WP4 TASK 2

Plant-level design and flexibility

ABSTRACT

Task 4.2 focused on the plant-level design and operation of different PtX systems. The interest of the research was to study flexibility and system integration, and as well as optimization of unit operations and capacities. The research was conducted by modelling single components and individual plants, using software such as Aspen Plus and Calliope. Techno-economic analysis was done for the production of hydrogen and e-methanol from electricity mixtures by wind, solar, and grid, with a mixed integer-linear programming (MILP) method. Calendar years were studied in one-hour time intervals. Process models were developed for hydrogen compressor and steel tank storage, and cryogenic capture of CO_2. Results show suggestions for H_2 compressor and tank design for different operation conditions, and the effect of storage cost to overall H_2 cost was estimated. Unit capacities and operation were optimized for hydrogen and e-methanol production, and the impact of uncertain cost parameters was estimated. Fully electrified, integrated CO_2 capture process showed cost and efficiency benefits.

MOTIVATION

New low-emission electricity production from solar and wind is the foundation for sustainable power-to-x products. This is a highly intermittent operation environment for large-scale industrial processes. Also, the cost of these green hydrogen-based products should be low enough to achieve wide usage. Many potential value chains include CO_2 capture and utilization, to re-use the CO_2 in atmosphere and to produce more valuable products like methanol. Detailed knowledge of PtX-processes and their implementation is required, to show the potential, limitations and costs. Knowledge from process modelling is applicable in techno-economic analysis of industrial cases.

RESULTS

Flexibility in processes brings additional benefits, i.e. flexibility has value. It allows production of green products from wind and solar while coping with the fluctuations in production and price, within the context of future regulation. Flexible processes can be more easily integrated with the rest of the energy system, allowing the operation according to the demands for electricity, heat, hydrogen, and other carriers, such as methanol, methane, or ammonia. Flexibility is gained from operation of storages (hydrogen, CO2, heat, end products), processes (electrolysis, synthesis, CO2 capture), and heat sources and sinks (CHP, district heat) that are integrated to the process.

Hydrogen storage has been found to be the key to flexibility in PtX-systems. Small, dedicated storages could be used at individual plants, or large-scale storages could be shared with multiple users. Storage has substantial costs, but it brings benefits during operation. Design of the storage is highly case-specific, due to for example the pressure levels and profiles of hydrogen production and consumption (Table 1).

Table 1. Hydrogen tank storage for 100 MW electrolysis (20 % of H2 is assumed to be delivered via storage).

Storage time (h/d)	Optimal pressure (bar)	Capacity (t)	LCOH (€/kgH2)
6 h	10	2.2	0.07
12 h	27	4.3	0.09
24 h	54	8.6	0.14
2 d	91	17.3	0.20
4 d	150	34.5	0.32
7 d	228	60.4	0.47
14 d	370	120.9	0.76

There are two main purposes for H_2 storage: 1) take advantage of electricity price differences and 2) allow operating the process with variable renewable electricity.***Figure 1*** Storage capacity (Figure 1) was determined by cost optimization, taking into account fluctuations in electricity prices, availability of resources (wind and solar), investment costs, and the capacity factors of units affected by storage size, such as electrolysis and synthesis. There are large differences between calendar years in the production of wind and solar and it was found that combining wind and solar together will reduce the storage demand.

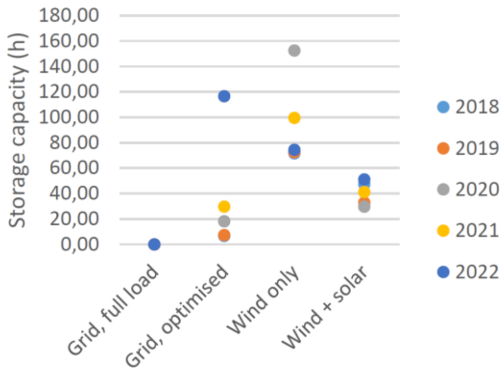

Figure 1. Optimized H2 storage capacity varies within years, wind+solar mixture reduces variation.

The optimal operation and unit capacities of the other processes (electrolysis, synthesis, CO_2 capture) were found to be **strongly case-specific** and depend on the input parameters. Especially the cost assumptions regarding future prices (equipment prices, energy prices, etc.) may affect the results significantly. Global sensitivity analysis can be used to address this, to find important parameters and interaction of them. As an example, high investment costs can cause the optimal system to be less flexible, as high full-load hours are required (Figure 2).

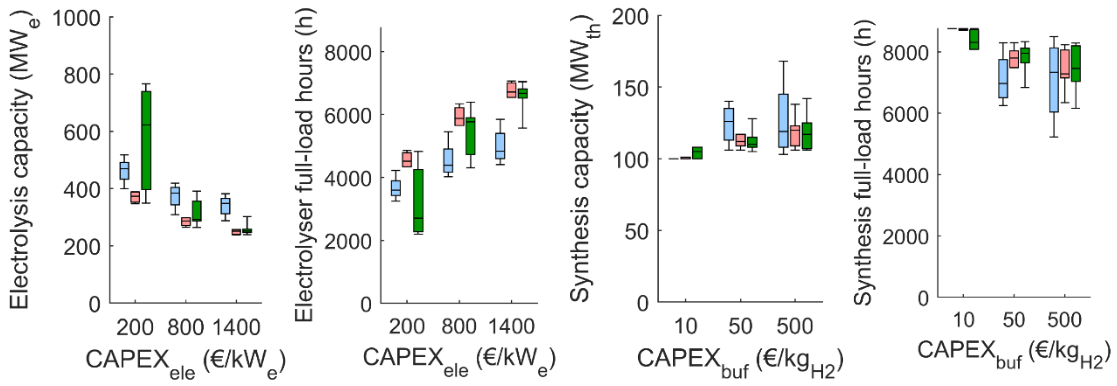

Figure 2. Effect of investment costs of electrolysis and H2 storage on capacities and full-load hours of electrolysis and synthesis. Whiskers show the minimum and maximum, the bar is for the middle 50% of the cases, and the horizontal line defines the median value among all studied cases.

Cryogenic CO_2 capture was studied as an example. This study investigated an integrated multigeneration system that produces power, cooling, and solid carbon dioxide by applying electricity-driven cryogenic carbon capture from flue gas. The integrated system comprises a gas turbine, Rankine cycle, absorption chiller, helium refrigeration cycle, and CO_2 capture process (Figure 3). Waste energy recovery is the key factor in this system. The benefits of the studied system were increased energy and exergy efficiency, low capture cost, and solid CO_2 as the product.

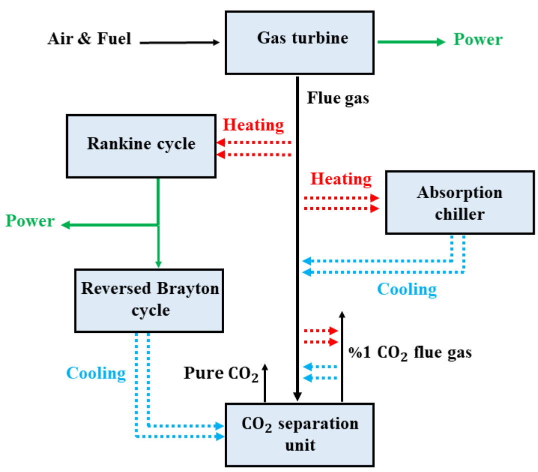

Figure 3. Schematic of the proposed integrated system.

APPLICATIONS/IMPACT

First, the results provide practical examples about how individual PtX processes and plants could be designed and operated to bring value from flexibility. The finding is relevant at the level of the individual plant and at national level and hence the question arises: is it desirable to build flexibility at the plant level or at the entire energy system level? Second, the study reveals the importance of H_2 storage optimizing. It should be considered whether storages should be built at local or at national scale, as the specific cost of large-scale cavern-type storage is much smaller compared to smaller plant-specific steel tanks or underground pipes. Third, it was found that process integration brings benefits. Local industries and communities should co-operate to find optimal PtX solutions already in the design phase.

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