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Energy Procedia 61 (2014) 2201 – 2205

Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Economic Feasibility of Pipe Storage and Underground Reservoir Storage Options for Power-to-Gas Load Balancing

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Abstract

This paper investigates the economic feasibility of Power-to-Gas (P2G) systems and gas storage options for both H_2 and renewable methane. The study is based on a model-based analysis using the net present value (NPV) method, as well as Monte Carlo simulation for taking fuel and electricity price risks into account. We study three investment cases: a *Base Case* where the gas is directly sold, a *Variant A* where temporal arbitrage opportunities between the electricity and gas market are exploited, and a *Variant B* where the balancing markets (secondary reserve market for electricity, external balancing market for natural gas) are addressed. Centralized and decentralized storage facilities are compared with each other and the optimal type and size determined. In a detailed sensitivity analysis and cost analysis we identify the key factors which could potentially improve the economic viability of the concepts assessed. We find that P2G for bridging the balancing markets for power and gas cannot be operated profitably. For both temporal arbitrage and balancing energy, pipe storage is preferred. Relatively high feed-in tariffs (100 € MW^{-1} for H_2, 130 € MW^{-1} for methane) are required to render pipe storage for P2G economically viable.

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Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: Underground reservoir storage; Power-to-gas; Load balancing; Synthetic natural gas (SNG)

1. Introduction

Power generation in Germany is shifting from fossil and nuclear fuels to renewables, thus increasing supply fluctuations and challenging security of supply. Energy storage, besides distributed generation, demand response, and the integration of new transmission lines, is expected to foster the balancing of the power system. In this context, P2G is a relatively new concept which enables to transform surplus power

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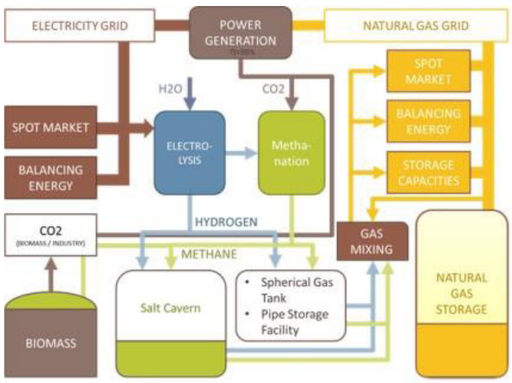
Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.109

to hydrogen (H_2) by electrolysis or even to renewable methane (CH_4) by additional methanation. The resulting product can then be marketed directly or stored in designated pipe storage or underground reservoir storage facilities. The conversion to hydrogen has an efficiency of about 75–80%; a further conversion to renewable methane yields a 60–65% and a Power-to-Gas-to-Power process would have an even lower efficiency of around 36% [1]. P2G combines the volatile supply characteristics of power from renewables with the seasonal demand characteristics of gas, the latter of which is partly kept in special storage facilities to supply the markets uninterruptedly also during the cold season. A key financial risk for investments in a P2G system stems from the price risks for power purchases and resulting gas sales. Feasible storage options can help to balance these price risks and enable P2G applications in the future. H_2, as an intermediate production input, requires larger storage volumes, demanding higher investment costs and thus lower profitability. In contrast, CH_4 requires 4–5 times less storage volume, enhancing its economic viability. P2G may also be used for temporal arbitrage in the spot market, or offered for ancillary system services to the TSO.

The main focus of our study is on the identification of the most feasible technologies and systems for future market applications, and their differentiation. Specifically, we compare P2G systems which are solely based on H_2 generation with and those which use the additional step of methanation to produce renewable methane (SNG). The economic analysis includes the assessment of storage requirements and the decision of an appropriate medium.

2. Methodology

Three investment cases for a P2G system are performed on different energy markets: The *Base Case* investigates the general production costs of H_2 and CH_4 and the procurement of power and the direct sales of gas on the respective spot markets. Stochastic modeling of power and natural gas prices is integrated to provide a probabilistic assessment. *Variant A* expands the Base Case and uses gas storage for temporary arbitrage between the electricity and the gas markets, with the aim of maximizing economic outcome. Project-specific storage facilities (salt cavern / gas tank / pipe storage) are compared with storage capacity reservations in a decentralized storage market. The optimal storage operation is investigated with regard to size and type. *Variant B* investigates a P2G system on the balancing markets, such as the secondary reserve market for electricity and the external balancing market for natural gas. This case includes some variations also used in Variant A. Figure 1 shows the structure of the P2G system model used.



The economic assessment is carried out using different approaches and steps. All models are assessed over a 20-year production period, and investments are all made in year 1 (21-year project life). An economic model is set up according to the *NPV method*. Input parameters, such as price, investment costs or production costs, are varied to check the project's feasibility. Depreciation schemes and tax rates can be altered to identify the pre-tax versus the post-tax outcomes and to study the fiscal impact on projects. Parameter variations are performed in a *sensitivity analysis* to determine the individual impact on the economic outcomes of the P2G system. A *Monte Carlo simulation* is performed, providing probabilistic and average values based on the probability distributions of the input parameters. Price risks within the market, as well as the retrieval of balancing energy, are analyzed through statistical tests. Optimal values for important decision and market variables (size, capacity, stop-loss, take-profit) are derived by means of *stochastic optimization* (see [2] for details). Electricity procurement and gas sales for the P2G system are provided by day-ahead trading on the spot market or through the offer of capacity service on the secondary reserve market (power) and the external balancing energy market (gas). A Brownian motion is applied for simulating the spot prices, to optimally integrate uncertainties though renewable power supply.

3. Results and discussion

All P2G systems (~5 MW) assessed in the *Base Case* or *Variant A* have negative *Net Cash Recoveries Before Tax* (NCR BT) regardless of the gas type or storage operations (Fig. 2, upper left plot). The integration of a salt cavern for long-term storage even further deteriorates the negative NCR BT. Overall, gas storage only improves the outcome with some smaller benefits reaped through the integration of cheaper gas tanks or pipe storage tanks. The P2G systems operating between the balancing markets in *Variant B* provide more positive outcomes, especially for higher capacity systems (~50 MW) showing positive NCR BT. Renewable methane has the highest NCR, due to the increased capacity offered on the secondary reserve market, and has reduced storage costs through the integration of a pipe storage facility. H_2 production also has a positive outcome for the high capacity plant, although only with a probability of 65%. However, in this case a higher-investment salt cavern is needed to manage the higher hydrogen volumes, adding investment risks especially for the gas type belonging to the first family.

Considering the standard deviations from Monte Carlo simulations for all NCR values before tax, we find that H_2 and CH_4 show similar values, except for *Variant B*. The integration of a surface storage device for P2G shows lower deviations by more than one third for all cases in comparison to the Base Case. This means that storage reduces the risk of price differentials, and provides a more robust operation between the electricity and gas sectors. The option of using a storage device between the balancing markets for power and gas, however, provide increased standard deviations with increasing system capacity. This relies on numerous factors. First, the retrieval of capacity for both the electricity and gas markets is characterized through uncertain fluctuations in the grids. Second, bid sizes and capacity rates provide price risks and uncertain positions in the merit order for the retrieval of system services.

A further comparison is given through the average specific production costs (Fig. 2, upper right plot). In comparison to H_2, the generation of renewable methane has higher production costs due to additional methanation capital investment requirements and to the lower overall conversion efficiency. The specific production costs also show what gas price is needed to achieve a 10% rate on return of the project or, put differently, that the NPV is just zero at a 10% discount rate. Here, it is obvious that the assessed cases are relatively far from being a profitable return scenario.

Finally, we compare storage sizes for a pressure range of 6–18 MPa (Fig. 2, lower right plot). For the *Base Case*, storage size has only a minor impact on the required geometric volume, as the on-site tank storage has the sole purpose of collecting the daily production volumes. The same applies to the third *Variant A* case for storage capacity. Cavern storage volume is about three times as high as that of pipe storage. A significant difference results from the optimization in *Variant B*, where hydrogen requires a five times greater geometric storage volume than methane. The only possible solution which could manage this type of operation is given through the integration of a larger salt cavern, which would, however, necessitate significant investments. Pipe storage as an alternative would require a pipe length of several kilometers. In the case of a spherical gas tank application, the installed capacity would require more than 100 units for a 40 MW-H_2-P2G system [2].

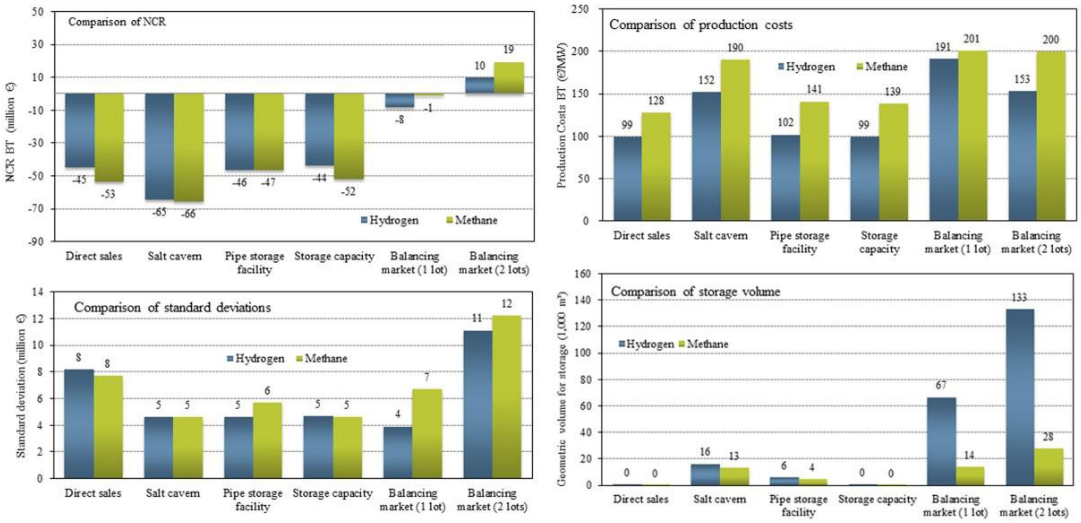


Fig. 2: Comparison of average means (million €) / standard deviations (million. €) for NCR BT, productions costs (€/MW) and storage volumes (m³) of investigated scenarios for hydrogen and renewable methane.

4. Conclusion

Presently, P2G cannot be economically operated between the balancing markets for power and gas, assuming an investment case at 10% discounting. An operation between the spot markets, with the purpose of direct sales or temporal arbitrage, has high uncertainties, while also creating highly negative economic results. The storage of H_2 is less attractive. The results from our analysis suggest to sell H_2 directly and to blend the gas into the pipeline grid. In the case of balancing energy, a high investment in a salt cavern would be required for the storage of larger quantities of H_2. The storage of renewable methane (SNG) has a positive economic impact. For temporal arbitrage and for balancing energy a pipe storage facility turns out to be the favored storage solution. Contractual storage capacities would theoretically improve the economic viability of H_2, if allowed. For renewable CH_4, capacity bookings provide little positive impact and lower flexibility. Both P2G technologies are exposed to price risks of the two commodities. Furthermore, balancing energy increases the risk through the uncertainty of retrieval. Predictions of the economic outcome are highly uncertain. To promote pipe storage for P2G, a fixed feed-in tariff of 100 € MW^{-1} for H_2 and 130 € MW^{-1} for methane would be required.

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Biography

Christoph Budny, MSc, is a portfolio manager at Trianel, a group of more than 50 municipal utilities with headquartered in Aachen, Germany, where he focuses on the strategic optimization of electricity portfolios and energy market analysis. He holds a master's degree in georesources management from RWTH Aachen University, Germany.

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Dr Christoph Hilgers is professor of reservoir petrology at RWTH Aachen University, Germany. He teaches reservoir geology, reservoir petrology, and energy resources management. His main research interests are porous and fractured reservoir-rocks as well as process and strategy analyses for the optimum utilization of reservoirs, storages, and georesources.