ANNEX 2: ForskEL 2014_1_12164_Final Report (P2G-Biocat)

Power-to-Gas via Biological Catalysis

WP9: Development of value maximizing strategy

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Contents

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Preface

This report is made as a part of the project: "Power-to-Gas via Biological Catalysis" that analyses and demonstrates commercial operation of a P2G facility producing pipeline ready biomethane from electricity. The report covers task 9-2 as described in the application, which is a part of WP9 – "Market analysis & Trading strategy".

The analyses and report are conducted by Lasse Helleskov Ravn, Neas Energy. The final calculations are made in October 2016 based on the latest known technical characteristics for the P2G plant. This report is made in continuation of "Market Analysis Report" that covers task 9-1. Both reports are submitted as an annexes to the final report.

The demonstration project is supported by the ForskEL program, which administered by Energinet.dk. The partners in the project are:

- Electrochaea (Project coordinator)
- Hydrogenics
- Audi
- Energinet.dk
- Neas Energy
- HMN Gashandel
- SVC Avedøre
- Insero Business Services

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1. Development of value maximizing strategy

The purpose of the analyses is to determine the optimal trading strategy and a model is developed for the purpose. Inputs to the model are technical characteristics for the P2G plant, historical electricity and gas market price data, other operation costs and revenue streams from output products. Two different scenarios and three different trading strategies are analyzed. Based on a comparison of the annual operation cost and revenue, the optimal trading strategy is determined.

2. Operation conditions

The electrolyzer has a maximum hourly production of 200 Nm^3 hydrogen and 90 Nm^3 oxygen. The electricity consumption is 5.23 kWh/Nm^3 H2 corresponding to 1.046 MWh electricity for producing 200 Nm^3 hydrogen. Additionally, the methanation plant consumes approximately 40 kW for the compressor, agitator and circulation pump. Therefore, the total electricity consumption for producing 200 Nm^3 H2 is 1.086 MW. When there is no flow i.e. when the electrolyser is not producing hydrogen the compressor and circulation pump is switched of and the methanation plant only consumes 4-5 kW (agitator). In standby mode the electrolyser consumes 0.3 kW when the outside temperature is positive and between 0.3-25 kW when the outside temperature is negative. In the model it is assumed that the plant consumes 5.3 kW when the electrolyser is not switched on (standby).

The stoichiometric ratio is 4:1 hydrogen to carbon dioxide that gives a maximum hourly production of 50 Nm^3 biomethane. The biomethane is assumed to be 98% methane with a high calorific value of 10.86 kWh/Nm^3 (low 10 kWh/Nm^3). The energy content in 50 Nm^3 biomethane is equal to 0.544 MWh.

In case raw biogas is supplied to the reactor as feedstock the biomethane output is higher due to the methane content in the biogas. Additional 75 Nm^3 of biomethane is produced assuming 40% of the biogas is CO_2. The high calorific value of the methane from the biogas is 11.10 kWh/Nm^3 (100% methane). The energy content from the biogas source is 0.832 MWh.

Heat is generated from both hydrogen and biomethane production, which can be utilized for heating purposes. It is possible to recover 0.27 MWh/h from the electrolyzers when it is running full load and 0.13 MWh/h from the bioreactor. The heat can be used at the treatment plant and it is assumed sold to BIOFOS.

The energy flows are illustrated in Figure 1:

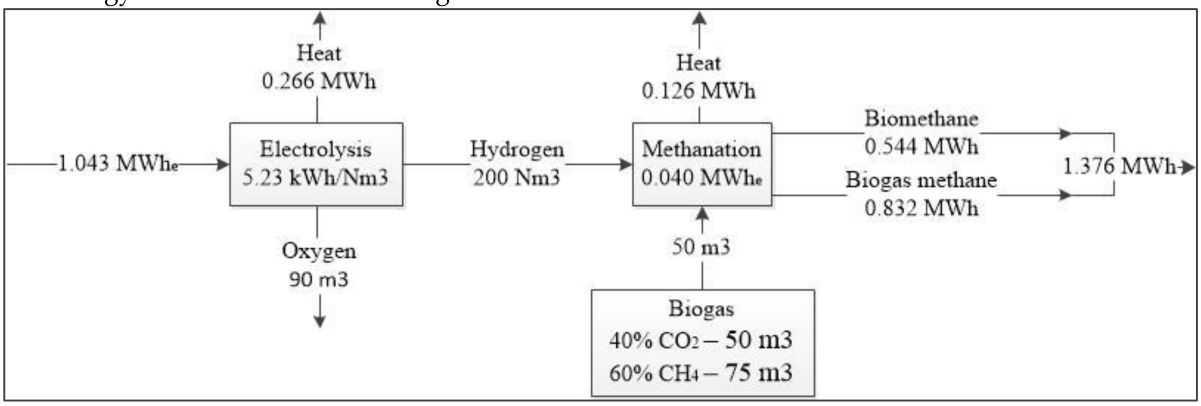

Figure 1: Energy flows at 1 full load hour at the P2G plant.

3. Scenarios

As mentioned, the CO_2 source for the bioreactor can both be biogas or pure CO_2. When the ENZUP-plant is ready for operation HMN Gashandel will purchase the biogas from BIOFOS and upgrade and inject the gas to the grid. The remaining CO_2 will be supplied to the P2G plant to be upgraded to biomethane in the bioreactor. Before the ENZUP-plant is ready, biogas is supplied to P2G plant.

As concluded in the "Market Analysis Report" made as a part of this project, the break-even price for the P2G plant is negative under current framework conditions. Therefore, the operation in the scenarios is limited to 20% full load operation. Table 1 illustrates production of biomethane under the different operation conditions.

	Hourly production (Nm^3/h)	Annual production from full load operation (Nm^3/year)	Annual production from 20% of full load operation (Nm^3/year)
Biomethane biological methanation	50	438,000	87,600
Biomethane biogas	75	657,000	131,400
Total	125	1,950,000	219,000

Table 1: Biomethane production from different operations. The biogas is assumed to contain 40% CO_2 and 60% methane.

3.1 Biogas scenario

In the biogas scenario, biogas is used as feedstock for the P2G plant. The raw biogas is only purchased from BIOFOS in hours where the plant is operated.

3.2 CO_2 scenario

In the CO_2 scenario, HMN purchases the raw biogas from BIOFOS and upgrade the biogas in their purification plant. The separated CO_2 is used, free of charge, as feedstock for the P2G plant. The CO_2 flow is 50 Nm^3/h but as mentioned before it is only in 20% of the CO_2 that is upgraded while the remaining CO_2 is assumed emitted to the atmosphere.

4. Costs and revenues

The costs can be divided in electricity costs, gas grid injection cost and raw biogas cost. The revenues are generated from selling the biomethane to the gas market value, biomethane subsidy, certificate value and heat value. The oxygen is estimated to have such a low value (9 DKK/90 Nm^3 oxygen) that it is not profitable to install a pipe and use it for aeration in the water treatment process.

Figure 2 illustrates costs and revenues for operating the plant for one full load hour (FLH) in the biogas scenario. One FLH consumes 1.086 MWh electricity and produce 0.544 MWh biomethane plus 0.832 MWh biomethane if biogas is used as feedstock.

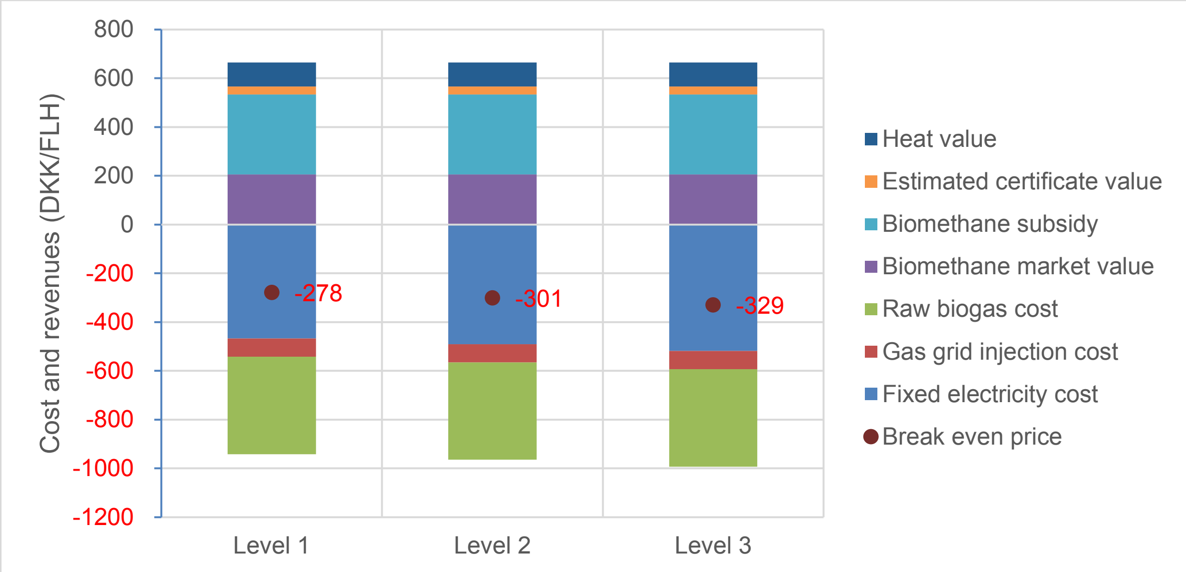

Figure 2: Cost and revenues related to operating the P2G plant for a FLH in the biogas scenario.

The three levels refer to the time-of-use DSO tariff, which is a part of the fixed electricity cost. The gas value is assumed equal to the gas market value at Nordic gas exchange, Gaspoint Nordic. Furthermore, it is assumed that the biomethane is sold to HMN to a price corresponding to the average gas market price in 2015, which was approximately 150 DKK/MWh. The subsidy for biogas injected to the grid was 394 DKK/MWh in 2015. The certificate value is assumed to be 40 DKK/MWh. The heat is assumed to have a value of 250 DKK/MWh heat.

The raw biogas is purchased from BIOFOS at a price of 0.48 DKK/kWh. The fixed electricity costs includes electricity tax, grid tariffs and PSO tariff that have a total cost of 431 DKK/MWh, 452 DKK/MWh and 478 DKK/MWh for price level 1-3, respectively. The gas grid injection cost is paid to HMN and is assumed to be 0.6 DKK/m3 corresponding to 40 DKK/MWh.

The fixed cost are higher than the revenues generated from selling the biomethane, certificate and heat. Biomethane subsidy and certificates are only paid for the part of biomethane that originates from the biogas. The biomathane that is upgraded from CO_2 cannot obtain subsidy or certificates. The brake even price for the three price levels are also illustrated in the figure. As it can be seen, it requires negative electricity prices to have a profitable operation.

Figure 3 illustrates costs and revenues for operating the plant for one FLH (1.086 MWh electricity) in the CO_2 scenario.

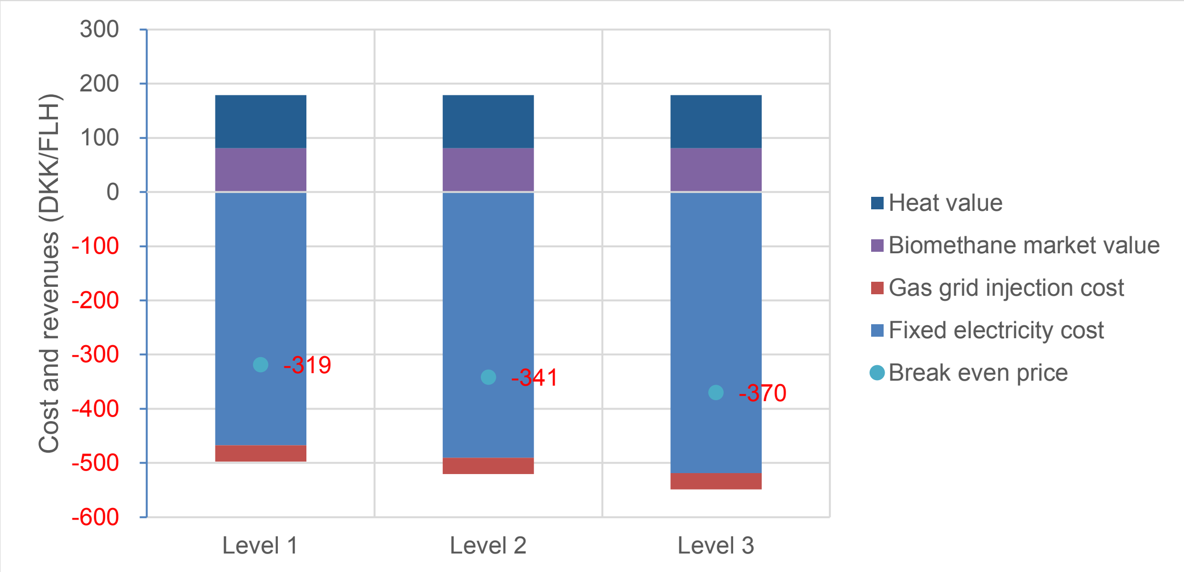

Figure 3: Cost and revenues related to operating the P2G plant for a FLH in the CO_2 scenario

In this scenario the biogas cost and revenues are excluded, otherwise the same costs and revenues are applied in this scenario. The break-even price in this scenario are even lower than in the other scenario. The electricity market price needs to be negative to have a profitable operation. It is not possible to achieve 20% of full load operation if the purchase bids in the Elspot market are negative.

5. Trading strategies

The purpose of the analysis is to determine the optimal trading strategy for P2G plant. One of the tasks in the project is to demonstrate the electrolyzer's capability of delivering frequency regulation i.e. FNR or FDR. These markets are included in their respective scenarios. Furthermore, all strategies applies the electrolyzer capacity in as many markets as possible (see "Market Analysis Report" for description of electricity markets).

For all strategies, the annual operation cost is estimated based on 20% of full load operation (see Table 1). An iterative approach is used to determine the purchase bid price for the market that results in the annual biomethane production of approximately 20% of full load operation. Purchase bids can be seen in Figure 4.

The bids are assumed submitted as hourly price dependent bids. The optimal strategy is the strategy with the lowest annual operation cost. The calculations are based on historical market price figures from 2015.

5.1 Strategy 1

In strategy 1, the electrolyzer capacity is applied in the Elspot, Elbas and the regulating power market. If the spot price is below the bid price, the P2G plant is accepted to consume power in the spot market. The power purchased day-ahead in the spot market can be sold back intraday on the Elbas market or as up regulation in the regulating power market. If this is the case, the P2G plant will not be switch on for the hour in question.

A selling bid for the Elbas market is submitted in hours power is purchased in the spot market. The selling bid for the Elbas market is spot price for the hour in question + 122 DKK/MWh. Selling back electricity has the consequence that the P2G plant is not operated for the hour in question and biomethane is not injected in the grid. This gas amount has to be produced at a later stage with associated electricity cost. Therefore, a certain profit from selling electricity back is needed. A selling price of spot price + 122 DKK/MWh is chosen as 112 DKK/MWh corresponds to the 20 percentile of the spot prices in 2015. An additional 10 DKK/MWh is added to the 20 percentile.

In hours where power is not purchased day-ahead in the spot market, a purchase bid for the Elbas market is submitted. The purchase bid in Elbas is set to 50 DKK/MWh.

The minimum bid capacity for the regulating power market is 10 MW and the electrolyzer is therefore dependent on other consumption units in Neas Energy's portfolio to participate in the market. The bid price for the market has to reflect an estimation of a realistic bid price for a pool of 10 MW consumption. The down regulation bid is assumed to be 0 DKK/MWh and the up regulation price is assumed to be 1000 DKK/MWh. It requires a negative down regulation price to be activated for down regulation (increase consumption). Furthermore, it requires a high up regulation price to be activated. It is rather extreme bid prices but it is because electric boilers are assumed to be a part of the pool. Electric boilers have a different operation pattern compared to a P2G plant.

5.2 Strategy 2

In strategy 2, the electrolyzer capacity is applied in Elspot, FDR, Elbas and the regulating power market. This strategy also includes participation in the FDR market, which is one of the frequency regulation markets in DK2. The market is only up regulation, which means that the electrolyzer has to operate to be able to decrease its consumption.

Bids for the market are given in blocks of three hours for the coming day starting from midnight. If the electrolyzer is accepted in the spot market for one block the full capacity is offered for FDR up regulation. If a bid for the FDR market is submitted it is assumed that the electrolyzer is accepted to deliver the regulation. The capacity has to be available in FDR and it is not possible to submit bids for other markets in the hours the unit is accepted in FDR. In the hours where it is not possible to make bids for FDR bids are made for Elbas and the regulating power market as described above.

5.3 Strategy 3

In strategy 3, the electrolyzer capacity is applied in Elspot, FNR, Elbas and the regulating power market. The FNR market is the other frequency regulation market in DK2. The FNR market is also divided in eight 3-hour blocks per day. However, the regulation service is symmetric meaning the unit must be able to both up and down regulate in accordance with the frequency. It influences the purchase bid for the spot market. The electricity purchase bid has to be half of the capacity instead of the full capacity. If the capacity is not supplied to the FNR market it is offered for Elbas and the regulating power market. As for the FDR market, the electrolyzer is assumed accepted in the FNR market if a bid is made.

5.4 Sum up

As mentioned, the purchase bids are determined from an iterative approach that results in an annual biomethane production corresponding to 20% of full load operation. Figure 4 illustrates the purchase bids for the spot market in the different strategies and scenarios.

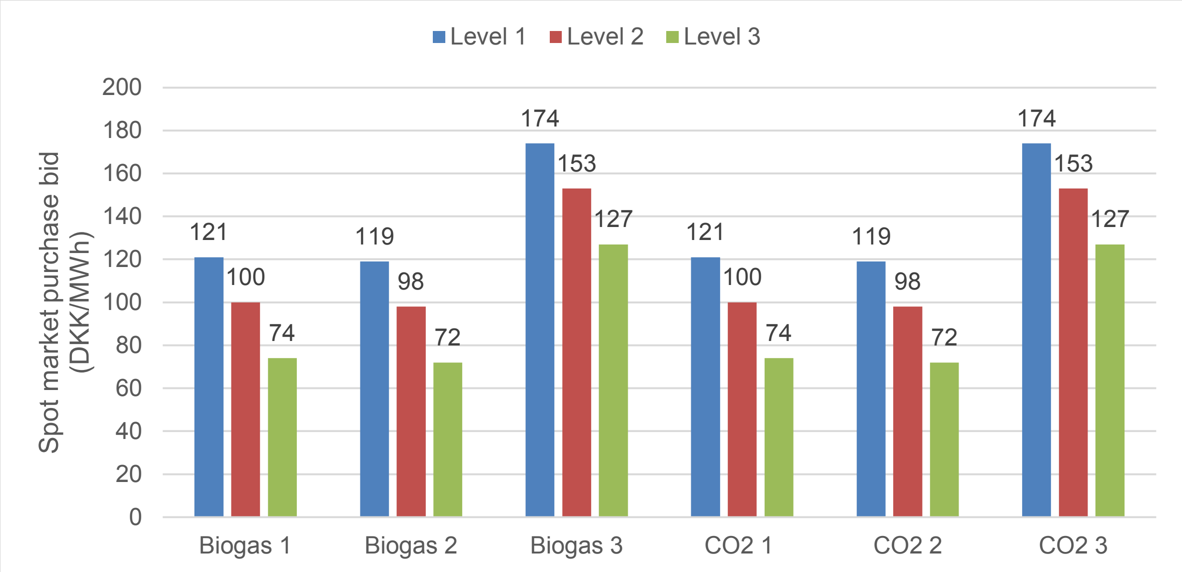

Figure 4: Purchase bid price for the spot market divided in the three price levels in the different scenarios.

Strategy 3 in both scenarios differs from the other strategies, which is due to the half capacity purchase bids at the spot market to offer symmetric capacity to the FNR market. It requires twice as much activations to supply the same amount of biomethane to the grid and therefore higher purchase bids are submitted to the spot market.

6. Results

The purpose of the analysis is to determine the optimal trading strategy for the P2G plant. Three different strategies are analyzed for two different scenarios. The purchase bid price for the market is set to reach 20% full load operation for the P2G plant.

The FDR and FNR market based on a pay-as-bid principle. In case the electrolyzer is accepted in FDR or FNR market the availability payment is equal the bid price. In this analysis, the average price for each block, in 2015, is applied as an indication of the possible revenue in the markets. All price data applied in the analysis is available at Energinet.dk's webpage. Figure 6 illustrates annual costs and revenues in the different scenarios.

Table 2 illustrates the number of hours the unit is traded in the different elelctricity markets. The annual electricity consumption is approximately the same corresponding to 20% full load operation.

	Biogas 1	Biogas 2	Biogas 3	CO_2 1	CO_2 2	CO_2 3
Spot	1711	1672	3276	1703	1663	3289
FDR		1380			1371	
FNR			2829			2841
Elbas sell	52	16	14	52	15	14
Elbas buy	105	103	144	104	103	144
Down regulation	2	2	0	2	2	0
Up regulation	0	0	0	0	0	0
Electricity cons. (MWh/a)	1958	1953	1941	1949	1944	1947

Table 2: Number of hours traded or activated in the different markets.

The majority of the electricity is purchased in the spot market but for some hours electricity is purchased at the Elbas market. For a few hours electricity purchased at the spot market is sold back intraday on Elbas. The P2G plant is never switched on in these hours but electricity is still traded. The activations in the regulation power market are very few due to the extreme bid prices that is a consequence of the minimum bid capacity of 10 MW.

In strategy 2 and 3, it requires activation in the spot market to be activated in the FDR or the FNR market. The electrolyzer is only accepted if it can provide the service for the entire 3-hour block.

The bid price for the spot market is higher in strategy 3, which results in more activations. However, it is only half capacity bid (0.542 MWh) that is submitted to the market. Figure 5 illustrates the annual biomethane production in the different scenarios.

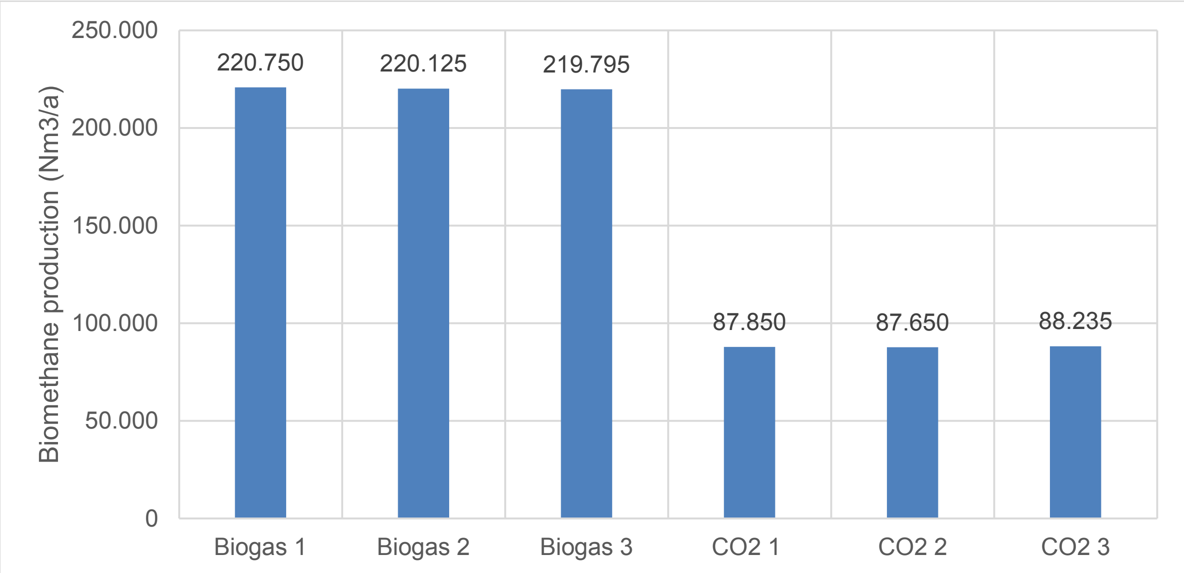

Figure 5: Annual production of biomethane in the different scenarios.

The biomethane production in the different scenarios is generally the same, which corresponds to approximately 20% full load operation. Figure 6 illustrates annual costs and revenues in the scenarios.

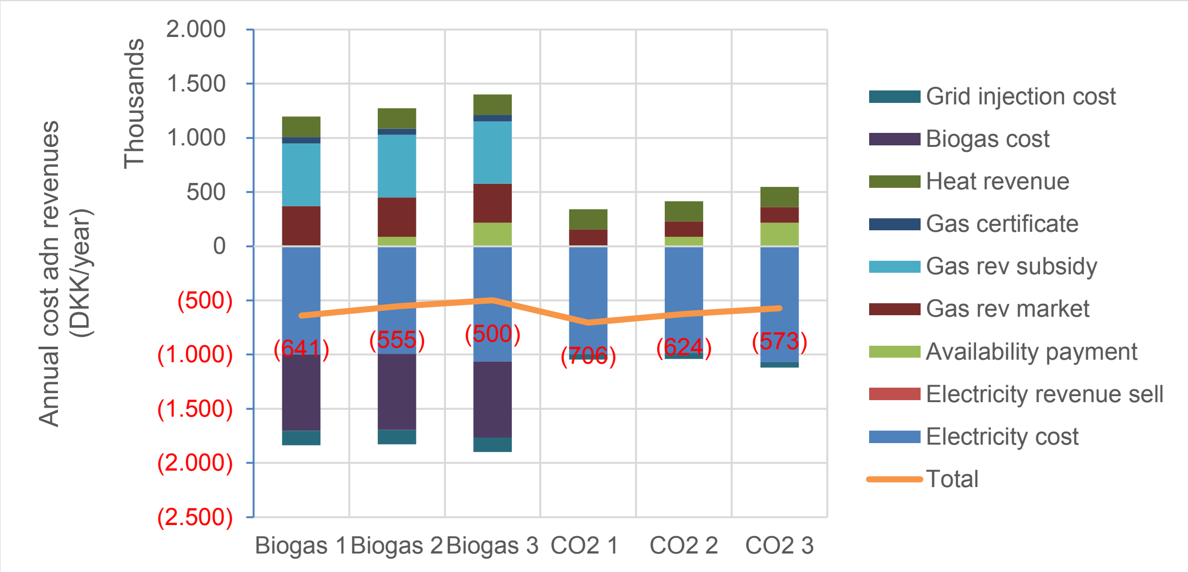

Figure 6: Annual costs and revenues related to one year of operation in the different scenarios.

The orange line illustrates the total annual costs. In all scenarios, there is a big cost associated with operating the P2G plant. In both the biogas and CO_2 scenario, it is trading strategy 3 that generates the lowest annual cost. The electricity cost in strategy 3 is higher than in the other strategies because the purchase bid prices are higher. However, the availability payment in the FNR market make up for the higher electricity cost, which results in a lower total cost.

The cost in the biogas scenario is lower than in the CO_2 scenario when the individual strategies are compared to each other. A small profit is generated from the buying raw biogas and selling the methane content in the biogas to gas market price, subsidy and estimated certificate value. However, these scenarios include the assumption that biogas is only bought during hours that the P2G plant is in operation.

Under current framework conditions, it can be concluded that the optimal trading strategy for the P2G plant is strategy 3 that includes frequency regulation in the FNR market.

7. Sensitivity analysis

It is quite clear that the profitability of operating a P2G plant under current framework conditions is not yet present. A sensitivity scenario is developed in which it is assumed the PSO-tariff is excluded from the electricity cost and all biomethane is included in the gas subsidy scheme and gas certificate scheme. It is only the CO_2 scenario that is included. The marginal cost is illustrated in Figure 7.

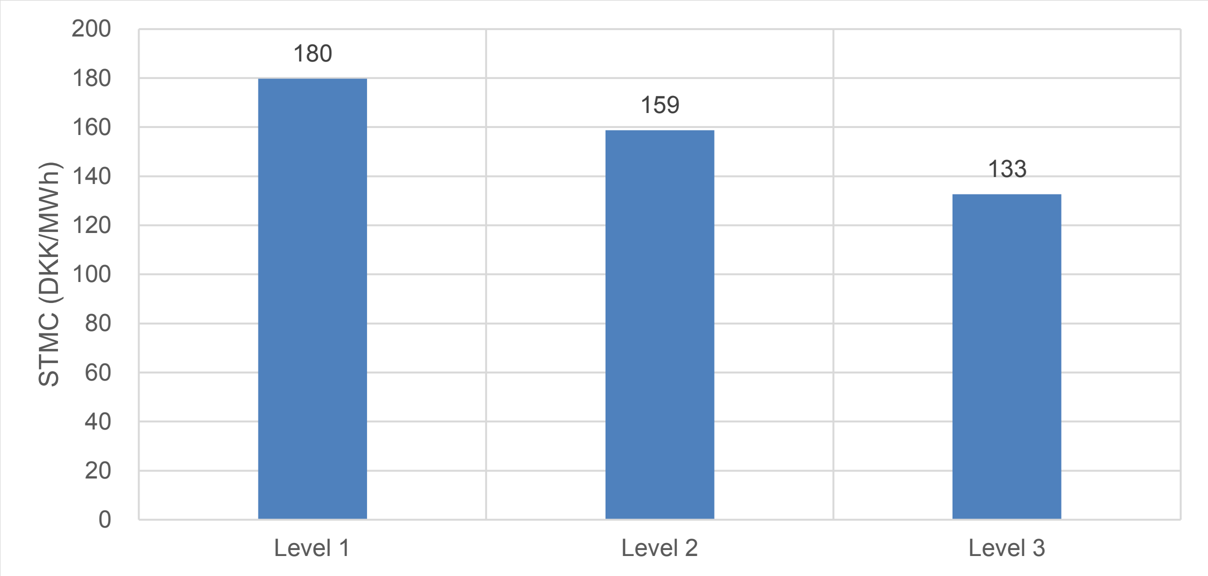

Figure 7: Marginal cost for the P2G plant in the three different price levels.

In this scenario there is a positive marginal cost. In the hours the spot price is below the marginal cost the P2G plant is allowed to operate. The trading strategies are the same as described in chapter 5. Figure 8 illustrates the annual costs and revenues in the scenarios.

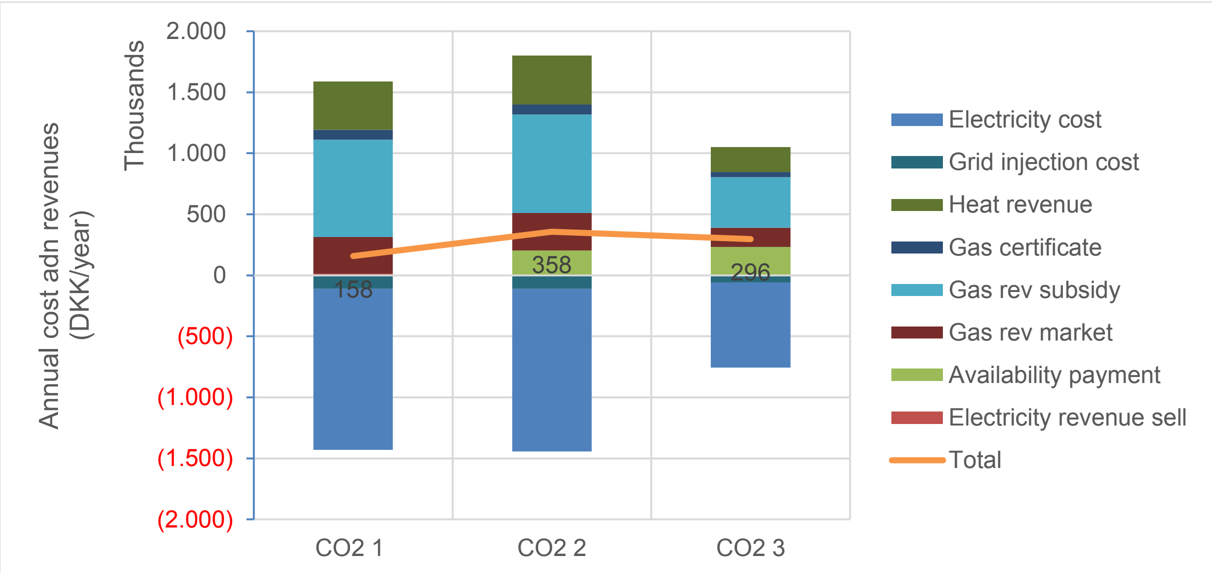

Figure 8: Annual costs and revenues related to one year of operation in the sensitivity analysis.

This scenario results in a total income generated from one year of operation. In this scenario the strategy 2 generates the highest income. With a positive marginal cost, it is more profitable to utilize the full capacity of the plant compared to strategy 3, in which only half of the electrical capacity in bid into the market for several hours. In strategy 2 the electricity consumption is 4125 MWh/a producing 188,600 Nm³ biomethane and in strategy the electricity consumption is 2131 MWh producing 96,759 Nm³ biomethane.

8. Conclusion

In this report the optimal trading strategy is estimated based on a simulation of operating the P2G plant for one full year. Two systems are analyzed based on the feedstock to the system: biogas and pure CO_2.

For each system three trading strategies are analyzed: 1) Spot market, Elbas and regulating power market, 2) Spot, FDR, Elbas and regulating power market, 3) Spot, FNR, Elbas and regulating power market. Strategy 2 and 3 includes participation in their respective frequency regulation market in DK2 in which it is possible to obtain an availability payment.

Under current framework conditions the marginal cost of the P2G plant is negative meaning that the market price needs to be negative to have a profitable operation. Obviously, this limits the operation hours in a commercial operation perspective. In the analyses it is assumed that the plant has to operate for minimum 20% of the time at the lowest cost as possible. Instead on using the marginal cost as bid price for the spot market a higher bid price is used to secure the plant will be accepted for a certain number of hours (20% load).

A total cost is generated for both systems and all trading strategies by operating the P2G plant under current framework conditions. The lowest cost is generated in strategy 3, which includes participation in the FNR market and therefore this strategy is estimated as the optimal strategy. It is obvious that framework conditions have to be changed if P2G (electrolysis and biological methanation) should be profitable in Denmark.

One major challenge for the profitability is that the biomethane produced by biological methanation cannot obtain the subsidy for upgraded biogas nor green gas certificates. If the PSO tariff is moved to the financial budget this will obviously increase the number of profitable operation hours for the P2G plant but as a standalone regulation, none of these two changes is sufficient to have a commercial operation of a P2G plant.