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Indicators matrix for different innovative technologies for small to medium scale biomethane production and supply and their applicability

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Authors:	Kathrin Bienert, Britt Schumacher, Martín Rojas Arboleda (DBFZ)	
Involved participants:	UWM, RISE	
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1 Record Biomap in a nutshell

The EU funded H2020 project "Record Biomap" has built up a knowledge transfer platform aiming to foster the use of research outcomes, which are often insufficiently exploited after the end of a research project. In the focus are technology solutions for a cost efficient biomethane production at small to medium scale, which is not yet economically competitive compared to large-scale applications. Record Biomap monitors the technology developments along the biomethane supply chain, from substrate pre-treatment, digestion systems up to gas upgrading processes, especially for those technologies, which are yet in the first phases of their development. Aim is to bridge the gap between research and industry through knowledge transfer and establishment of new cooperation.

2 Introduction

The aim of this deliverable is to present the different technologies for small and medium scale biomethane production in the form of an indicators matrix. The data for the technologies was collected in Task 1.2 and is available on the project website in the form of technology descriptions.

It is planned to publish a more detailed assessment based on these data in a scientific paper in 2019.

3 Methodology

The assessment covered 11 innovative small to medium scale technologies for upgrading biogas to biomethane. Biomethane is an outcome from separating biogas (e.g. from digestion), predominantly consisting of CH_4 and CO_2, into those two fractions. Among the 11 technologies are also two technologies, which follow the power-to-gas (PtG) approach. Those technologies use the biogas as an input stream and convert the carbon dioxide in the biogas to additional methane by adding hydrogen. It is assumed that the hydrogen for the PtG is produced via electrolysis from excess electricity (e.g. from wind power) and reacts with the carbon dioxide to methane. The use of those technologies ("Biological Methanation" and "Trickle bed reactor for methanation") will lead to the production of additional biomethane compared to the methane content that was included in the biogas stream. Therefore, they are not directly comparable to the conventional upgrading technologies.

The technologies are considered as small for the purposes of this research when they have an estimated production of gas less than 200 m^3 (Standard Temperature and Pressure, 273.15 K, 1.01325 10^5 Pa). The focus of the project was to only consider technologies that are still in their development with a TRL-level between TRL 3 and TRL 7. According to EC-definition [1]: TRL 3 means "Experimental proof of concept" and TRL 7 stands for "System prototype demonstration in operational environment".

Data gathering measures focused on a template called "Technology Description". It characterizes in precise detail each technology and was filled by the technology developer together with the project partner who was responsible for the collection. All technology descriptions are made available for further scrutiny on the project website from Record Biomap.

One of the main challenges for the integral assessment of these technologies was that technologies presented a different development status, e.g. different TRL´s. Naturally, consumption in production and volumes are different with different TRL´s, making comparison a difficult challenge. Data quality of early TRL´s can also be considered lower. It was intended to collect data based on a market ready stage of the technology (based on test runs of current technology). However, sometimes data on this basis were not available and had to be based on estimates or even on the current TRL-level of the technology.

A reference for biomethane upgrading was defined based on average data of large-scale, market ready technology. The values for the reference technology are included in the last column of the indicators matrix. Those were obtained based on published data in [2]. An average of the published data for all plants with a capacity of 700 m^3/h of raw gas was used. It should be noted that the reference is included only to give a rough indication for the performance of larger, market ready technology. Of course, it is not possible to compare innovative, smaller scale technology directly with the reference.

To develop a useful indicators matrix we monitored and compared the following indicators:

3.1 Technical indicators

Electricity and heat demand were included in the assessment as they represent the main energy inputs. In addition, the methane slip, methane content in the product gas and the delivery pressure of the product gas were included in the indicators matrix.

3.2 GHG Emissions indicators

The base for calculus is based on the methane slip –as a powerful GHG- and electricity & heat demand of the technologies, which represent the main energy inputs [3]. It was decided to focus on the GHG-Emissions associated with the application of the technology, which means that emissions related to the production of the biogas or logistics are not included.

The calculus process went as follows: multiplication of the specific value for electricity and heat demand (e.g. in kWh/m^3) with the respective emission factor[1] (e.g. kg CO_2-equivalent/kWh). The sum of those three values indicates the technology related emissions.

3.3 Economic indicators

The aim of this comparison is to enable performance assessment of the biomethane production step (or upgrading). Costs data were not available for some technologies, mainly due to the low TRL. The base for assessment is the annuity method according to VDI 2067 [6]. For the

[1] The emission factor for the EU-electricity mix was taken from [4], for heat (defined as heat that is supplied from a wood chip boiler) was based on [5]. The methane slip was considered and multiplied with the global warming potential for methane provided in [4].

calculation, 2016 was chosen as the base year. Further economic parameters and assumptions are stated in Table 1.

Table 1: Assumptions for the economic assessment

Parameter	Unit	Value
Electricity cost (mix Europe) [7]	ct/kWh	10.74
Heat cost (average price for Europe) [8]	ct/kWh	6.49
Interest rate for equity [a]	% p.a.	10
Equity Share [a]	%	20
Interest rate for debt [a]	%	2
Share of debt [a]	%	80
Discount rate (WACC) [a]	%	3.6
Inflation for capital-linked costs [a]	% p. a.	1
Inflation for other cost (operation, consumption, other cost) [a]	% p. a.	2
Insurance cost [a]	% p. a.	0.5
Unforeseen cost [a]	%	1
Specific staff costs [a]	€/h	25
Maintenance cost [a,b]	% p. a.	2
Project Development, Planning, Permission, Building cost [9]	%	10.5
Full load hours [a,b]	h	8400

The consumption costs were based on the energy demand with the average price for electricity and heat. Additionally, costs regarding operation (personnel), maintenance, insurance, unforeseen costs, specific capital costs, were also part of the assessment.

Keep in mind that the “Biological Methanation” and “Trickle bed reactor for methanation” technologies are not comparable under this perspective because they consume a considerable amount of electricity due to the nature of their process. It is typically expected for them that this electricity shall be covered via excess electricity. Therefore, this results in more biomethane than was included in the raw gas. This means that the specific costs in €ct/kWh raw gas would not be comparable to the conventional upgrading technologies and those were therefore not included in the matrix.

3.4 Categories

In order to achieve a graphical representation of the values, three different categories were defined for all technical, GHG emission and economic indicators. In general, the data sets consist of natural numbers. The median was determined and a range for the category “middle” of median plus 1/3 for the upper limit and as well as median minus 1/3 for the lower limit of this category was calculated. Data below the lower limit of the category “middle” were defined as “low” and data above the upper limit as “high”, respectively (Figure 1). One exemption was made for the methane content in the product gas. In order to avoid that all values would be in the same category the lower level was defined to be equal or below 95 % and the higher level to be above 95 %. Only 2 categories were chosen here. The value of 95 % was chosen as this mostly represents the minimum requirement for injection of biomethane into the gas grid.

The different categories are represented with different shades of green in the resulting matrix. Depending on the type of indicator it is favorable to have a low number (e.g. for electricity consumption) or a high number (e.g. for methane content in the product gas). Therefore, the darkest shade always represents the more favorable condition and the lightest green the least favorable condition for the specific indicator.

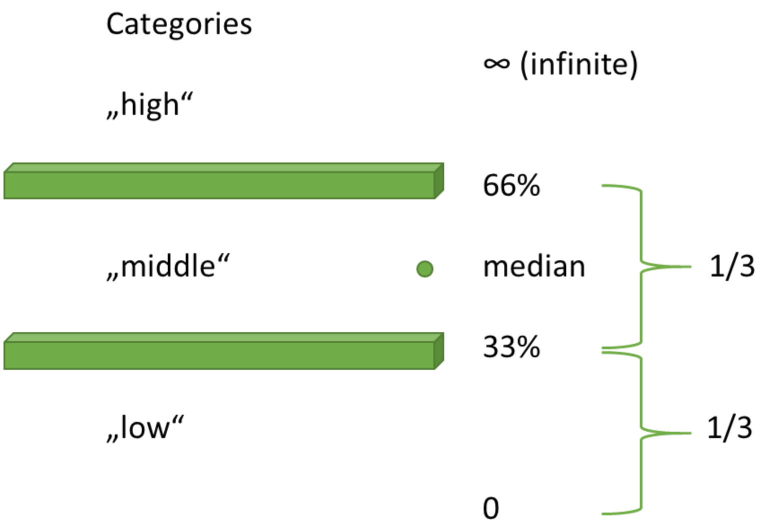

Figure 1: Matrix´s categories

4 Indicators Matrix for upgrading technologies

The main results for the technologies are presented in the following matrix.

As explained in the previous section, the different shades of green highlight how good the technologies perform for the individual indicators. E.g. the technology “ash filter” shows favourable results for most indicators and is in the medium range for delivery pressure and upgrading costs. However, it should be noted that it always depends on the individual conditions (e.g. downstream/upstream technology, site conditions, use of product etc.) if a technology is more or less suitable/favourable for a certain purpose.

In addition to the indicators the main characteristic for each technology are included in the table.

Table 2: Indicators Matrix for innovative small to medium scale biomethane technologies (TRL3-7)

Technology Provider	TRL	Data basis*	Name of Technology	Flow rate (range) /upgrading capacity (m^3 raw gas/h)	Possible range of upscaling (m^3/h)	Methane content in product gas (%)	Electricity demand (kWhel/m^3 raw gas)	Heat demand (kWhth/m^3 raw gas)	Biomethane slip (% of biomethane production)	Delivery pressure (bar abs)	Complexity***	Total upgrading cost (€ct/kWh raw gas)	Total GHG emission kg CO2-eq. /m^3 biomethane	Possibility of H_2S removal through technology	Specific characteristics
University of Valladolid	5	3	**Algal Bacterial System for biogas upgrading**	0.4	<300	93.50	0.09	0.00	2 %	1.00	complex	1.46	0.40	Technology itself removes 99 % of total H_2S-content of raw gas	Ideal for tropical climate; no need for prior H_2S-removal. Only applicable in conjunction with continuous microalgae production in tropical climate.
Electrochaea**	7	1	**Biological Methanation**	125	213	97.00	0.60	0.00	0.5 %	9.00	medium complex	-	0.36	Yes, the biological catalyst has an uptake rate of H_2S	Specific strain of microorganism is used. Requires chemicals and additives. Produces usable heat. Power to gas system using biogas as a CO_2 source, the H_2 is provided by electrolysis.
NEOZEO	7	1	**Vacuum Pressure Swing Adsorption - VPSA**	200	200-2000	97.00	0.28	0.00	1 %	3.00	medium complex	1.59	0.38	< 99% (if H_2S concentration is below 100 ppm)	Uses durable absorbent material. It is a complex device that requires expert maintenance.
RISE	5	1	**Ash filter**	38.05	57	99.00	0.02	0.00	0.2 %	1.02	simple	2.36	0.05	Technology itself removes >99 % of total H2S-content of rawgas	Requires ash: 3.6 – 7.1 kg/Nm3 raw gas. Simple and cheap, however it includes ash logistics if not available on site.
Centrale Supélec	5	2	**G-PUR Membrane technology**	100	12,6 - 126	97.00	0.22	0.00	2 %	6.00	medium complex	1.61	0.50	not known	Uses membrane contactors as a gas-liquid exchanger. Complex 3 stage technology using membranes and absorbents.

Technology Provider	TRL	Data basis*	Name of Technology	Flow rate (range) /upgrading capacity (m^3 raw gas/h)	Possible range of upscaling (m^3/h)	Methane content in product gas (%)	Electricity demand (kWhel/m^3 raw gas)	Heat demand (kWhth/m^3 raw gas)	Biomethane slip (% of biomethane production)	Delivery pressure (bar abs)	Complexity***	Total upgrading cost (€ct/kWh raw gas)	Total GHG emission kg CO2-eq. /m^3 biomethane	Possibility of H_2S removal through technology	Specific characteristics
RISE	5	1	**In-situ methane enrichment**	38.05	571	77.50	0.25	0.00	1.75 %	1.00	simple technology, complex operation	2.47	0.48	Technology itself removes 50-80 % of total H_2S-content of rawgas	Ideal for pre-upgrading, may reach German L gas specs (>=90%). Technology is simple but operation is complex as methane enrichment is integrated to its production.
APEX	7	2	**Blue Feed Membrane technology**	100	possible but not in focus	96.00	0.30	0.00	1 %	7.50	simple	2.81	0.40	no	Option of parallel or individual operation of feed-in into grid and fueling of vehicles.
University Landshut	4	3	**Cryogenic treatment of biogas**	37.8	20-200	99.90	1.00	0.00	0 %	1.20	medium complex	-	0.69	not known	Produces high purity liquid biomethane and CO_2 (dry-ice) as by-product. Requires gas pre-treatment; no information about CAPEX yet, high electr. demand.
AzzeroCO2 srl	5	3	**Biogame VSA**	0.5	350	98.00	4.00	0.00	5 %	6.00	medium complex	-	4.52	not known	Adsorbing material is natural zeolite
UWM	3	2	**Upgrading with algae biomass**	4	100	88.00	1.50	0.20	0 %	1.00	medium complex	15.06	1.03	Yes, 80-90 % of H_2S are removed	Small heat demand
GICON**	5	3	**Trickle-bed reactor for methanation**	1	500	95.00	0.12	0.12	0 %	1.00	simple	-	0.06	no	Production of methane can be increased by incorporating H_2 from excess electricity. Excess electricity can therefore be stored as methane in the gas grid.
Reference case (Nawaro-700)	9	-	REFERENCE	700	-	96.3	0.21	0.16	1.7 %	5.50	-	1.39	0.44		State of the art.

* 1= market ready stage of technology (based on test runs of current technology), 2= market ready stage of technology (based on estimate), 3= current level (TRL) of technology.
** Technologies are power-to-gas technologies, which need excess electricity to convert the CO_2 in the raw biogas into additional CH_4. The additional electricity for this is not included here.
*** Rating by project partner that was in contact with technology developer

Legend:

favourable
medium favourable
less favourable

5 Discussion and conclusion

It can be concluded that an assessment for technologies, which are still in their development stage is difficult. However, the indicators matrix shows the general pictures for the technologies and for the chosen reference. The electricity demand of most upgrading technologies is similar to the reference. In addition, the requirements for gas grid connection (usually between 95 and 97 % biomethane) are met by most of the innovative technologies. The main driver for GHG-emissions is the methane slip, followed by the electricity demand. The methane slip of some technologies has to be reduced significantly in order to meet the regulations in most European countries. The economic indicator shows that for some of the technologies the upgrading costs are close to the reference with about 1.5 €ct/kWh raw biogas. All technologies have specific particularities as well as advantages and disadvantages, which makes them suitable for different cases.

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