of combustion plants like industrial or heating CHP plants. Carbon capture process is energy intensive and has an impact on the thermal power output of the CHP plant. This must also be considered in system design and operation.

Hydrogen end use and refining processes are not flexible but must be operated at constant operation points or within a narrow operation range with slow change rate of the operation point. They cannot be frequently switched on and off. This results that Power2X value chain must contain also hydrogen buffer storages to smooth the variable hydrogen production to constant supply flow for further processes. It is also an optimization task to design the optimal storage capacity according to the investment cost of storage capacity and value of increased production achieved by a certain storage capacity.

Renewable electricity production sites are distributed over large regions. This leads to a need of energy transmission. If hydrogen is produced near electricity production, the transferred media will be hydrogen. If hydrogen is produced near industrial end use, huge amount of electricity must be transferred across the country. Which is feasible depends on the geographical locations of the renewable energy production sites in relation with the main power transmission grid and required capacities. In case of huge power transmission needs, hydrogen grid is superior. One 1,2 m diameter hydrogen pipe at 80 bar pressure can transmit 12 GW power, which is as much power as 15 parallel 400 kV electricity lines.

As described, Power2X value chain has many interconnected characteristics and sectoral connections, which must be considered when designing the structure and the operation of the total system. The role of automation will be essential when synchronizing and optimizing the operation of the whole value chain. In the proposed paper we will introduce some results about different scenarios modelled and simulated about the future Finnish energy system. The scenarios will analyze the behavior of different capacities and locations of renewable electricity, hydrogen, and end product productions and resulting needs of energy transportation and storing.

The presented research work is done mainly in Business Finland financed HYGCEL research project in 2022 - 2024.