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Short Description
The document contains the prefeasibility study for Power2Gas (P2G) hubs for Austria, in three basic configuration options: collocated with renewable energy or industrial plants or as a greenfield investment. Optimization tool V2.0 is used for obtaining all the results in this pre-feasibility study.

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Responsible Partner for the compilation of this document

ERDF PP3 Energy Institute at the Johannes Kepler University Linz (AT)

CONTENT

1. METHODOLOGY

Infrastructure and Biomass databases for Austria given within the Atlas are prerequisite for any use of Optimization tool (OT). After the selection or manual entry of sources, connection points, etc. is done, optimization of P2G hub sizing and operation with the OT can be started.

2. CASE STUDIES

Three locations for potential P2G investment are considered[1]. The first one is industrial plant near Vienna (noted as IP), the second one is a wind park in Styria (noted as REP). The third one is a greenfield location (noted as GF) in south-eastern part of Austria.

3. RESULTS

3.1 SUMMARY

For each one of case studies (IP, REP and GF), variations of natural gas prices and subsidies are considered. In Table 1, the overview about the calculated business cases are given:

Table 1. Simulation cases

	Conservative natural gas / »renewable natural gas« prices			**Higher natural gas / »renewable natural gas« prices**		
	No increase IP	**No increase REP**	**No increase GF**	**10x increase IP**	**10x increase REP**	**10x increase GF**
No subsidy	Hydrogen production Fig. 1	Hydrogen production Fig. 2	Hydrogen production Fig. 3	Renewable gas and biochar production, Fig. 7	Renewable gas and biochar production, Fig. 8	Renewable gas and biochar production, Fig. 9
Subsidy of 50%	Hydrogen production Fig. 3	Hydrogen production Fig. 5	Hydrogen production Fig. 6	Renewable gas and biochar production, Fig. 10	Renewable gas and biochar production, Fig. 11	Renewable gas and biochar production, Fig. 12

Every solution from Table 1 is obtained using the simulation period of one year. Increases of natural gas / »renewable natural gas« prices noted as "10x increase" refer to the increases in the "Gas price without grid/operator fees, including taxes" which is an attribute in the Gas prices section of the Excel interface of the OT. Its conservative value ("1x") is set to 0,0468 €/kWh for both winter and summer period. Grid fees and taxes of gas price are not affected with this increase. Hydrogen selling price is set to 10 €/kg. All set inputs for the case studies may be checked in the annexed OT Excel interface documents for all the

[1] In case publicly available data wasn't available, estimations have been used instead.

considered 12 scenarios. They are given in a zip file with Excel names clearly indicating each of the 12 case studies. Detailed results of simulations are given in the following sections.

3.1 RESULTS WITH CURRENT GAS PRICES WITHOUT SUBSIDIES

Figures 1 to 6 shows results for cases without additional subsidies and current / conservative natural gas / »renewable natural gas prices. Best investment option is to produce hydrogen via electrolysis and sell the by-product oxygen, as well as to produce »renewable natural gas« in the IP case. The production of biochar, for example, wouldn't be economically feasible for all three cases as shown in Figures 1 to 3.

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	0,00	0,000000	kg/s
	Wet anaerobic digestor	0,00	0,000000	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	0,00	0,000000	kg/s
	Methanation reactor	0,00	0,000000	mol/s
	Electrolyser	5 373 677,25	2 149,47	kW
	Demineralizer	535,97	5,359654	mol/s
	Precipitation collector	2 000,00	1 000,00	m²
	Heat exchanger	18 518,52	185,19	kW
	Gas compressor station	0,00	0,0000	kWe
	Total for processes	**5 394 731,73**		
Storages	Dry biomass storage	0,00	0,00	kg
	Wet biomass storage	0,00	0,00	kg
	Biochar storage	0,00	0,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	0,00	0,00	m³
	Total for storages	**0,00**		
Connections enlargement	Electrical connection	0,00	0,00	MW
	Gas connection	0,00	0,00	MW
	Water connection	0,00	0,35	m³/h
	Total for connections	**0,00**		
	Total investment	**5 394 731,73**		
	Payoff period	**11,94**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	0,00	0,00	MWh
	Consumed by IP	41 920 000,00	320 000,00	MWh
	Net consumption without investment	41 920 000,00	320 000,00	MWh
	Mean peak power without investment	2 191 780,82	36,53	MW
	Consumed by P2G	2 504 073,66	19 115,07	MWh
	Net consumption with investment	**44 424 073,66**	**339 115,07**	**MWh**
	Mean peak power with investment	**2 322 708,16**	**38,71**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-1 622,22	MWh
	Net production with investment	**0,00**	**1 622,22**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	878 902,36	11 630,00	MWh
	Net consumption without investment	878 902,36	11 630,00	MWh
	Produced by P2G	0,00	0,00	MWh
	Net consumption with investment	**878 902,36**	**11 630,00**	**MWh**
Water	Water from the grid consumed by P2G	4 209,00	2 475,88	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	0,00	0,00	t
	Wet biomass bought	0,00	0,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**0,00**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	0,00	0,00	t
	Total revenue from additional sales	**3 686 500,00**		
Residues	Residue from dry anaerobic digester	0,00	0,00	t
	Residue from wet anaerobic digester	0,00	0,00	t
	Tar from gasification + water gas shift plan	0,00	0,00	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without investi	**44 990 683,18**		
	Total operational cost with investmer	**43 943 393,19**		
	Savings with introduction of P2G	**1 047 290,00**		

Fig. 1 Results for optimal P2G hub next to IP with conservative prices of natural gas / »renewable natural gas« and no subsidy.

This business case shows optimal scenario for current prices of natural gas / »renewable natural gas« and Industrial Plant (IP) nearby (see Fig. 1). It is recommended to produce hydrogen (it reaches also the maximum in this case). As no biochar is produced means that its production is not recommended, because it wouldn't be economically feasible. For implementation of such a business case investments at around 5 Mio. Euros are needed. The calculated payoff period would be around 12 years.

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	0,00	0,000000	kg/s
	Wet anaerobic digestor	0,00	0,000000	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	0,00	0,000000	kg/s
	Methanation reactor	0,00	0,000000	mol/s
	Electrolyser	5 373 677,25	2 149,47	kW
	Demineralizer	5 000,00	50,000000	mol/s
	Precipitation collector	2 000,00	1 000,00	m²
	Heat exchanger	18 518,52	185,19	kW
	Gas compressor station	0,00	0,0000	kWe
	Total for processes	**5 399 195,77**		
Storages	Dry biomass storage	0,00	0,00	kg
	Wet biomass storage	0,00	0,00	kg
	Biochar storage	0,00	0,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	3 903,54	177,43	m³
	Total for storages	**3 903,54**		
Connections enlargement	Electrical connection	0,00	0,00	MW
	Gas connection	0,00	0,00	MW
	Water connection	0,00	3,25	m³/h
	Total for connections	**0,00**		
	Total investment	**5 403 099,31**		
	Payoff period	**9,94**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	580 750,00	6 900,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	-580 750,00	-6 900,00	MWh
	Mean peak power without investment	0,00	0,00	MW
	Consumed by P2G	2 504 073,66	19 115,07	MWh
	Net consumption with investment	**1 609 551,23**	**12 215,07**	**MWh**
	Mean peak power with investment	**128 968,25**	**2,15**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-1622,22	MWh
	Net production with investment	**0,00**	**1 622,22**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	0,00	0,00	MWh
	Net consumption with investment	**0,00**	**0,00**	**MWh**
Water	Water from the grid consumed by P2G	4 209,00	2 475,88	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	0,00	0,00	t
	Wet biomass bought	0,00	0,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**0,00**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	0,00	0,00	t
	Total revenue from additional sales	**3 686 500,00**		
Residues	Residue from dry anaerobic digester	0,00	0,00	t
	Residue from wet anaerobic digester	0,00	0,00	t
	Tar from gasification + water gas shift plant	0,00	0,00	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without investm	**-580 750,00**		
	Total operational cost with investmen	**-1 943 771,51**		
	Savings with introduction of P2G	**1 363 021,51**		

Fig. 2 Results for optimal P2G hub next to REP with conservative prices of natural gas / »renewable natural gas« and no subsidy.

For this scenario with current prices of gas and without subsidies, P2G hub next to renewable energy plant shows similar results as the previous scenario (see Fig. 2). Using renewable electricity to produce hydrogen and also oxygen as by-products and selling it would be highly profitable and the limit is reached in the maximum allowed amount of daily hydrogen and oxygen sales. Payoff for this business case would be around 10 years. Biochar production is not recommended.

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	0,00	0,000000	kg/s
	Wet anaerobic digestor	0,00	0,000000	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	0,00	0,000000	kg/s
	Methanation reactor	0,00	0,000000	mol/s
	Electrolyser	5 373 677,25	2 149,47	kW
	Demineralizer	514,60	5,145962	mol/s
	Precipitation collector	2 000,00	1 000,00	m²
	Heat exchanger	18 518,52	185,19	kW
	Gas compressor station	0,00	0,0000	kWe
	Total for processes	**5 394 710,36**		
Storages	Dry biomass storage	0,00	0,00	kg
	Wet biomass storage	0,00	0,00	kg
	Biochar storage	0,00	0,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	227,33	10,33	m³
	Total for storages	**227,33**		
Connections enlargement	Electrical connection	577 046,68	2,19	MW
	Gas connection	0,00	0,00	MW
	Water connection	0,00	0,33	m³/h
	Total for connections	**577 046,68**		
	Total investment	**5 971 984,38**		
	Payoff period	**12,68**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Mean peak power without investment	0,00	0,00	MW
	Consumed by P2G	2 504 073,66	19 115,07	MWh
	Net consumption with investment	**2 504 073,66**	**19 115,07**	**MWh**
	Mean peak power with investment	**130 926,54**	**2,18**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-1 622,22	MWh
	Net production with investment	**0,00**	**1 622,22**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	0,00	0,00	MWh
	Net consumption with investment	**0,00**	**0,00**	**MWh**
Water	Water from the grid consumed by P2G	4 209,00	2 475,88	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	0,00	0,00	t
	Wet biomass bought	0,00	0,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**0,00**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	0,00	0,00	t
	Total revenue from additional sales	**3 686 500,00**		
Residues	Residue from dry anaerobic digester	0,00	0,00	t
	Residue from wet anaerobic digester	0,00	0,00	t
	Tar from gasification + water gas shift plant	0,00	0,00	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without investm	**0,00**		
	Total operational cost with investmen	**-1 047 290,80**		
	Savings with introduction of P2G	**1 047 290,80**		

Fig. 3 Results for optimal P2G hub as GF with conservative prices of natural gas / »renewable natural gas« and no subsidy.

Building P2G hub as GF investment shows again that producing and selling biochar is not profitable with current prices used in the OT. The production of renewable hydrogen and selling it beside the selling of by-products would be economically feasible option (see Fig. 3). The limit of daily hydrogen production / selling (1 ton) is reached. Payoff period is around 13 years.

3.2 RESULTS WITH CURRENT GAS PRICES WITH SUBSIDIES

For development of energy system related business cases additional subsidies may be needed. Following figures show results for scenarios where subsidies are included. Although the OT can use different subsidies for each part of P2G hub, Figures 4 to 6 show results for scenarios with current natural gas / »renewable natural gas« prices and 50% of subsidies on entire investments needed.

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	0,00	0,000000	kg/s
	Wet anaerobic digestor	0,00	0,000000	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	0,00	0,000000	kg/s
	Methanation reactor	0,00	0,000000	mol/s
	Electrolyser	2 686 838,62	2 149,47	kW
	Demineralizer	267,98	5,359654	mol/s
	Precipitation collector	1 000,00	1 000,00	m²
	Heat exchanger	9 259,26	185,19	kW
	Gas compressor station	0,00	0,0000	kWe
	Total for processes	**2 697 365,87**		
Storages	Dry biomass storage	0,00	0,00	kg
	Wet biomass storage	0,00	0,00	kg
	Biochar storage	0,00	0,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	0,00	0,00	m³
	Total for storages	**0,00**		
Connections enlargement	Electrical connection	0,00	0,00	MW
	Gas connection	0,00	0,00	MW
	Water connection	0,00	0,35	m³/h
	Total for connections	**0,00**		
	Total investment	**2 697 365,87**		
	Payoff period	**8,47**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	0,00	0,00	MWh
	Consumed by IP	41 920 000,00	320 000,00	MWh
	Net consumption without investment	41 920 000,00	320 000,00	MWh
	Mean peak power without investment	2 191 780,82	36,53	MW
	Consumed by P2G	2 504 073,66	19 115,07	MWh
	Net consumption with investment	**44 424 073,66**	**339 115,07**	**MWh**
	Mean peak power with investment	**2 322 708,16**	**38,71**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-1 622,22	MWh
	Net production with investment	**0,00**	**1 622,22**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	878 902,36	11 630,00	MWh
	Net consumption without investment	878 902,36	11 630,00	MWh
	Produced by P2G	0,00	0,00	MWh
	Net consumption with investment	**878 902,36**	**11 630,00**	**MWh**
Water	Water from the grid consumed by P2G	4 209,00	2 475,88	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	0,00	0,00	t
	Wet biomass bought	0,00	0,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**0,00**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	0,00	0,00	t
	Total revenue from additional sales	**3 686 500,00**		
Residues	Residue from dry anaerobic digester	0,00	0,00	t
	Residue from wet anaerobic digester	0,00	0,00	t
	Tar from gasification + water gas shift plar	0,00	0,00	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without inves	**44 990 683,18**		
	Total operational cost with investme	**43 943 393,19**		
	Savings with introduction of P2G	**1 047 290,00**		

Fig. 4 Results for optimal P2G hub next to IP with conservative prices of natural gas / »renewable natural gas« and subsidy of 50%.

Adding subsidy in all calculated cases do not change any plant sizes or production and consumption profiles, but only has an impact on payoff period duration, which would shorten from 12 years (see Fig. 1) to around 9 years (see Fig. 4).

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	0,00	0,000000	kg/s
	Wet anaerobic digestor	0,00	0,000000	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	0,00	0,000000	kg/s
	Methanation reactor	0,00	0,000000	mol/s
	Electrolyser	2 686 838,62	2 149,47	kW
	Demineralizer	2 500,00	50,000000	mol/s
	Precipitation collector	1 000,00	1 000,00	m²
	Heat exchanger	9 259,26	185,19	kW
	Gas compressor station	0,00	0,0000	kWe
	Total for processes	**2 699 597,88**		
Storages	Dry biomass storage	0,00	0,00	kg
	Wet biomass storage	0,00	0,00	kg
	Biochar storage	0,00	0,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	1 951,77	177,43	m³
	Total for storages	**1 951,77**		
Connections enlargement	Electrical connection	0,00	0,00	MW
	Gas connection	0,00	0,00	MW
	Water connection	0,00	3,25	m³/h
	Total for connections	**0,00**		
	Total investment	**2 701 549,65**		
	Payoff period	**7,47**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	580 750,00	6 900,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	-580 750,00	-6 900,00	MWh
	Mean peak power without investment	0,00	0,00	MW
	Consumed by P2G	2 504 073,66	19 115,07	MWh
	Net consumption with investment	**1 609 551,23**	**12 215,07**	**MWh**
	Mean peak power with investment	**128 968,25**	**2,15**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-1 622,22	MWh
	Net production with investment	**0,00**	**1 622,22**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	0,00	0,00	MWh
	Net consumption with investment	**0,00**	**0,00**	**MWh**
Water	Water from the grid consumed by P2G	4 209,00	2 475,88	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	0,00	0,00	t
	Wet biomass bought	0,00	0,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**0,00**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	0,00	0,00	t
	Total revenue from additional sales	**3 686 500,00**		
Residues	Residue from dry anaerobic digester	0,00	0,00	t
	Residue from wet anaerobic digester	0,00	0,00	t
	Tar from gasification + water gas shift plan	0,00	0,00	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without invest	**-580 750,00**		
	Total operational cost with investmer	**-1 943 771,51**		
	Savings with introduction of P2G	**1 363 021,51**		

Fig. 5 Results for optimal P2G hub next to REP with conservative prices of natural gas / »renewable natural gas« and subsidy of 50%.

When needed investment costs are subsidised by a half, the payoff period reduces accordingly by around 2 years to 7,5 years (see Fig. 5). The biochar production is still not profitable in this case.

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	0,00	0,000000	kg/s
	Wet anaerobic digestor	0,00	0,000000	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	0,00	0,000000	kg/s
	Methanation reactor	0,00	0,000000	mol/s
	Electrolyser	2 686 838,62	2 149,47	kW
	Demineralizer	257,30	5,145962	mol/s
	Precipitation collector	1 000,00	1 000,00	m²
	Heat exchanger	9 259,26	185,19	kW
	Gas compressor station	0,00	0,0000	kWe
	Total for processes	**2 697 355,18**		
Storages	Dry biomass storage	0,00	0,00	kg
	Wet biomass storage	0,00	0,00	kg
	Biochar storage	0,00	0,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	113,67	10,33	m³
	Total for storages	**113,67**		
Connections enlargement	Electrical connection	577 046,68	2,19	MW
	Gas connection	0,00	0,00	MW
	Water connection	0,00	0,33	m³/h
	Total for connections	**577 046,68**		
	Total investment	**3 274 515,53**		
	Payoff period	**9,21**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Mean peak power without investment	0,00	0,00	MW
	Consumed by P2G	2 504 073,66	19 115,07	MWh
	Net consumption with investment	**2 504 073,66**	**19 115,07**	**MWh**
	Mean peak power with investment	**130 926,54**	**2,18**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-1 622,22	MWh
	Net production with investment	**0,00**	**1 622,22**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	0,00	0,00	MWh
	Net consumption with investment	**0,00**	**0,00**	**MWh**
Water	Water from the grid consumed by P2G	4 209,00	2 475,88	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	0,00	0,00	t
	Wet biomass bought	0,00	0,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**0,00**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	0,00	0,00	t
	Total revenue from additional sales	**3 686 500,00**		
Residues	Residue from dry anaerobic digester	0,00	0,00	t
	Residue from wet anaerobic digester	0,00	0,00	t
	Tar from gasification + water gas shift plar	0,00	0,00	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without invest	**0,00**		
	Total operational cost with investme	**-1 047 290,80**		
	Savings with introduction of P2G	**1 047 290,80**		

Fig. 6 Results for optimal P2G hub as GF with conservative prices of natural gas / »renewable natural gas« and subsidy of 50%.

Like in the previous cases with REP and IP, adding subsidies did not change any plant sizes or production and consumption profiles and amounts. The payoff period shortens by 3 years and the operation would be profitable after around 9 years (see Fig. 6).

3.3 RESULTS WITH INCREASED GAS PRICES WITHOUT SUBSIDIES

As natural gas price is increasing constantly during the last year, scenarios with higher natural gas prices are included in the analysis. For the next six scenarios (Figures 7 to 12), 10x increase in natural gas / »renewable natural gas« prices is used in the OT. Such sensitivity calculations are made to explore optimal business cases and whether other possible plants and production pathways may became economically feasible. Figures 7 to 9 show scenarios for IP, REP and GF without investment and Figures 10 to 12 show scenarios with 50% subsidy on the investment cost. Results show that after this significant price increase, »renewable natural gas« production and biochar production becomes economically profitable. As well as the capacity of the electrolyser increased.

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	2 430 555,56	0,115741	kg/s
	Wet anaerobic digestor	2 430 555,56	0,115741	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	2 314,81	0,002315	kg/s
	Methanation reactor	3 093 202,08	7,278123	mol/s
	Electrolyser	16 223 931,95	6 489,57	kW
	Demineralizer	1 711,25	17,112460	mol/s
	Precipitation collector	2 000,00	1 000,00	m²
	Heat exchanger	237 863,23	2 378,63	kW
	Gas compressor station	46 821,48	58,5269	kWe
	Total for processes	**24 468 955,91**		
Storages	Dry biomass storage	100 000,00	10 000,00	kg
	Wet biomass storage	50 000,00	10 000,00	kg
	Biochar storage	15 000,00	1 000,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	0,00	0,00	m³
	Total for storages	**165 000,00**		
Connections enlargement	Electrical connection	0,00	0,00	MW
	Gas connection	79 689,46	0,53	MW
	Water connection	0,00	1,11	m³/h
	Total for connections	**79 689,46**		
	Total investment	**24 713 645,37**		
	Payoff period	**8,20**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	0,00	0,00	MWh
	Consumed by IP	41 920 000,00	320 000,00	MWh
	Net consumption without investment	41 920 000,00	320 000,00	MWh
	Mean peak power without investment	2 191 780,82	36,53	MW
	Consumed by P2G	14 377 350,63	109 750,77	MWh
	Net consumption with investment	**56 297 350,63**	**429 750,77**	**MWh**
	Mean peak power with investment	**2 943 500,64**	**49,06**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-20 307,57	MWh
	Net production with investment	**0,00**	**20 307,57**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	5 777 458,36	11 630,00	MWh
	Net consumption without investment	5 777 458,36	11 630,00	MWh
	Produced by P2G	20 016 307,16	51 323,86	MWh
	Net consumption with investment	**-15 480 607,16**	**-39 693,86**	**MWh**
Water	Water from the grid consumed by P2G	15 584,61	9 167,42	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	881 131,57	3 650,00	t
	Wet biomass bought	200 955,12	3 650,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**1 082 086,68**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	222 650,00	365,00	t
	Total revenue from additional sales	**3 909 150,00**		
Residues	Residue from dry anaerobic digester	0,00	109,50	t
	Residue from wet anaerobic digester	0,00	547,50	t
	Tar from gasification + water gas shift plan	0,00	7,30	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without invest	**49 889 239,18**		
	Total operational cost with investmer	**40 948 765,41**		
	Savings with introduction of P2G	**8 940 473,78**		

Fig. 7 Results for optimal P2G hub next to IP with higher prices of natural gas / »renewable natural gas« (x10) and no subsidy.

P2G hub next to IP with large biochar production and »renewable natural gas« production is an economically optimal solution for this input parameters and, beside the production of hydrogen, also the selling of oxygen is part of this particular business case (see Fig. 7). As well as electrolyser capacity increased significantly. Hydrogen and biochar (restricted by biomass input limits) production reaches their daily production limits. The payoff period is shorter, when the natural gas / »renewable natural gas« prices are higher (compared to business case displayed in Fig. 1) and is around 8 years for this business case.

Optimal business case for REP shows similar results, where the production of biochar and »natural renewable gas« would became feasible (see Fig. 8).

Investment specifications				
	Element	Cost	Size	
Processes	Dry anaerobic digestor	2 430 555,56	0,115741	kg/s
	Wet anaerobic digestor	2 430 555,56	0,115741	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	2 314,81	0,002315	kg/s
	Methanation reactor	3 093 202,08	7,278123	mol/s
	Electrolyser	16 223 931,95	6 489,57	kW
	Demineralizer	1 981,66	19,816603	mol/s
	Precipitation collector	2 000,00	1 000,00	m²
	Heat exchanger	237 863,23	2 378,63	kW
	Gas compressor station	195 036,85	243,7961	kWe
	Total for processes	**24 617 441,69**		
Storages	Dry biomass storage	100 000,00	10 000,00	kg
	Wet biomass storage	50 000,00	10 000,00	kg
	Biochar storage	15 000,00	1 000,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	625,14	28,42	m³
	Total for storages	**165 625,14**		
Connections enlargement	Electrical connection	1 331 923,86	8,88	MW
	Gas connection	16 756 531,34	5,86	MW
	Water connection	0,00	1,29	m³/h
	Total for connections	**18 088 455,20**		
	Total investment	**42 871 522,03**		
	Payoff period	**11,09**	**years**	

Operational costs for selected period				
		Cost	Amount	
Electrical energy	Produced by REP	580 750,00	6 900,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	-580 750,00	-6 900,00	MWh
	Mean peak power without investment	0,00	0,00	MW
	Consumed by P2G	14 589 958,16	111 373,73	MWh
	Net consumption with investment	**13 686 058,16**	**104 473,73**	**MWh**
	Mean peak power with investment	**762 059,49**	**12,70**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-20 307,57	MWh
	Net production with investment	**0,00**	**20 307,57**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	20 008 824,14	51 323,86	MWh
	Net consumption with investment	**-20 008 824,14**	**-51 323,86**	**MWh**
Water	Water from the grid consumed by P2G	15 584,61	9 167,42	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	394 260,86	3 650,00	t
	Wet biomass bought	207 574,03	3 650,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**601 834,90**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	222 650,00	365,00	t
	Total revenue from additional sales	**3 909 150,00**		
Residues	Residue from dry anaerobic digester	0,00	109,50	t
	Residue from wet anaerobic digester	0,00	547,50	t
	Tar from gasification + water gas shift plant	0,00	7,30	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without investm	**-580 750,00**		
	Total operational cost with investmen	**-8 852 436,99**		
	Savings with introduction of P2G	**8 271 686,99**		

Fig. 8 Results for optimal P2G hub next to REP with higher prices of natural gas / »renewable natural gas« (x10) and no subsidy.

Due to increased natural gas (renewable natural gas) prices by 10, production of biochar is getting economically feasible and thus become part of this business case. The capacity of the electrolyser increased by three times comparing to the business case with actual gas prices and without additional subsidies. Additionally, also selling of biochar is, beside the selling of hydrogen, oxygen and »renewable natural gas« becomes economically feasible. However, the payoff period of this business case is around 11 years, which is the longest time period between all calculated REP cases.

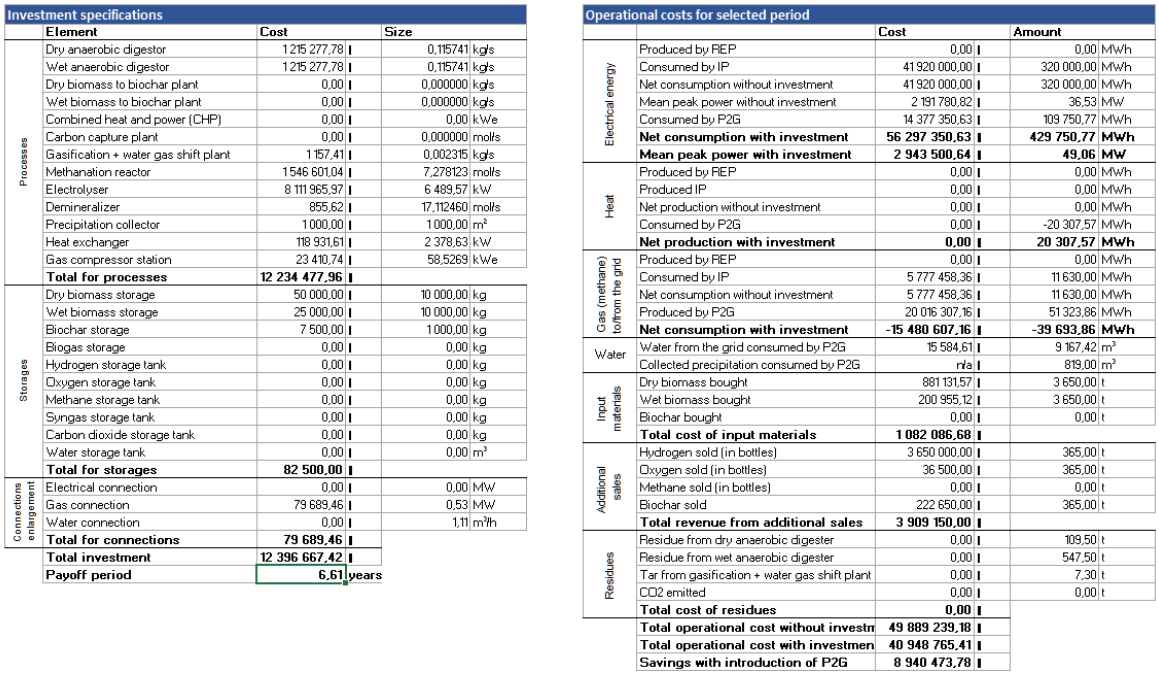
Investment specifications					
	Element	Cost		Size	
Processes	Dry anaerobic digestor	2 430 555,56		0,115741	kg/s
	Wet anaerobic digestor	2 430 555,56		0,115741	kg/s
	Dry biomass to biochar plant	0,00		0,000000	kg/s
	Wet biomass to biochar plant	0,00		0,000000	kg/s
	Combined heat and power (CHP)	0,00		0,00	kWe
	Carbon capture plant	0,00		0,000000	mol/s
	Gasification + water gas shift plant	2 314,81		0,002315	kg/s
	Methanation reactor	3 093 202,08		7,278123	mol/s
	Electrolyser	16 223 931,95		6 489,57	kW
	Demineralizer	1 689,88		16,898768	mol/s
	Precipitation collector	2 000,00		1 000,00	m²
	Heat exchanger	237 863,23		2 378,63	kW
	Gas compressor station	46 821,48		58,5269	kWe
	Total for processes	**24 468 934,54**			
Storages	Dry biomass storage	100 000,00		10 000,00	kg
	Wet biomass storage	50 000,00		10 000,00	kg
	Biochar storage	15 000,00		1 000,00	kg
	Biogas storage	0,00		0,00	kg
	Hydrogen storage tank	0,00		0,00	kg
	Oxygen storage tank	0,00		0,00	kg
	Methane storage tank	0,00		0,00	kg
	Syngas storage tank	0,00		0,00	kg
	Carbon dioxide storage tank	0,00		0,00	kg
	Water storage tank	227,33		10,33	m³
	Total for storages	**165 227,33**			
Connections enlargement	Electrical connection	3 305 683,95		12,53	MW
	Gas connection	33 461 174,83		5,86	MW
	Water connection	0,00		1,10	m³/h
	Total for connections	**36 766 858,78**			
	Total investment	**61 401 020,65**			
	Payoff period	**13,83**	years		

Operational costs for selected period					
		Cost		Amount	
Electrical energy	Produced by REP	0,00		0,00	MWh
	Consumed by IP	0,00		0,00	MWh
	Net consumption without investment	0,00		0,00	MWh
	Mean peak power without investment	0,00		0,00	MW
	Consumed by P2G	14 377 350,63		109 750,77	MWh
	Net consumption with investment	**14 377 350,63**		**109 750,77**	**MWh**
	Mean peak power with investment	**751 719,02**		**12,53**	**MW**
Heat	Produced by REP	0,00		0,00	MWh
	Produced IP	0,00		0,00	MWh
	Net production without investment	0,00		0,00	MWh
	Consumed by P2G	0,00		-20 307,57	MWh
	Net production with investment	**0,00**		**20 307,57**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00		0,00	MWh
	Consumed by IP	0,00		0,00	MWh
	Net consumption without investment	0,00		0,00	MWh
	Produced by P2G	20 016 307,16		51 323,86	MWh
	Net consumption with investment	**-20 016 307,16**		**-51 323,86**	**MWh**
Water	Water from the grid consumed by P2G	15 584,61		9 167,42	m³
	Collected precipitation consumed by P2G	n/a		819,00	m³
Input materials	Dry biomass bought	389 114,63		3 650,00	t
	Wet biomass bought	208 880,44		3 650,00	t
	Biochar bought	0,00		0,00	t
	Total cost of input materials	**597 995,06**			
Additional sales	Hydrogen sold (in bottles)	3 650 000,00		365,00	t
	Oxygen sold (in bottles)	36 500,00		365,00	t
	Methane sold (in bottles)	0,00		0,00	t
	Biochar sold	222 650,00		365,00	t
	Total revenue from additional sales	**3 909 150,00**			
Residues	Residue from dry anaerobic digester	0,00		109,50	t
	Residue from wet anaerobic digester	0,00		547,50	t
	Tar from gasification + water gas shift plan	0,00		7,30	t
	CO2 emitted	0,00		0,00	t
	Total cost of residues	**0,00**			
	Total operational cost without investi	**0,00**			
	Total operational cost with investmer	**-8 182 807,84**			
	Savings with introduction of P2G	**8 182 807,84**			

Fig. 9 Results for optimal P2G hub as GF with higher prices of natural gas / »renewable natural gas« (x10) and no subsidy.

Similar results are obtained with natural gas / »renewable natural gas« price increase on scenario with GF investment as with REP and IP scenarios (see Fig. 9). Very long payoff period should be noticed here.

3.4 RESULTS WITH INCREASED GAS PRICES WITH SUBSIDIES



Investment specifications

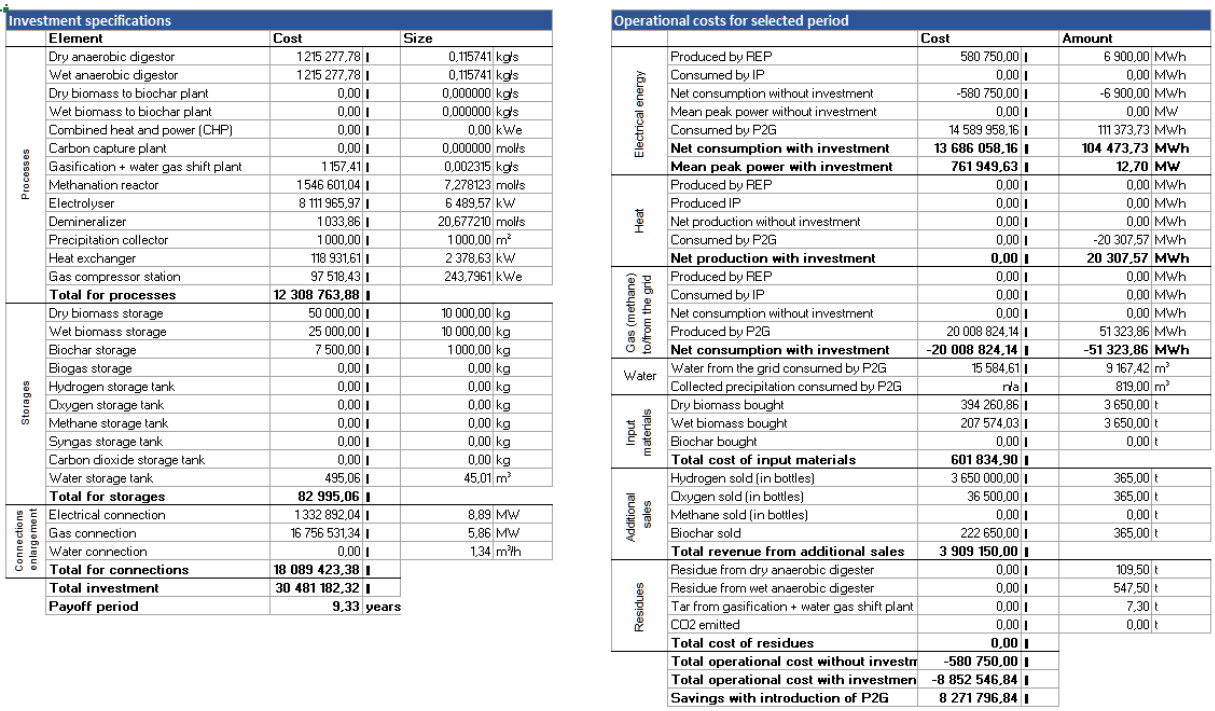
	Element	Cost	Size	
Processes	Dry anaerobic digestor	1 215 277,78	0,115741	kg/s
	Wet anaerobic digestor	1 215 277,78	0,115741	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	1 157,41	0,002315	kg/s
	Methanation reactor	1 546 601,04	7,278123	mol/s
	Electrolyser	8 111 965,97	6 489,57	kW
	Demineralizer	855,62	17,112460	mol/s
	Precipitation collector	1 000,00	1 000,00	m²
	Heat exchanger	118 931,61	2 378,63	kW
	Gas compressor station	23 410,74	58,5269	kWe
	Total for processes	**12 234 477,96**		
Storages	Dry biomass storage	50 000,00	10 000,00	kg
	Wet biomass storage	25 000,00	10 000,00	kg
	Biochar storage	7 500,00	1 000,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	0,00	0,00	m³
	Total for storages	**82 500,00**		
Connections enlargement	Electrical connection	0,00	0,00	MW
	Gas connection	79 689,46	0,53	MW
	Water connection	0,00	1,11	m³/h
	Total for connections	**79 689,46**		
	Total investment	**12 396 667,42**		
	Payoff period	**6,61**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	0,00	0,00	MWh
	Consumed by IP	41 920 000,00	320 000,00	MWh
	Net consumption without investment	41 920 000,00	320 000,00	MWh
	Mean peak power without investment	2 191 780,82	36,53	MW
	Consumed by P2G	14 377 350,63	109 750,77	MWh
	Net consumption with investment	**56 297 350,63**	**429 750,77**	**MWh**
	Mean peak power with investment	**2 943 500,64**	**49,06**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-20 307,57	MWh
	Net production with investment	**0,00**	**20 307,57**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	5 777 458,36	11 630,00	MWh
	Net consumption without investment	5 777 458,36	11 630,00	MWh
	Produced by P2G	20 016 307,16	51 323,86	MWh
	Net consumption with investment	**-15 480 607,16**	**-39 693,86**	**MWh**
Water	Water from the grid consumed by P2G	15 584,61	9 167,42	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	881 131,57	3 650,00	t
	Wet biomass bought	200 955,12	3 650,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**1 082 086,68**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	222 650,00	365,00	t
	Total revenue from additional sales	**3 909 150,00**		
Residues	Residue from dry anaerobic digester	0,00	109,50	t
	Residue from wet anaerobic digester	0,00	547,50	t
	Tar from gasification + water gas shift plant	0,00	7,30	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without investm	**49 889 239,18**		
	Total operational cost with investmen	**40 948 765,41**		
	Savings with introduction of P2G	**8 940 473,78**		

Fig. 10 Results for optimal P2G hub next to IP with higher prices of natural gas / »renewable natural gas« (x10) and subsidy of 50%.

Subsidy only affects the payoff period, which is shorter than in the case without subsidies (see Fig. 7) and is around 6,5 years (Fig. 10).



Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	1 215 277,78	0,115741	kg/s
	Wet anaerobic digestor	1 215 277,78	0,115741	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	1 157,41	0,002315	kg/s
	Methanation reactor	1 546 601,04	7,278123	mol/s
	Electrolyser	8 111 965,97	6 489,57	kW
	Demineralizer	1 033,86	20,677210	mol/s
	Precipitation collector	1 000,00	1 000,00	m²
	Heat exchanger	118 931,61	2 378,63	kW
	Gas compressor station	97 518,43	243,7961	kWe
	Total for processes	**12 308 763,88**		
Storages	Dry biomass storage	50 000,00	10 000,00	kg
	Wet biomass storage	25 000,00	10 000,00	kg
	Biochar storage	7 500,00	1 000,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	495,06	45,01	m³
	Total for storages	**82 995,06**		
Connections enlargement	Electrical connection	1 332 892,04	8,89	MW
	Gas connection	16 756 531,34	5,86	MW
	Water connection	0,00	1,34	m³/h
	Total for connections	**18 089 423,38**		
	Total investment	**30 481 182,32**		
	Payoff period	**9,33**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	580 750,00	6 900,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	-580 750,00	-6 900,00	MWh
	Mean peak power without investment	0,00	0,00	MW
	Consumed by P2G	14 589 958,16	111 373,73	MWh
	Net consumption with investment	**13 686 058,16**	**104 473,73**	**MWh**
	Mean peak power with investment	**761 949,63**	**12,70**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-20 307,57	MWh
	Net production with investment	**0,00**	**20 307,57**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	20 008 824,14	51 323,86	MWh
	Net consumption with investment	**-20 008 824,14**	**-51 323,86**	**MWh**
Water	Water from the grid consumed by P2G	15 584,61	9 167,42	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	394 260,86	3 650,00	t
	Wet biomass bought	207 574,03	3 650,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**601 834,90**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	222 650,00	365,00	t
	Total revenue from additional sales	**3 909 150,00**		
Residues	Residue from dry anaerobic digester	0,00	109,50	t
	Residue from wet anaerobic digester	0,00	547,50	t
	Tar from gasification + water gas shift plant	0,00	7,30	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without investm	**-580 750,00**		
	Total operational cost with investmen	**-8 852 546,84**		
	Savings with introduction of P2G	**8 271 796,84**		

Fig. 11 Results for optimal P2G hub next to REP with higher prices of natural gas / »renewable natural gas« (x10) and subsidy of 50%.

Additional subsidies reduced the payoff period in comparison with the results with no subsidies (Fig. 8).

Investment specifications

	Element	Cost	Size	
Processes	Dry anaerobic digestor	1 215 277,78	0,115741	kg/s
	Wet anaerobic digestor	1 215 277,78	0,115741	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	1 157,41	0,002315	kg/s
	Methanation reactor	1 546 601,04	7,278123	mol/s
	Electrolyser	8 111 965,97	6 489,57	kW
	Demineralizer	844,94	16,898768	mol/s
	Precipitation collector	1 000,00	1 000,00	m²
	Heat exchanger	118 931,61	2 378,63	kW
	Gas compressor station	23 410,74	58,5269	kWe
	Total for processes	**12 234 467,27**		
Storages	Dry biomass storage	50 000,00	10 000,00	kg
	Wet biomass storage	25 000,00	10 000,00	kg
	Biochar storage	7 500,00	1 000,00	kg
	Biogas storage	0,00	0,00	kg
	Hydrogen storage tank	0,00	0,00	kg
	Oxygen storage tank	0,00	0,00	kg
	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	113,67	10,33	m³
	Total for storages	**82 613,67**		
Connections enlargement	Electrical connection	3 305 683,95	12,53	MW
	Gas connection	33 461 174,83	5,86	MW
	Water connection	0,00	1,10	m³/h
	Total for connections	**36 766 858,78**		
	Total investment	**49 083 939,71**		
	Payoff period	**12,06**	**years**	

Operational costs for selected period

		Cost	Amount	
Electrical energy	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Mean peak power without investment	0,00	0,00	MW
	Consumed by P2G	14 377 350,63	109 750,77	MWh
	Net consumption with investment	**14 377 350,63**	**109 750,77**	**MWh**
	Mean peak power with investment	**751 719,02**	**12,53**	**MW**
Heat	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
	Net production without investment	0,00	0,00	MWh
	Consumed by P2G	0,00	-20 307,57	MWh
	Net production with investment	**0,00**	**20 307,57**	**MWh**
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	20 016 307,16	51 323,86	MWh
	Net consumption with investment	**-20 016 307,16**	**-51 323,86**	**MWh**
Water	Water from the grid consumed by P2G	15 584,61	9 167,42	m³
	Collected precipitation consumed by P2G	n/a	819,00	m³
Input materials	Dry biomass bought	389 114,63	3 650,00	t
	Wet biomass bought	208 880,44	3 650,00	t
	Biochar bought	0,00	0,00	t
	Total cost of input materials	**597 995,06**		
Additional sales	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
	Methane sold (in bottles)	0,00	0,00	t
	Biochar sold	222 650,00	365,00	t
	Total revenue from additional sales	**3 909 150,00**		
Residues	Residue from dry anaerobic digester	0,00	109,50	t
	Residue from wet anaerobic digester	0,00	547,50	t
	Tar from gasification + water gas shift plan	0,00	7,30	t
	CO2 emitted	0,00	0,00	t
	Total cost of residues	**0,00**		
	Total operational cost without investi	**0,00**		
	Total operational cost with investmer	**-8 182 807,84**		
	Savings with introduction of P2G	**8 182 807,84**		

Fig. 12 Results for optimal P2G hub as GF with higher prices of natural gas / »renewable natural gas« (x10) and subsidy of 50%.

Additional subsidies did not change any plant sizes and production volumes, but had an impact only on the shorter payoff period, which is still quite long in comparison with all other business cases calculated (see Fig. 12).

4. CONCLUSIONS

Pre-feasibility studies for three typical location cases for a P2G hub investment in Austria have been conducted with the Optimization Tool developed during the project. Maximum allowed return on investment period of 20 years was set for all business cases, however often the optimum economical setup of the investment yields in much shorter return on investment periods. In general, production of renewable hydrogen takes place in all the cases in Austria, however the production of renewable natural gas gets feasible only when the price for selling and injecton is higher as natural gas prices in the baseline scenario. Also, similar tendencies are observed also for biochar production.