IFAISTOS

Intelligent electroFuel production for An Integrated STOrage System

Deliverable

7.2 - Report on the application of the scalable methodology to two plant

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems. The initiative has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreements no. 646039 and no. 755970.

Smart
Energy
Systems
ERA-Net

Date

Document status

Deliverable No.:	7.2
Deliverable title:	Report on the application of the scalable methodology to two plant
Version:	0
Date created:	10/11/2023
Date updated:	10/11/2023
Date submitted:	

Document preparation

	Date	**Name**	**Organization**
Authored by:	10/11/2023	Paolo Carminati	Siram Veolia
Reviewed by:			
Approved by:	13/12/2023	General Assembly	

Document sensitivity

Moderately sensitive

Available status options:

- Not sensitive
- Moderately sensitive
- Sensitive
- Highly sensitive & confidential

Table of Contents

Executive summary

The IFAISTOS project undertakes exploratory research in the ever-changing landscape of modern energy technologies and solutions, with the objective of assessing the techno-economic feasibility of integrated renewable energy projects and synthetic methane production plants by recovering carbon dioxide produced from the combustion of natural gas. These solutions fall into the category referred to below as Power to Gas (PtG).

The following paper is part of a series of two papers aimed at the technical-economic evaluation of PtG solutions applicable to real cases. Specifically, in paper D7.1 the solution evaluation methodology was explained, while in this paper the results of applying this methodology to two case studies are presented.

In particular, the two case studies considered are representative of two typical consumer situations: one belonging to the tertiary sector (the University of Parma) and one belonging to the industry sector. The two cases are representative of two different types of consumption, since in the first situation consumption is mainly related to space heating in the winter phase and has energy demand profiles dependent on time of day and season. In the case of industry, the energy demand profiles are almost constant because they depend only on the activity that takes place in the industry, which is usually on a continuous cycle.

In this paper, the benefits that could arise from the implementation of a PtG solution for these two types of consumers are therefore analyzed, with particular attention to the economic results. After appropriate plant sizing, using simulation tools, the plant construction costs (Capex) and all operating costs (Opex) were calculated, which also take into account any plant maintenance, all income from the sale of excess electricity, and savings from increased independence from natural gas. This analysis did not take into account the potential recovery of the thermal energy produced by the exothermic methanation reaction.

In all cases investigated, a major obstacle was found to be the high costs of CO2 capture systems and hydrogen production through water electrolysis, and the resulting plant operating costs.

1. Introduction

The purpose of the following paper D7.2 is to illustrate the application of the calculation methodology illustrated in paper D7.1 to two real cases of different types. A techno-economic evaluation of the application of power-to-gas technology was carried out in two types of applications: one using a storage for excess hydrogen produced by the electrolyzer, the other using a battery storage for excess electricity produced by the photovoltaic system. These two types of solutions correspond to those outlined in previous delivery document D7.1.

The two case studies were taken as a reference of two typical plant situations, one of public administration and the other of an industry. The difference between the two types of operation lies mainly in the hourly thermal energy requirements of the two customers. In the case of the public administration, the heat load is time-varying and has variations throughout the year: more heat is required during the heating season because the plant has to produce heat for both heating and domestic hot water consumers. In the case of industry, the energy demand is almost constant throughout the year because the heat is used for industrial processes, which are never interrupted.

➢ 1.1 Configurations

As has already been outlined in D7.1, the Power to Gas system configurations considered in this analysis are as follows, which we resume for the sake of completeness.

■ 7.2.1 Power to Gas with H_2 Storage

This configuration involves the conversion of renewable electricity to hydrogen through electrolysis. The generated hydrogen is stored and later used for methanation to produce synthetic methane, from the CO_2 capture from the boiler. The system relies on hydrogen storage to manage energy fluctuations. As shown in fig 1.

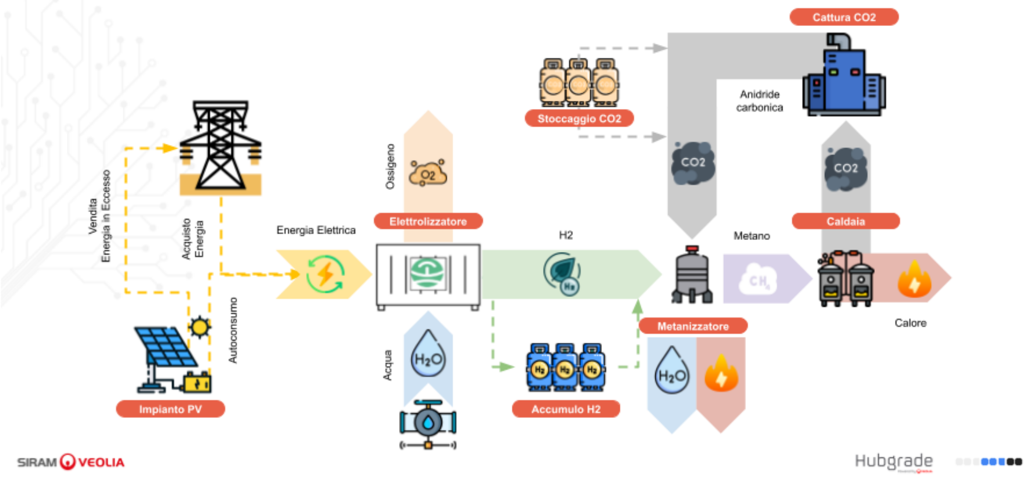

Fig 1. Power to Gas with H_2 Storage configuration

■ 7.2.2 Power to Gas with Electric Storage

This configuration involves the conversion of renewable electricity to hydrogen through electrolysis. The generated electricity is stored and later used for energizing the electrolyzer that supplies methanation to produce synthetic methane. In this configuration, excess electricity is stored directly in an electric storage system. Electricity can be retrieved when needed to support methanation or other energy-demanding processes. It offers a flexible approach to energy storage. As shown in fig 2.

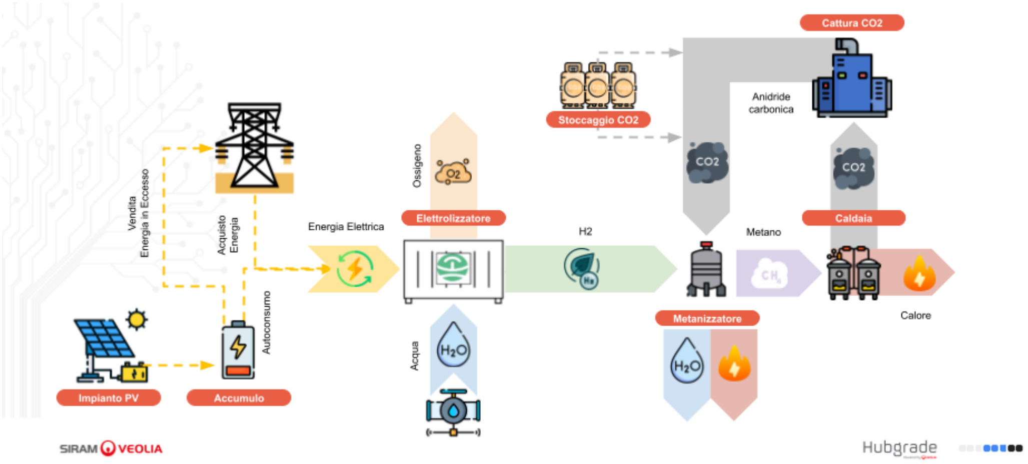

Fig 2. Power to Gas with Electric Storage configuration

2. Case Studies

To illustrate the real-world applicability of the Power-to-Gas (PtG) initiative, Siram Veolia presents 2 case studies. These studies showcase how PtG solutions could be implemented in industrial and public administration contexts, highlighting their benefits and possible feasibility.

➢ 2.1 Case Study: University Campus Parma

The University Campus Parma boasts a substantial thermal power installation, totaling 9.97 MW, distributed as illustrated by Table 1.

Boilers		
Boiler	*Description*	*kW_th*
E1	GREENOX.e300	**3.150,0**
E2	ICI REX351F	**3.670,0**
E4	GREENOX.e300	**3.150,0**
TOTAL POWER		**9970**

Table 1. Thermal plant at the University Campus Parma

This is a typical public administration context for exploring the implementation of PtG solutions: we evaluate two different options in this context.

This case is representative of a type of consumption that is not constant, because it is related to the heating of rooms occupied by university staff and students at certain times of the day and during the heating season. During the summer period, the boilers work differently from the winter period, with much lower consumption, in order to provide hot water.

This case study can be considered representative of all PtG technology application contexts where there is an hourly and seasonal dependency of consumption and intermittent requirements.

■ 2.1.1 Configuration 1: Hydrogen storage

This configuration relies on hydrogen storage technology produced from renewable sources to mitigate the daily fluctuations of electricity that comes from this type of natural source. The application of this type of Power to Gas technology has the effect of reducing CO_2 emissions, in fact this approach results in the capture of about 50% of the CO_2 produced by the 9.97 MW boiler system. The liquefied gas is partly used for CH_4 production, resulting in savings of 5% of natural gas per year, while the excess can be used to generate revenues from sales to the food industry.

As can be seen from Table 2, this solution amounts, in terms of initial economic investment (Capex) to about €20’600’000, while the operating costs (Opex) turn out to be €2’837’000 per year.

Table 3 shows the results of the model's economic calculation. Revenues are also found to be good, relative to Capex, but the operating costs of the plant are so high that the net profit is negative. This result is mainly due to the high energy cost of hydrogen production by the electrolyzer and the high operating cost of the CO_2 recovery system.

	Size	***Cost [€]***
PV Plant	4000 kW	4’800’000 €
Electrolyser + storage 180kg	200 Nmc/h	1’450’000 €
Methanizer	53 SmC/h	218’000 €
CO_2 Capture	4115 tCO_2/year	9’741’000 €
Capex	+150,000 € Meters +15% Installation + 2% Security charges +10% Pipe	***Total*** 20’600’000 €/tantum
Opex	Maintenance Electricity purchased from the grid	***Total*** 2’837’000 €/year

Table 2. Economic overview solution with hydrogen storage

Results	
Natural Gas saved	213’000 Smc/year
CO_2 capture	4115 ton/year
Revenues	2’283’000 €/year
Net profit	-554’000 €/year

Table 3. Economic results solution with hydrogen storage

This estimation does not take into account the possibility of recovering heat from the methanation reaction, which is an exothermic reaction.

2.1.2 Configuration 2: Electric storage

This configuration is based on battery electricity storage technology produced from renewable sources to mitigate the daily fluctuations of electricity from this type of natural source. The application of this type of Power to Gas technology has the effect of reducing CO_2 emissions; in fact, this configuration allows 50% of the CO_2 produced by the 9.97 MW boiler system to be captured. The liquefied gas is partly used to produce synthetic methane, which reduces the plant's dependence on natural gas by 5% annually, while the surplus, as in the previous configuration, can be used to generate revenues from sales to the food industry.

	Size	***Cost [€]***
PV Plant + storage 3MWh	4000 kW	6’300’000 €
Electrolyser	200 Nmc/h	1’000’000 €
Methanizer	53 SmC/h	218’000 €
CO_2 Capture	4115 tCO_2/a	9’741’000 €
Capex	+150,000 € Meters +14% Installation + 2% Security charges +10% Pipe	***Total*** 21’920’000 €/tantum
Opex	Maintenance Electricity purchased from the grid	***Total*** 3’116’000 €/year

Table 4. Economic overview solution with battery storage

As can be seen from Table 4, this solution amounts, in terms of initial economic investment (Capex) to about €21’920’000, while the operating costs (Opex) turn out to be €3’116’000 per year.

Table 5 shows the results of the model's economic calculation. Revenues are also found to be good, relative to the investment cost, but the operating costs of the plant are so high that the net profit is negative. Compared with the previous situation, it can be seen that the cost of operating an electric storage system is more expensive than operating a hydrogen storage facility.

Results	
Natural Gas saved	213’000 Smc/year
CO_2 capture	4115 ton/year
Revenues	2’347’000 €/year
Net profit	-769’000 €/year

Table 5. Economic results solution with battery storage

This estimation does not take into account the possibility of recovering heat from the methanation reaction, which is an exothermic reaction.

➢ 8.1.4 Conclusion

The case study conducted at the University Campus Parma explains the diverse possibilities and considerations inherent to the implementation of Power-to-Gas (PtG) solutions in public administration context.

Each of the two PtG options evaluated show negative net profits, a symptom of the fact that the system absorbs a lot of energy to work. With the actual technologies, revenues could be increased by adding PV panels to the plant, but the available area on the roofs is not sufficient for this purpose, and in any case this would increase the capex of the intervention and the maintenance costs of the system.

The most expensive aspects of the economic plan of the project are definitely the size and operation of the CO_2 capture system and the electrolyzer for hydrogen production. This suggests that if technical improvements were made to the electrolyzer technology so as to make hydrogen production more efficient and the cost of the CO_2 recovery plant was reduced, the intervention could become economically profitable.

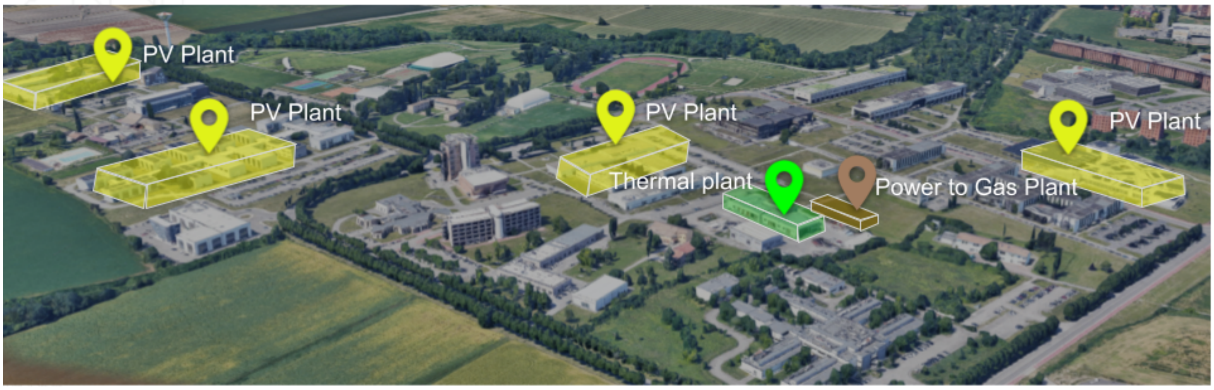

Fig 4. Case Study PtG at the University Campus Parma

➢ 2.1 Case Study: Food industry

In this case study, we analyze the use of Power to Gas technology applied to a typical industry whose boiler plant size has been chosen as a benchmark of 50 MW. The industrial case is interesting compared to the tertiary sector application because typically heat generation (and thus CO_2 generation) is constant over time and does not exhibit fluctuating trends on a daily and annual basis.

This type of energy demand, with an almost constant profile, certainly allows for a more efficient use of the energy storages within the system. We see below the simulation results for the two options, one with hydrogen storage and the other with battery power storage.

■ 2.1.1 Configuration 1: Hydrogen storage

As shown in the previous case study, in this Power to Gas configuration, it has been studied the techno-economic feasibility of a Power to Gas system that relies on a 200 kg hydrogen storage to mitigate the intermittent effects of power generation from renewable sources. The application of this configuration to the industrial plant under consideration has the effect of reducing CO_2 produced by the 50 MW boiler system by about 15%, corresponding to 13 000 tons of CO_2 per year. The liquefied gas is partly used for CH_4 production, resulting in savings of about 1% of natural gas per year, while the excess can be used to generate revenues from sales to the food industry or for self-consumption, if the food industry needs it.

As can be seen from Table 6, this solution amounts, in terms of initial economic investment (Capex) to about €67’300’000, while the operating costs (Opex) turn out to be €8’975’000 per year.

Table 7 shows the results of the model's economic calculation. For this case, revenues are more than operating costs of the plant, so the net profit is positive, amounting to 1.28 million euros, that corresponds to more or less 2% of the Capex. This result could be improved if the CO_2 produced was then purified and reused at the same plant, but this would require the plant to undergo an upgrade to purify CO_2 for food use.

	Size	**Cost [€]**
PV Plant	20 000 kW	24’000’000 €
Electrolyser + storage 200kg	200 Nmc/h	1’500’000 €
Methanizer	40 SmC/h	164’000 €
CO_2 Capture	13 000 tCO_2/year	27’600’000 €
Capex	+150,000 € Meters +15% Installation + 2% Security charges +10% Pipe	**Total** 67’300’000 €/tantum
Opex	Maintenance Electricity purchased from the grid	**Total** 8’975’000 €/year

Table 6. Economic overview solution with hydrogen storage

Results	
Natural Gas saved	336’000 Smc/year
CO_2 capture	13 000 ton/year
Revenues	10’250’000 €/year
Net profit	**1’275’000 €/year**

Table 7. Economic results solution hydrogen storage

This estimation does not take into account the possibility of recovering heat from the methanation reaction, which is an exothermic reaction.

2.1.2 Configuration 2: Electric storage

This second option relies on an energy storage system in advance of the electrolyzer, within a battery storage system of the size of 2.5 MWh. The application of this type of Power to Gas configuration has the effect of reducing CO_2 emissions of about 15%, corresponding to 13 000 tons of CO_2 per year, and using part of it to produce synthetic methane and reduce dependence on natural gas by about 1%, the remaining part generates revenue through sales on the food industry.

	Size	***Cost [€]***
PV Plant + storage 2.5MWh	20 000 kW	25’250’000 €
Electrolyser	200 Nmc/h	1’000’000 €
Methanizer	40 SmC/h	164’000 €
CO_2 Capture	13 000 tCO_2/year	27’600’000 €
Capex	+150,000 € Meters +14% Installation + 2% Security charges +10% Pipe	***Total*** 68’240’000 €/tantum
Opex	Maintenance Electricity purchased from the grid	***Total*** 9’850’000 €/year

Table 8. Economic overview solution with battery storage

As can be seen from Table 8, this solution amounts, in terms of initial economic investment (Capex) to about €68’240’000, while the operating costs (Opex) turn out to be €9’850’000 per year.

Table 9 shows the results of the model's economic calculation. Revenues are in this case more than operating costs of the plant and so the net profit is positive, amounting to 0.8 million euros, that corresponds to more or less 1.2% of the Capex. This result could be improved if the CO_2 produced was then purified and reused at the same plant, but this would require the plant to undergo an upgrade to purify CO_2 for food use.

Results	
Natural Gas saved	336’000 Smc/year
CO_2 capture	13 000 ton/year
Revenues	10’655’000 €/year
Net profit	**805’000 €/year**

Table 9. Economic results solution with battery storage

This estimation does not take into account the possibility of recovering heat from the methanation reaction, which is an exothermic reaction.

➢ 8.1.4 Conclusion

The techno-economic feasibility study of a Power to Gas project in industry showed how the investment can be profitable in economic terms if applied to a plant that works more constantly than in the case of the public administration application.

This allows for smaller storage systems, since the amount of energy to be stored relates to the day-night pattern without embracing an annual seasonality. The most profitable configuration, as in the previous case, is hydrogen storage with respect to electric storage.

On the basis of our economic evaluations and with the costs of management, operation and maintenance of the systems we identified, the net profit to be obtained by implementing a Power to Gas solution turns out to be about 2% of the initial investment cost. It would certainly be interesting to evaluate the solution in which the self-consumption of CO_2 derived from the recovery system is maximized by upgrading it and equipping it with a purification system.

In any case, from our evaluations, it still appears that the cost of the carbon dioxide recovery system for large sizes is very high, and the electrolysis of hydrogen for the CO_2 methanation operation is very expensive in energy terms.

3. Conclusions

This paper aimed to make an application to two typical case studies of Power to Gas configurations so that the investment evaluation procedure described in D7.1 could be made explicit.

Two examined cases were chosen on the basis of two different types of consumption: those of a public administration situation, with heat production mainly concentrated in the winter season, and an industrial plant, with more or less constant heat output.

The techno-economic evaluation considered two different types of Power to Gas plants. In both configurations, the beneficial economic effects of installing a Power to Gas plant was evaluated, considering revenues generated by CO_2 capture and the increased independence from natural gas of the plants. In both configurations, a renewable energy storage system was included in the plant to mitigate daily source fluctuations, with both hydrogen and electricity storage.

What emerged from our evaluations is that a Power to Gas system with the current technical characteristics is difficult to apply in the tertiary sector, while it turns out to have economic convenience in the industrial sector. A determining factor for this type of result is due to the strong imbalance between gas consumption in the summer-winter period of the tertiary sector, a difficulty which does not occur in industrial application.

In both case studies, the configuration with hydrogen storage rather than electricity storage turns out to be more profitable. In the case of industrial application, on the basis of our economic evaluations and with the costs of management, operation and maintenance of the systems we identified, the net profit to be obtained by implementing a Power to Gas solution turns out to be about 2% of the initial investment cost. In order to promote the project, it is therefore recommended to receive funding to encourage the technology, bring attention to the possible benefits of implementing these solutions so that the operating costs of CO2 capture systems and hydrogen production by electrolysis can be lowered.

In any case, the most expensive aspects of the economic plan of the project are definitely the size and operation of the CO_2 capture system and the electrolyzer for hydrogen production. This suggests that if technical improvements were made to the electrolyzer technology so as to make hydrogen production more efficient and the cost of the CO_2 recovery plant was reduced, the intervention could become economically profitable.