BIOMETHANE INDUSTRIAL PARTNERSHIP

INSIGHTS INTO THE CURRENT COST OF BIOMETHANE PRODUCTION FROM REAL INDUSTRY DATA

OCT 2023 // PREPARED BY TASK FORCE 4.2

BIP Europe
Biomethane Industrial Partnership

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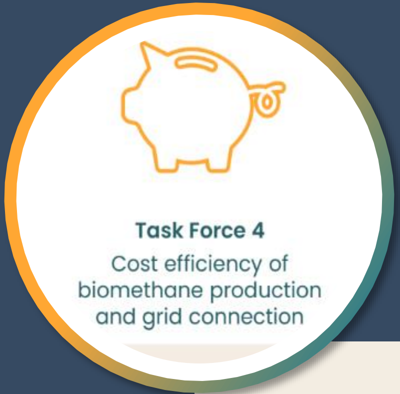
to investigate the cost of EU biomethane production

Executive summary



The Biomethane Industrial Partnership Task Force 4 provides insights into best practices for efficient & low-cost biomethane production, and grid injection.

Sub group 4.2: focusses on the cost of biomethane production

First-of-a-kind anonymous data collection using real company data

- facilitated by Common Futures with careful consideration for EU competition law

Results now in final draft, with highlights shown in this report.

17 companies across the biomethane supply chain joined efforts, 13 companies submitted data.

Initial results and **ideas on cost reductions** were discussed at a **workshop in Brussels together with all companies**

Executive summary

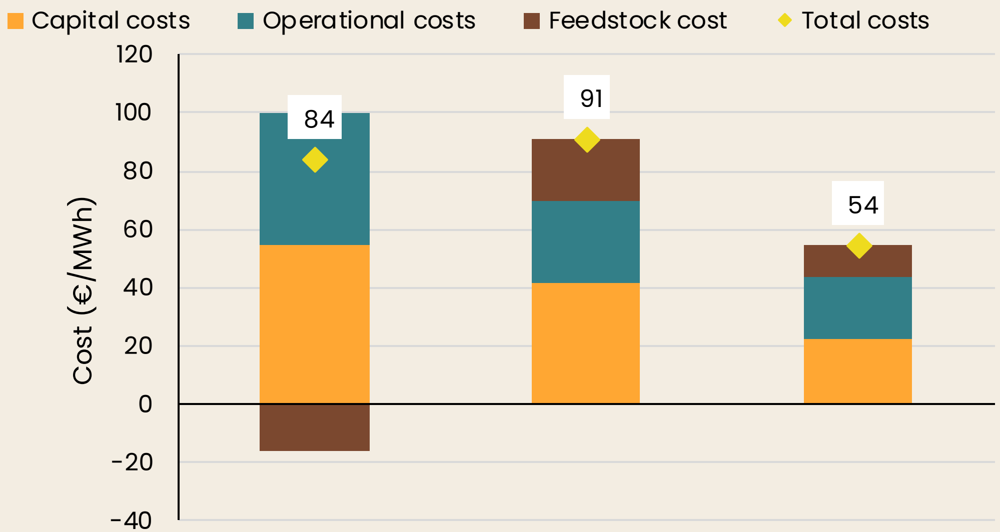
Biomethane production costs show large economies of scale

The total cost of biogas production and upgrading ranges from €54-91/MWh

Economies of scale are evident, especially in the capital costs

- Size category 2 has submissions with "*public feedstocks*". **This leads to the negative average feedstock cost.**
- The cost of production from other feedstocks shows that using public feedstocks leads to on average higher capital and operational costs than production with other feedstocks.

Total cost of biomethane production and upgrading



Size Category	2	2	4
Biogas (m3/h)	500 - 1300	500 - 1300	>2000
Biomethane (m3/h)	300 - 780	300 - 780	>1200
Biomethane (MW)	3 - 8	3 - 8	>14
Submission types	All feedstocks	Excluding public feedstocks*	All feedstocks

**Public feedstocks* are public waste streams which can be used as feedstocks but commonly require significant levels of pre-treatment, and thus come with no cost or a negative cost (gate fee)

Biogas facility most significant cost in biomethane supply chain; feedstock mix dependent

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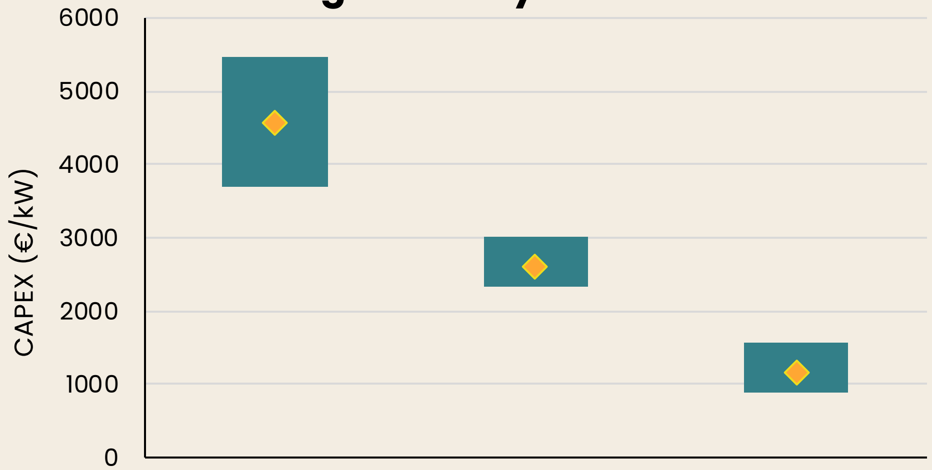
- **The biogas production facility is the most significant cost in the biomethane supply chain on average**
  - Digesters, civil works, & wastewater + digestate handling facilities are the dominating costs

- When separating the public feedstock and non-public feedstock production**, the capital investments are shown to be 80% higher on average for public feedstock production.**
  - Pre-treatment facilities are notably more expensive for public feedstock production.

- **Economies of scale is strong in capital costs**, with investments required per capacity **decreasing by a factor of 2** with an increase in size from size category 2 to 4.

Digesters, civil works, & wastewater + digestate handling facilities are the dominating costs

Biogas facility CAPEX

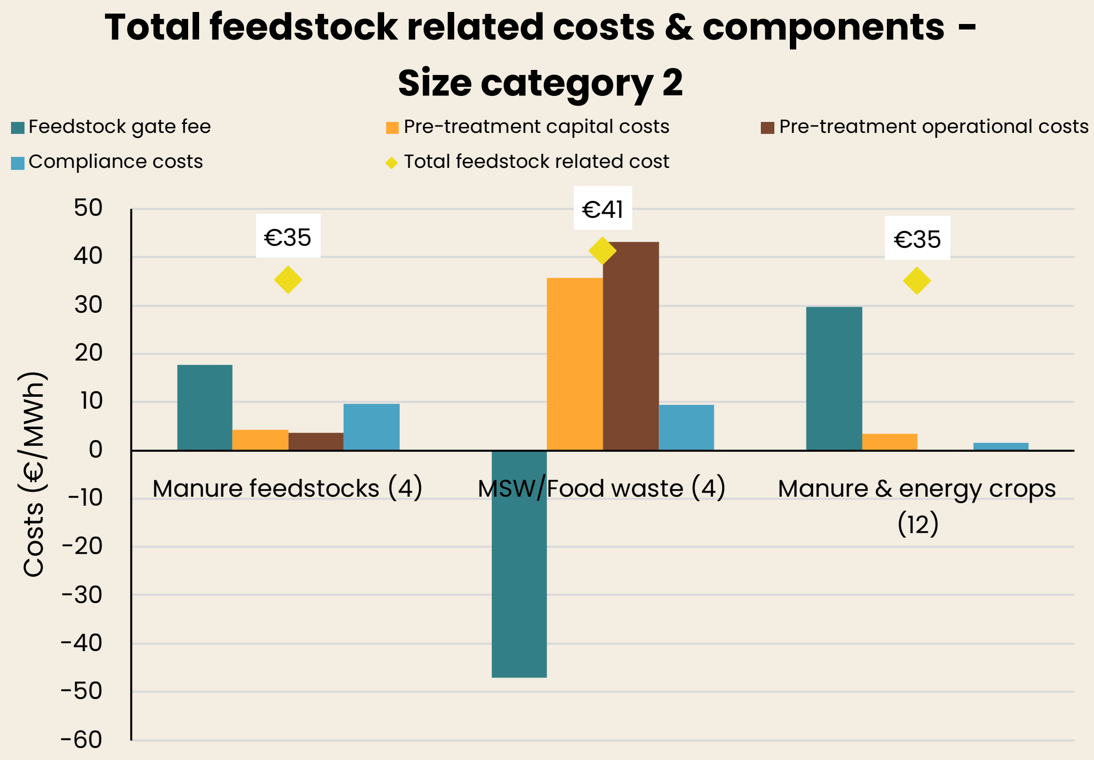


Size Category	2 (public only)	2 (non-public)	4
Biogas (m3/h)	500 - 1300	500 - 1300	>2000
Biomethane (m3/h)	300 - 780	300 - 780	>1200
Biomethane (MW)	3 – 8	3 – 8	>14
No. of plants	4	23	4

Feedstock mix costs have large range
but the total cost related to a feedstock mix choice are similar

Executive summary

Feedstock mix costs from submissions range between -€94 and €43/MWh$_{biomethane}$.



A *"total feedstock related cost"* parameter can be calculated to see how the feedstock cost relates to the costs induced by your feedstock mix choice

The costs considered are:

The results show that despite the large range in feedstock cost, the total feedstock-related cost is comparable for very different feedstock mixes.

Conclusions

Executive summary

1

The **cost of biomethane production** in 2021 was **on average €87/MWh** for producers of **~ 540 Nm3/h, and €54/MWh** for producers of **>1200 Nm3/h.**

2

Economies of scale are strong in biomethane production, **especially in the capital costs.**

3

Despite feedstock costs ranging from –€94 to €43/MWh when considering the cost of pre-treatment and other costs incurred by feedstock mix choice, the **"total feedstock related costs" are comparable for differing feedstock mixes.**

4

If compared with the natural gas wholesale TTF price and a cost of carbon a of €64/MWh[1], **large producers** could **already be cost competitive,** but **biomethane production remains on average more expensive.**

5

Benefits of biomethane not fully captured in a cost analysis based on its use as an energy vector. Biomethane's role in enabling other sustainable processes and allowing emission reduction in hard-to-abate end uses will likely bring a high value for biomethane.

[1] A TTF cost for natural gas of €44/MWh (ICE: "CAL 24" TTF future price) and an EU ETS price of €100/t CO_2 with an emission factor of natural gas of 56gCO_2/MJ, leading to €20/MWh_{NG}.

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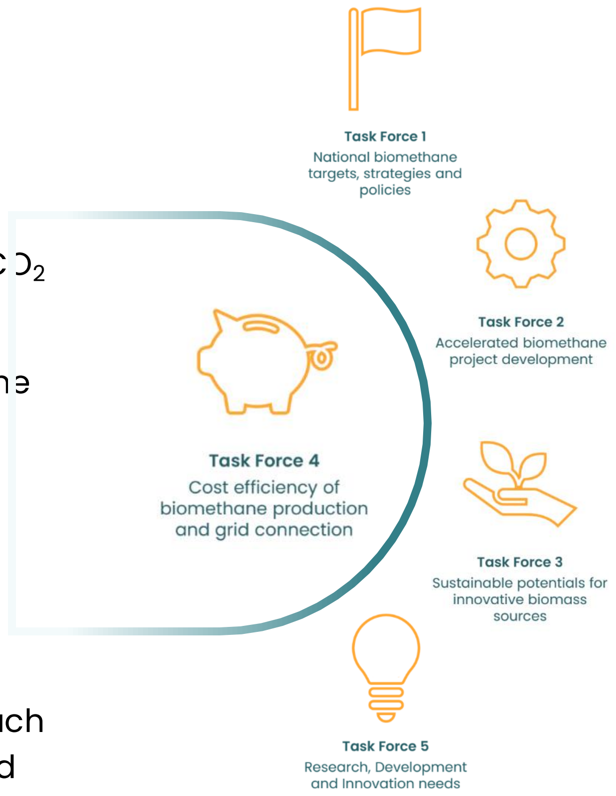
The Biomethane Industrial Partnership

The launch of the BIP by EVP Timmermans and Commissioner Simson on the 28 of September during the European Sustainable Energy Week.

- The Biomethane Industrial Partnership (BIP) was created with the intention to **help to achieve the REPowerEU target of 35 bcm of annual biomethane production by 2030.**
- The European Commission introduced the 35 bcm target as it recognises the important benefits of biomethane in enhancing Europe's **energy security** and to **reduce greenhouse gas emissions** (including the ability to generate **negative emissions**).
- Biomethane also has other important benefits as an enabler of more **environmentally friendly, circular agriculture,** plus biomethane also has important **energy system benefits** as a storable, energy dense renewable energy source which can be transported through existing gas infrastructure.

Task Force 4.2 focuses on production costs

- Work of the BIP takes place in five Task Forces, each with their own focus
    - Task Force 4 aims to provide insights into best practices for efficient and low-cost biomethane production and grid injection.
- **Task Force 4 is divided into three subgroups:**
    - Task Force 4.1 – Valorisation of by-products of biomethane production e.g. digestate, biogenic CO_2
    - **Task Force 4.2 – The cost of biomethane production and how this can be reduced**
    - Task Force 4.4 – Optimise grid connections and grid reinforcements to allow low cost biomethane injection
- **The present report captures the results of Task Force 4.2**
    - This work is also linked to the work of other Taskforces, e.g. the work of Task Force 2 where the business case is evaluated, with many topics such as the de-risking of projects discussed here which can have a large influence on the cost of biomethane production.
    - Additionally, the results of this Task Force 4.2 report are useful to the work of other Task Forces such as Task Force 1, as national governments would like to know the cost of production to understand how best to support biomethane supply chains.



Introduction

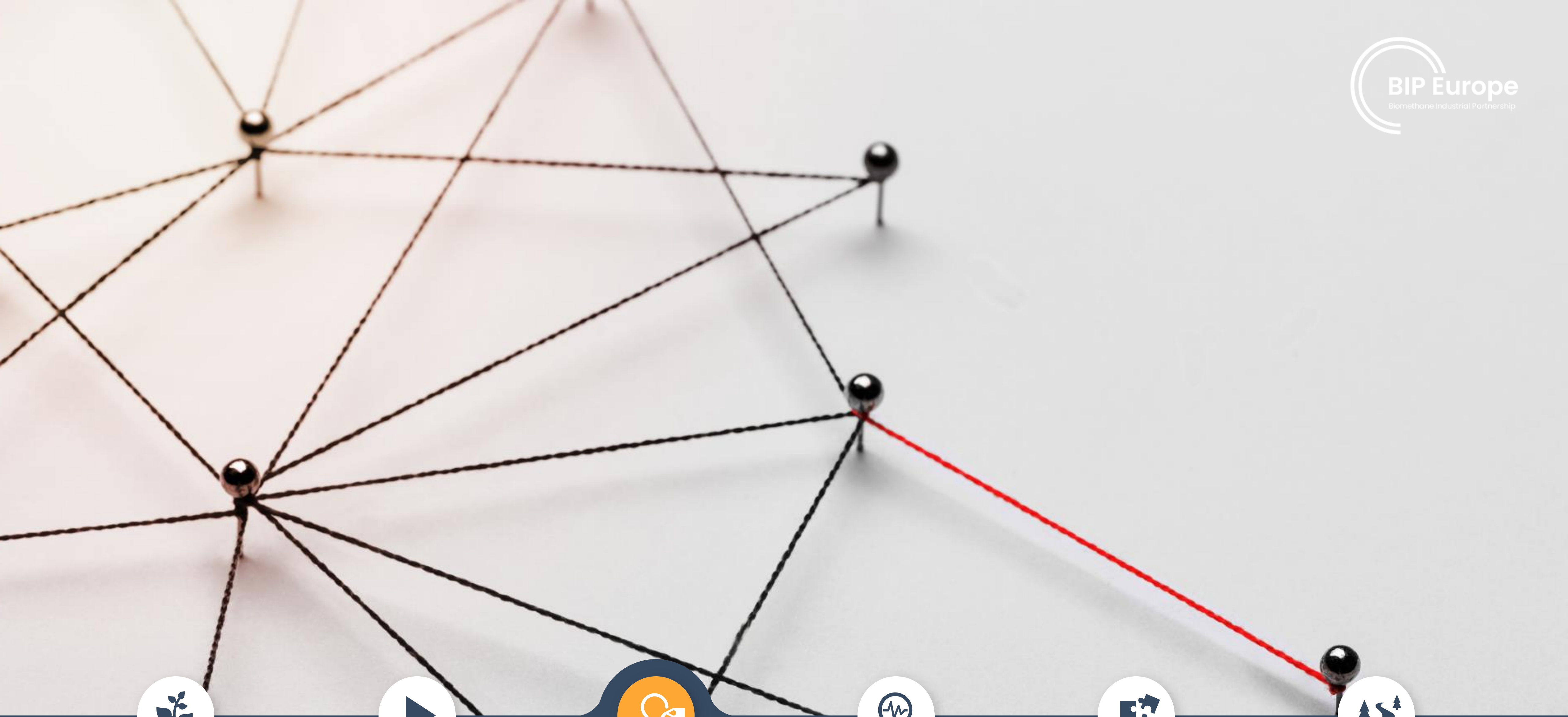
First-of-a-kind data collection effort

Given the lack of recent publications on biomethane costs, and the desire to understand real cost data, **a first-of-a-kind anonymous data collection process using real company data has been facilitated by Common Futures for Task Force 4.2, with careful consideration for EU competition law.** The following steps were followed:

A **large group of plant owners, operators, developers, EPCs and technology providers** were invited to join the Task Force 4.2 effort. Of these, 17 companies joined, of which 13 have submitted data anonymously. Anaerobic digestion was the only production route investigated given its current market dominance, and the lack of data that would be anonymously available from companies producing from other methodologies.

An excel questionnaire was then used to anonymously collect data from these participants and the **initial results** and **ideas on cost reductions** were discussed at a **workshop in Brussels with the Task Force 4.2 members**.

These results have been refined and improved in collaboration with the participating companies and are presented in this report.



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- **Way of Working**
- Biomethane Cost Results
- Conclusions
- Way Forward

Way of working

Scope of data collection considered gate-to-gate of biomethane plant

The questionnaire used for this data collection considered the biomethane supply chain from the **feedstock entering the gate to the biomethane being prepared to leave the facility**.

The following points were taken into account in the questionnaire:

- All data was asked for corrected to the year 2021 in order to avoid collecting costs from 2022 which is seen as a crisis year
- Data was asked for on a cost basis without any subsidies.

Multiple cost headings were considered

The main cost headings that were considered in the questionnaire were:

Feedstock cost: the cost of procurement and transport to the facility.
Unit: €/$MWh_{biomethane}$

Biogas production cost:

- **CAPEX:** the cost of the facility to produce biogas from this feedstock, including *civil works, pre-treatment facility, digesters, balance of plant, and waste water and digestate treatment facilities*. Unit: €/$MW_{biomethane}$ installed capacity.
- **OPEX:** the cost of operating the biogas plant with the *cost of additives, pre-treatment OPEX, cost of labour, cost of maintenance, cost of compliance with national and other regulation/environmental reporting, external energy use (Unit: MWh/MWh) and the cost of this energy.* Unit: €/$MWh_{biomethane}$.

Biogas upgrading cost:

- **CAPEX:** the cost of the upgrading facility, including the *civil works costs, upgrading technology costs, balance of plant costs, gas handling costs, and biogenic CO_2 storage costs*. Unit: €/$MW_{biomethane}$ installed
- **OPEX:** the cost of operating the upgrading facility, including *the cost of additives, the cost of labour, the cost of maintenance, the external energy use* (Unit: MWh/MWh) and the cost of this energy. Unit: €/$MWh_{biomethane}$.

Downstream biomethane costs:

- **Grid injection (8 bar grid pressure):** CAPEX and OPEX for injection of biomethane onto the lower pressure gas grid.
- **Grid injection (54-80 bar grid pressure):** CAPEX and OPEX for injection of biomethane onto the higher pressure gas grid.
- **Bio-CNG production:** CAPEX and OPEX for compression and storage of bio-CNG (250 bar).
- **Bio-LNG production:** CAPEX and OPEX for liquefaction and storage of bio-LNG (~-160 degrees celcius).

By-products:

- Although some questions were asked regarding the primary by-products, e.g. *investment into digestate handling facilities/biogenic CO_2 storage* there was less of a focus on the costs associated with these by-product streams as their valorisation is the focus of Task Force 4.1.

Way of working

Requirements to consider data points in analysis and other assumptions

Several requirements were made on the collected data points in order to integrate them in the analysis:

- **The minimum requirement for a data point to be shown was having at least three plants submitting that data point, from at least two companies.**
- Limited data availability in certain parts of the supply chain leads to the reduced possibility for full analysis of the biomethane supply chain.
- As such, the **results here only concern the cost of biomethane production (biogas production and upgrading) and not the downstream costs of biomethane (preparation for distribution, e.g. liquefaction)**
- In this analysis limited data also reduces the possibility to calculate the cost of production with different feedstock mixes. A general **distinction can be made between public and non public feedstocks, public feedstocks being in this case namely Municipal Solid Waste (MSW) or Waste Water Treatment Plant (WWTP) sewage sludge.** Any future work with more submissions would hopefully allowed more detailed analysis.
- **The current data analysis takes averages with equal weight between companies submissions** instead of between plants. This is done as there is a wide range in the number of plants per company submission (1-35), thus this averaging protects the weight of each company's data.
- A point of note on the results that will follow is that feedstocks with gate fees for feedstocks (negative feedstock costs) only occurred at one size, in size category 2. As such the range of costs here are larger than the other size categories, and some averages are also influenced by this.
- **For making capital costs comparable to operational costs a discount rate of 10% and a lifetime of 25 years** is considered to convert CAPEX values into capital costs. See Appendix B for further elaboration.
- For direct comparability of operational costs in this **analysis an external energy cost of €55/$MWh_{energyinput}$ was assumed** independent of energy type.

Way of working

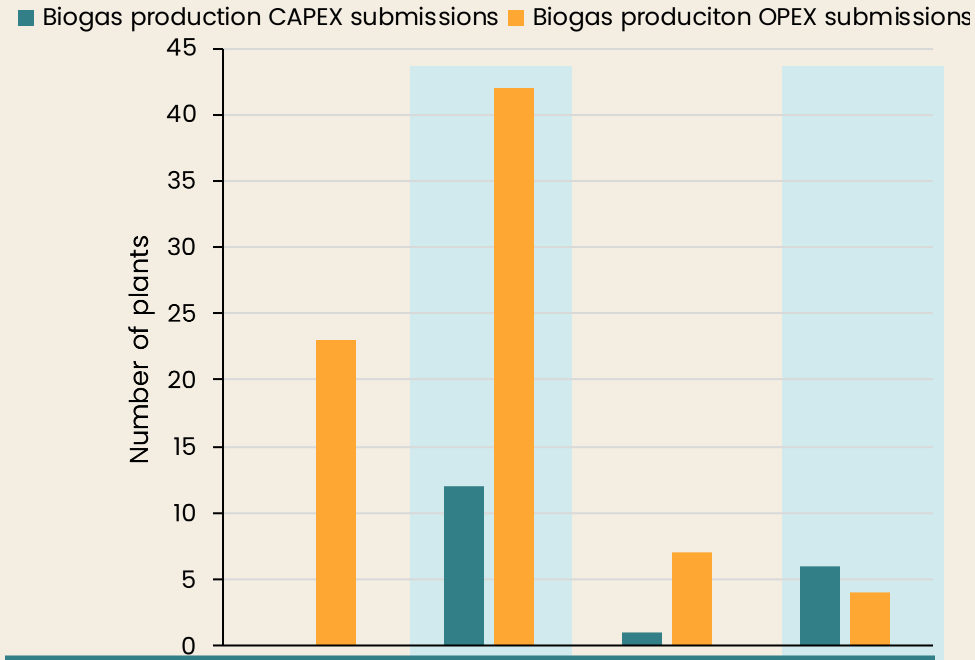
Submitted data represents ~10% of total EU biomethane production

General

- 13 submissions received from companies within Task Force 4.2.
- These 13 submissions represent a combined biomethane output of ~3.5 TWh/year

Biogas production

- More operational cost submissions than capital cost for biogas production
- Full analysis limited to **size categories 2 & 4**



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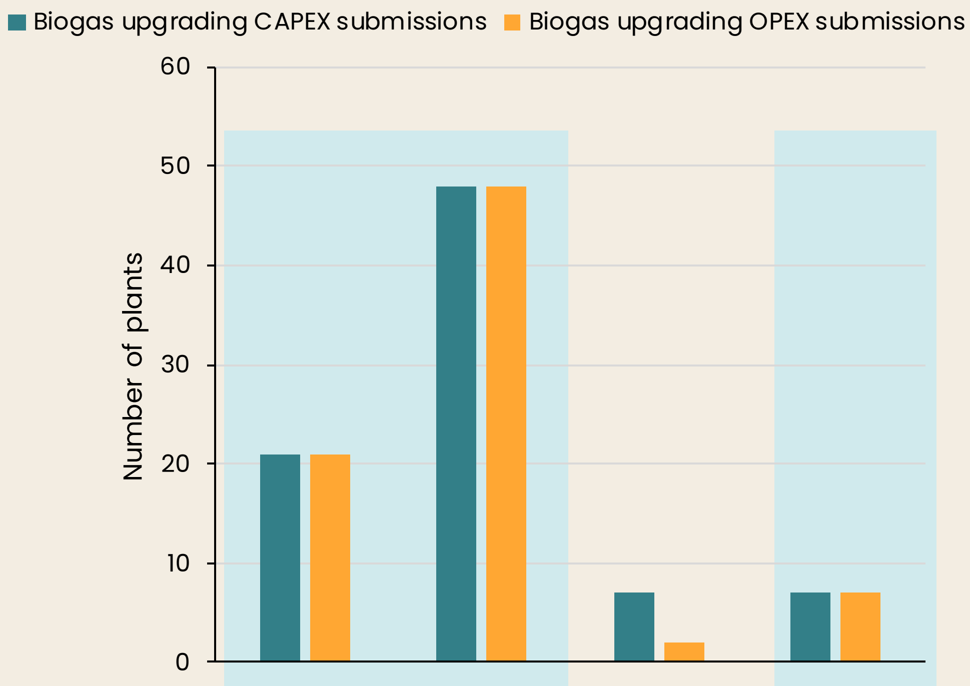
Biogas (m3/h)	<500	500 - 1300	1300 - 2000	>2000
Biomethane (m3/h)	<300	300 - 780	780 - 1200	>1200
Biomethane (MW)	<3	3 - 8	8 - 14	>14

Review of submissions

Biogas upgrading submissions have good data coverage

Biogas upgrading

- Biogas upgrading has better data coverage than biogas production.
- Full analysis possible for **all plant sizes except size category 3**, where there is not enough operational cost data.



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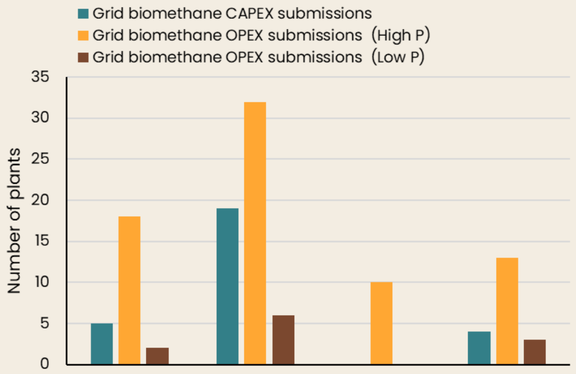
Biomethane (MW)	<3	3 - 8	8 - 14	>14

Limited data coverage of the biomethane distribution methods costs restricts analysis

Downstream biomethane costs

- When considering the distribution methods of biomethane following upgrading, as grid biomethane, bio-CNG, or bio-LNG, the data coverage is in general too limited to provide a good analysis.
- Bio-CNG submissions for CAPEX are all from 1 company, and so cannot be shown.



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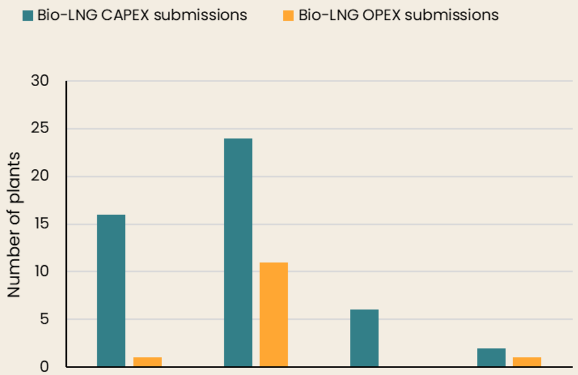

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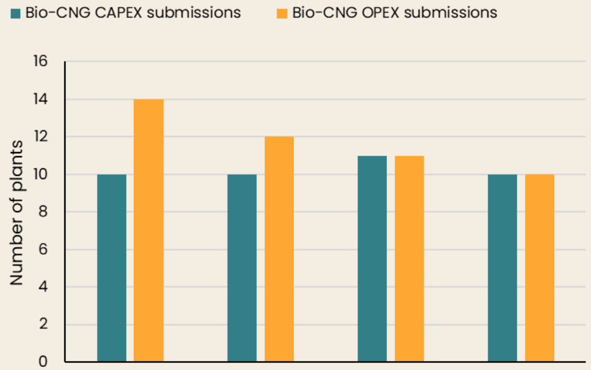

Size Category	1	2	3	4
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Biomethane (m3/h)	<300	300 - 780	780 - 1200	>1200
Biomethane (MW)	<3	3 - 8	8 - 14	>14


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Overview of cost categories

Biomethane Production

The study analysed 7 different cost categories that are related to biomethane production:

01. Total costs

02. Pre-FID costs

03. Feedstock costs

04. Biogas production costs

05. Biogas upgrading costs

06. Downstream biomethane costs

07. Other relevant costs

01.

Total costs of biomethane production

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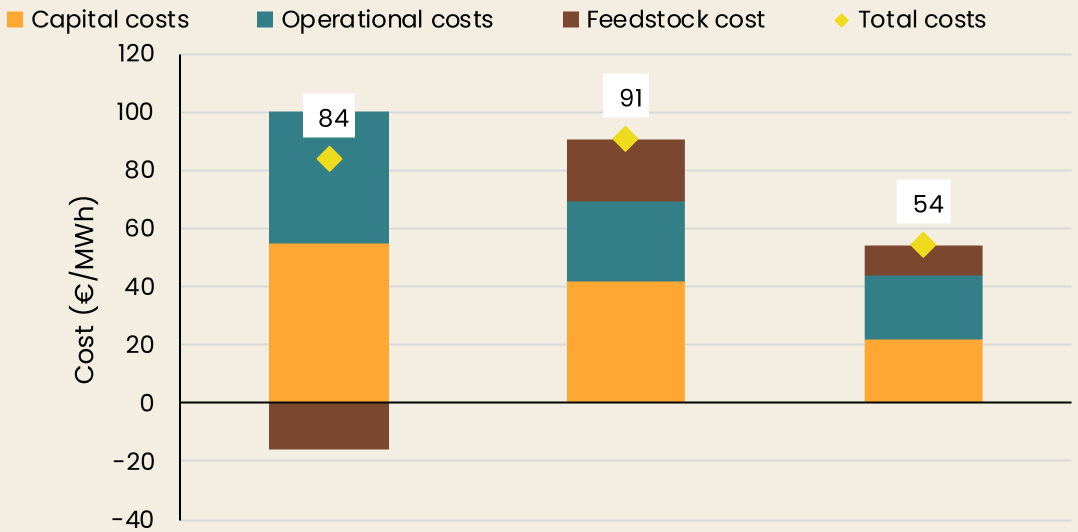
Biomethane production costs show substantial economies of scale

- **The total cost of biogas production and upgrading taken as the average of all submissions at the relevant size.**
- Size category 2 has an negative average feedstock cost due to the occurrence of public feedstocks here. This negative feedstock cost comes with higher production costs than production with other feedstocks.
- When removing the public feedstock plants, capital and operational costs reduce but the big change to the cost of feedstocks leads to a higher total cost of production.
- Size category 4 shows a typical production cost breakdown, with notable economies of scale from size category 2.

01.

Total costs of biomethane production

Total cost of biomethane production and upgrading



Size Category	2	2	4
Biogas (m3/h)	500 - 1300	500 - 1300	>2000
Biomethane (m3/h)	300 - 780	300 - 780	>1200
Biomethane (MW)	3 - 8	3 - 8	>14
Submission types	All feedstocks	Excluding public feedstocks*	All feedstocks

02.

Pre-FID costs

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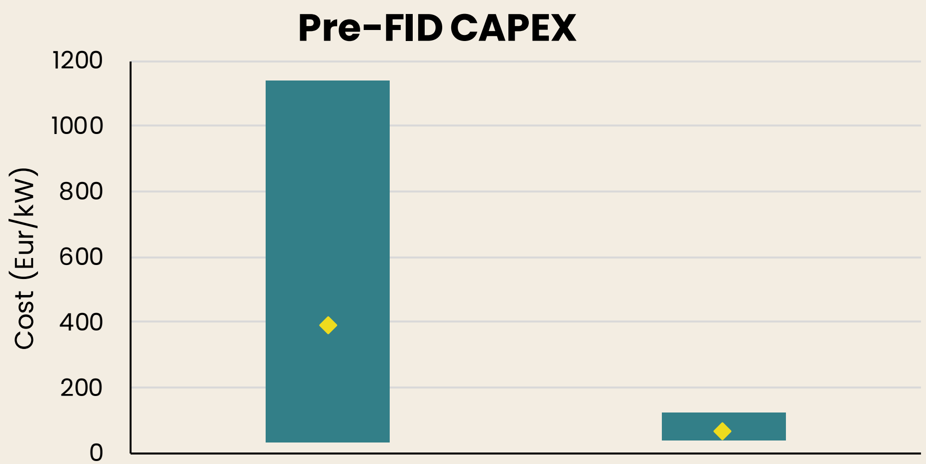
Biomethane cost results

Pre-FID costs increase for smaller plants & potentially smaller companies

02.

Pre-FID costs

- Pre-FID costs show a large economies of scale
- **High cost outliers** are hypothesized to come from projects where the **plant has been purchased from a developer** who has sold the Pre-FID costs at a premium, with “value pricing”.
- Further investigation is needed into how this could change between plants using different feedstock types, as limitations in the data set did not allow this analysis.
- The size and experience of companies could influence pre-FID costs as well, though with anonymous data this is not possible to conclude from this study.



Size Category	1&2	3&4
Biogas (m3/h)	<1300	>1300
Biomethane (m3/h)	<780	>780
Biomethane (MW)	<8	>8
No. of plants	9	5

03.

Feedstock costs

Feedstock costs have a large range and can be negative depending on the feedstock mix

- **Feedstock costs from submissions range between -€94 and +43/MWh$_{\text{biomethane}}$.** Some producers use feedstocks where they can charge a gate fee for accepting those (negative cost). These feedstocks are typically "public feedstocks", i.e. MSW or WWTP sewage sludge.*
- **The average cost weighted per submission is €2/MWh and weighted per plant is €19/MWh**.
- These feedstock costs change significantly between different feedstock mixes with the costs distribution shown below.

Feedstock mix	Units	Manure	Manure & energy crops	MSW/Food waste ± Industrial waste (inc. ABP) & WWTP sludge*	Other
Feedstock costs	€/MWh$_{CH4}$	8-43	23-39	(-94)-0	0-24
Number of plants	#	6	52	8	8

***MSW**: Municipal solid waste
WWTP: Waste water treatment plant
ABP: Animal by-products

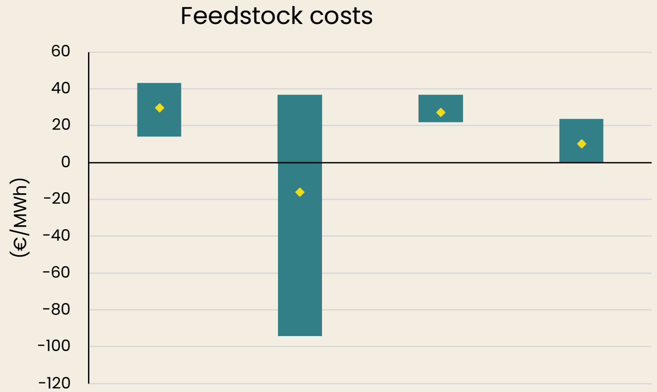
03.

Feedstock costs

Biomethane cost results

Feedstock cost do not increase for larger plants despite the assumed larger procurement radius

- The feedstock procurement radius of larger plants tends to increase compared to smaller plants, this can be expected to bring an increase in transport costs. However, the results indicate that the **increased cost of longer transport distances is not significant. and is not seen in the data. This could indicate that benefits of economies of scale counteract this expected increase in transport costs.**
- When removing the public feedstocks from size category 2 to isolate the cost of non-public feedstocks it confirms **this general decreasing trend for non-public feedstock costs with increased size**.



Size Category	1	2	3	4
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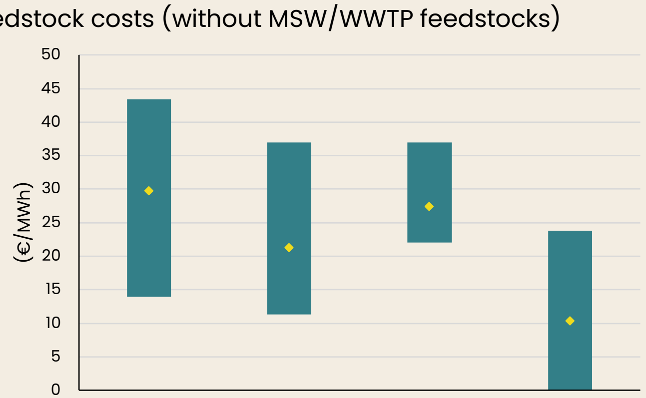
Biomethane (m3/h)	<300	300 - 780	780 - 1200	>1200
Biomethane (MW)	<3	3 - 8	8 - 14	>14
No. of plants	18	27	7	4



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Biomethane (MW)	<3	3 - 8	8 - 14	>14
No. of plants	18	19	7	4

03.

Feedstock costs

Biomethane cost results

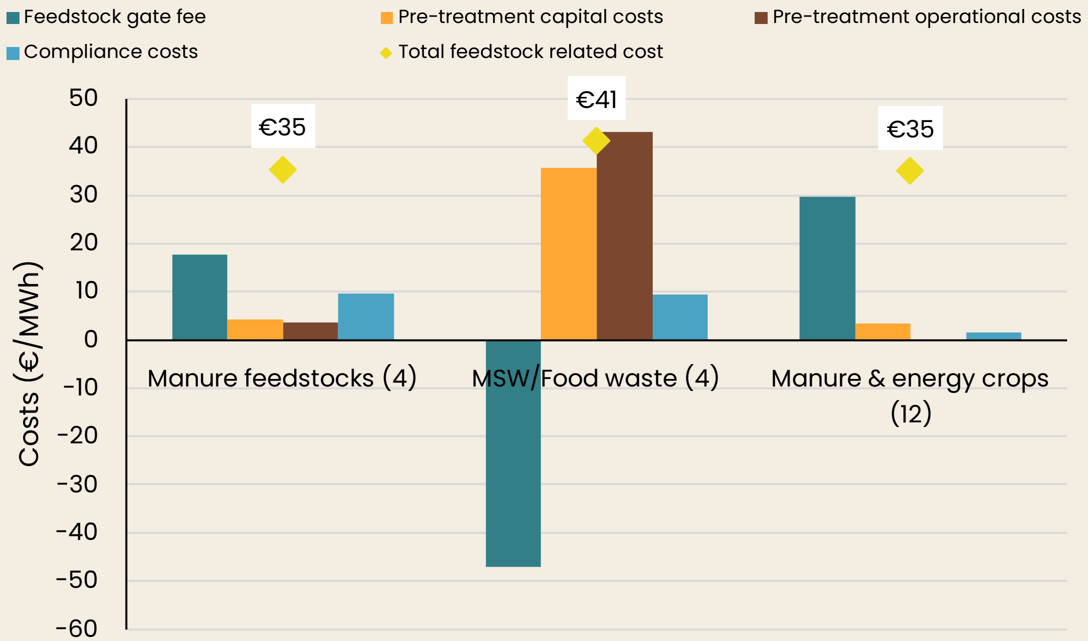
A *'total feedstock related cost'* shows that the feedstock cost at the gate does not tell the full story

- A *total feedstock related cost* can be calculated to see how the feedstock cost relates to the costs induced by your feedstock mix choice.
- The costs considered here are:
  - ***The feedstock costs*** – the cost of the feedstock and its delivery to the plant.
  - ***The pre-treatment capital costs*** – namely the pre-treatment and the waste water and digestate handling facilities.
  - ***The pre-treatment operational costs*** – namely the pre-treatment OPEX and the cost of additives to the digester.
  - ***The compliance costs*** – these are the costs for administrative effort to comply with national and other regulation, do environmental reporting and achieve certification.
- The results show that despite the large range in feedstock costs, **the *total feedstock related cost* is comparable for very different feedstock mixes.**
- **The costs of labour and maintenance are the only OPEX costs not considered here, however, the data indicates that these costs may be higher for MSW/Food waste plants than the plants using other feedstocks.**

03.

Feedstock costs

Total feedstock related costs & components - Size category 2



Biomethane cost results

Yields were not considered in this work; policy incentivising manure use as a feedstock is working

- **Manure has a relatively low energy yield compared to other feedstocks**. This was not asked in this questionnaire but is an important consideration to make.
- **Policy measures in RED II have given manure a 45 gCO_{2eq}/MJ emission accounting bonus.** This has incentivised its use as a feedstock despite its low yield. This questionnaire shows that the use of manure is high, and its cost per MWh is comparable to other higher yield feedstocks e.g. high quality industrial wastes.
    - This indicates a successful implementation of well targeted policy at EU level.
- However, **not considering feedstock yields will have influenced the costs reported**.
- **E.g. A digester producing 5 MW of biomethane a year from manure will be a lot bigger in volume than a digester producing 5 MW of biomethane from energy crops**
- This yield and other feedstock characteristics e.g. volume of volatile solids, is also an issue for the digestate management, **where you can expect more digestate per MWh for certain feedstocks than others.**
- While this questionnaire did consider the capital investment in digestate handling facilities, it did not consider the costs of transport and storage of the digestate, highlighted as a large cost to some participants, of between €20-55/MWh biomethane, though more consideration on the by-products of biomethane is taken in Task Force 4.1.

04.

Biogas production costs

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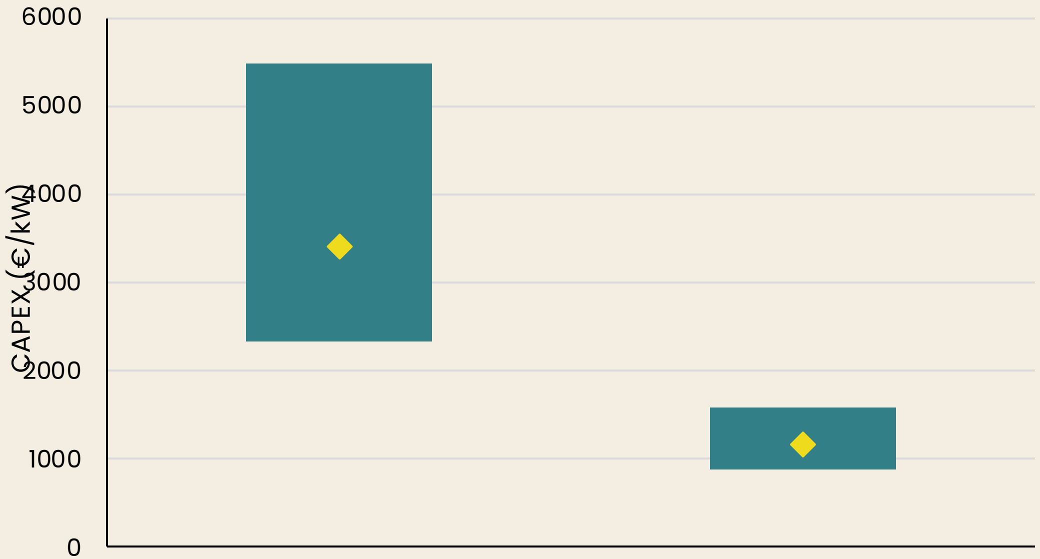
Biomethane cost results

Biogas production is the costliest investment in the biomethane supply chain

- **Biogas production facility is responsible for 75-90% of the total plant CAPEX**
- Economies of scale are notable here, with **costs reducing by a factor of 3 with an increase in plant size from size category 2 to 4.**
- The large range in CAPEX investments in the size category 2 is seen as a result of the higher investment needed for feedstock facilities in plants using public feedstocks.

Biogas facility CAPEX



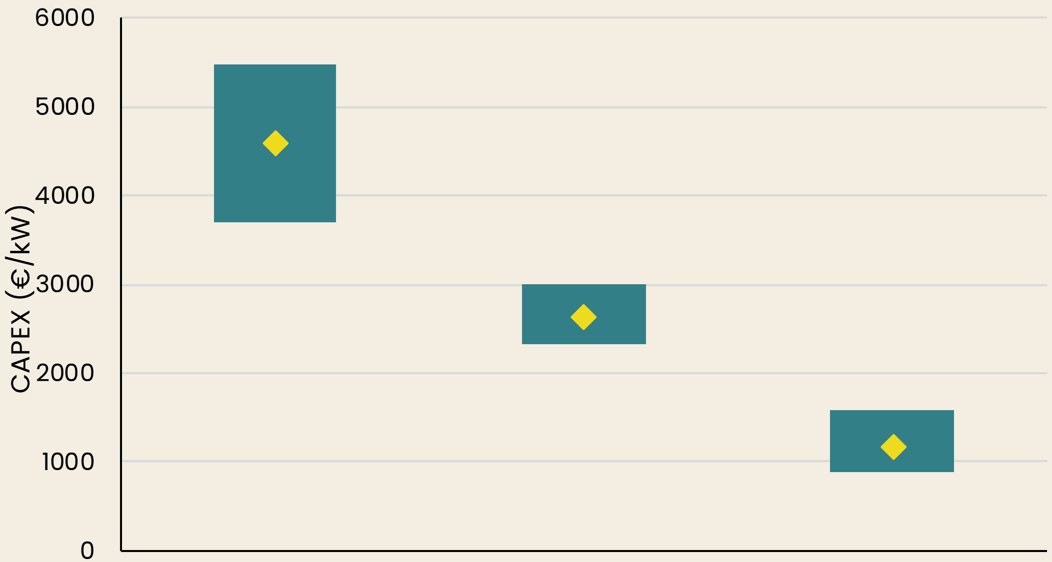
Size Category	2	4
Biogas (m3/h)	500 - 1300	>2000
Biomethane (m3/h)	300 – 780	>1200
Biomethane (MW)	3 – 8	>14
No. of plants	12	6

Biomethane cost results

Biogas production with public feedstock requires ~80% more investment than other plants

- When **separating the public** feedstock production and **non-public** feedstock **production the capital investments are shown to be 80% higher on average for public feedstock plants.**
- Non-public feedstock plants have factor of 2 economy of scale with an increase in size from size category 2 to 4.

Biogas facility CAPEX



Size Category	2 (public only)	2 (non-public)	4
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Biomethane (m3/h)	300 - 780	300 - 780	>1200
Biomethane (MW)	3 – 8	3 – 8	>14
No. of plants	4	23	4

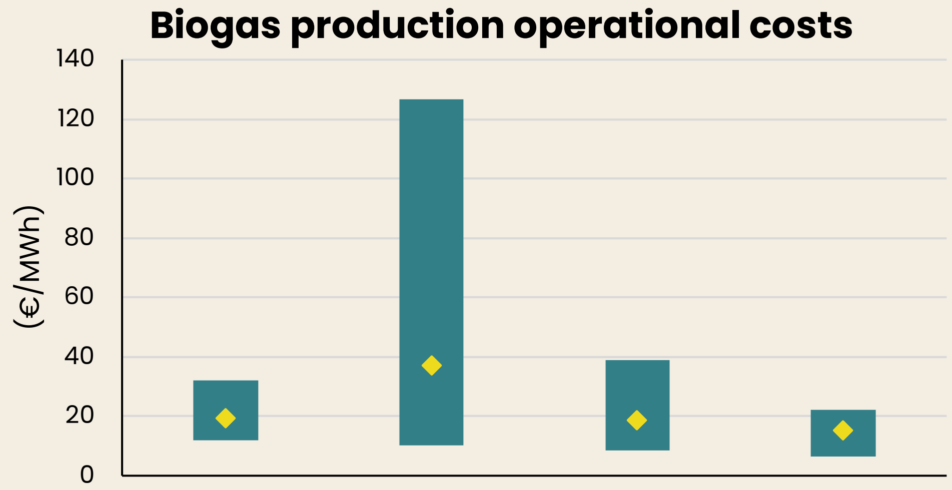
Biomethane cost results

Biogas production operational costs show limited economies of scale

- Biogas production operational costs show limited economies of scale
- **A factor of 2 cost decrease is seen with increased size from size category 2 to 4, though in size category 2 many plants use public feedstocks.**
- **This economy of scale is not very evident from the other sizes** however, indicating that although reducing on average, **operational costs reduce less than capital costs with scale**

04.

Biogas production costs

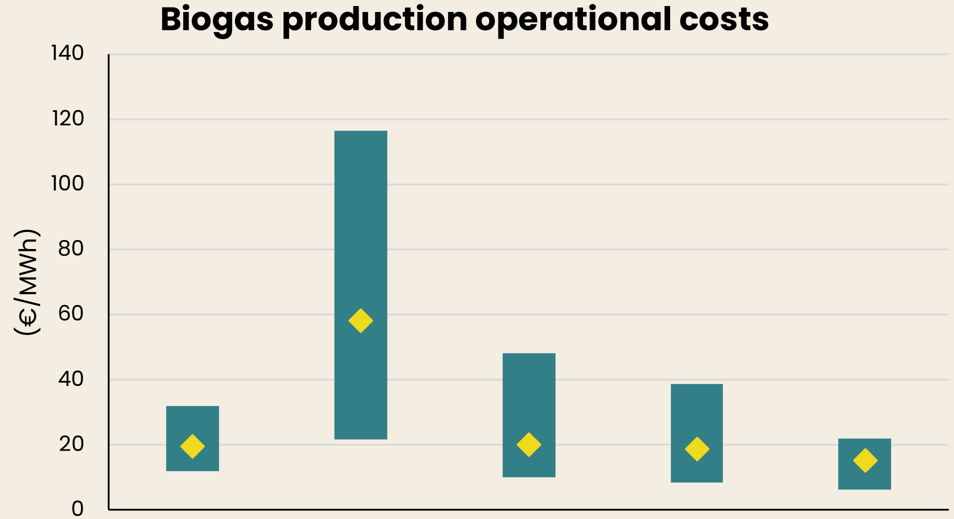


Size Category	1	2	3	4
Biogas (m3/h)	<500	500 - 1300	1300 – 2000	>2000
Biomethane (m3/h)	<300	300 – 780	780 – 1200	>1200
Biomethane (MW)	<3	3 – 8	8 - 14	>14
No. of plants	18	27	7	4

Biomethane cost results

Public feedstock use leads to operational costs significantly higher than other feedstocks

- When splitting up the operational costs it is clear **the plants with higher operational costs at size category 2 are those using public feedstocks.**
- **The average operational costs of the public feedstock plants at this size are a factor of 3 higher than production using other feedstocks**.
- The operational costs for production with other feedstocks does not vary largely, with the average remaining around €20/MWh for all size categories.

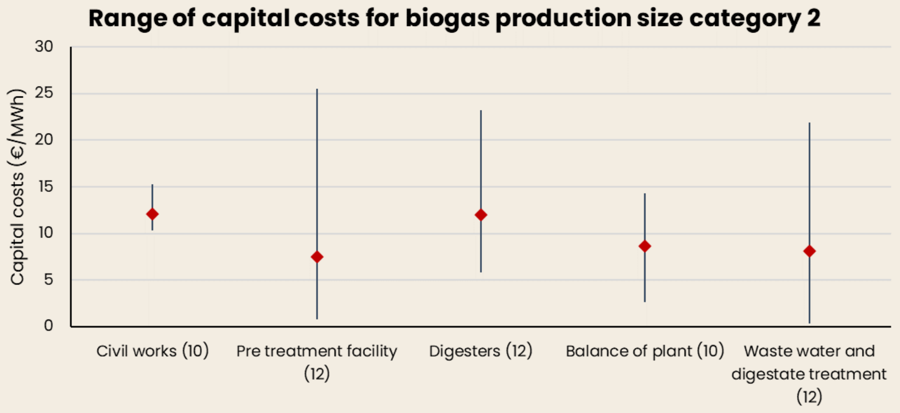


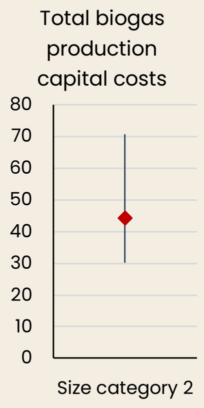
Size Category	1	2 (public only)	2 (non-public)	3	4
Biogas (m3/h)	<500	500 - 1300	500 - 1300	1300 – 2000	>2000
Biomethane (m3/h)	<300	300 – 780	300 – 780	780 – 1200	>1200
Biomethane (MW)	<3	3 – 8	3 – 8	8 - 14	>14
No. of plants	18	8	22	7	4

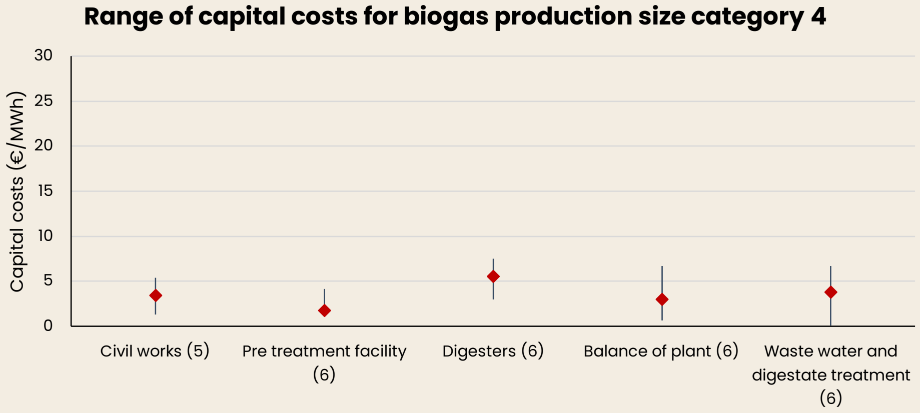
Biomethane cost results

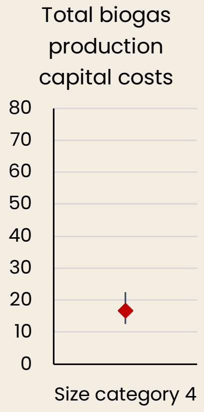
Digesters are the largest investment for biogas production; feedstock choice influential

- **The digesters and civil works are the largest cost of biogas production at size category 2 while the waste water and digestate treatment facility is also significant in the larger facilties.**
- Large range of pre-treatment and waste water and digestate treatment capital costs in smaller plants comes from using feedstocks with high pre-treatment requirements at this size (e.g. public feedstock mixes)
- **Most cost components show a 2-3 fold cost decrease as the size increases between the two size categories**







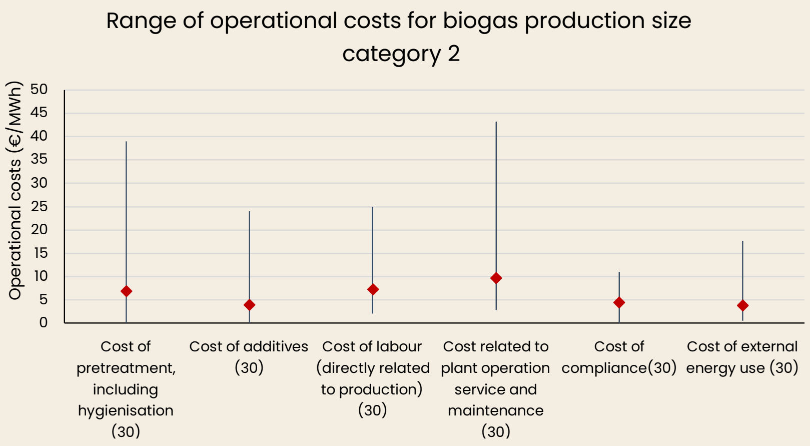


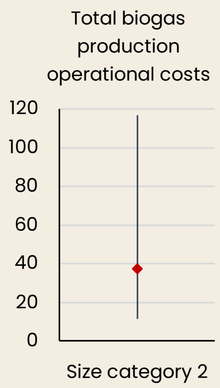
- *The number of plants for each data range is found in the brackets. Caution should be taken with these results as some submissions do not consider civil works and balance of plant separately. This could lead to inflated costs for some components and unfair comparisons.*
- *The minimum, maximum, and average of the ranges can be found in Appendix C.*

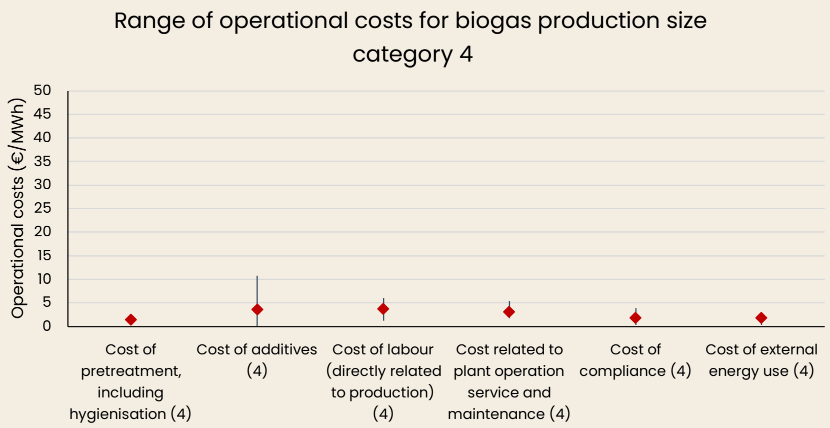
Biomethane cost results

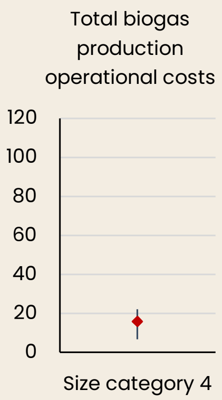
Operational costs show reduced economies of scale compared to capital costs

- **Operational costs for biogas production show economies of scale between size category 2 to 4**, with a cost decrease by a factor of 2 coming from increasing the size.
- The large range of costs at the lower size category likely comes from production with public feedstock mixes with high pre-treatment requirements.
- Labour and additives costs are the largest cost components for larger plants;
  labour costs, pre-treatment costs, and plant maintenance costs are the largest for smaller plants.
- Internal energy use is not accounted for here, so true operational energy costs likely higher.









05.

Biogas upgrading costs

Submitted data on upgrading technologies reflects the current market status

- **The dominant upgrading technology on the market today is membrane separation**, found in approximately 40% of facilities in 2021.[1]
- The submissions received reflect this market dominance with **70% of CAPEX and 60% of OPEX submissions concerning membrane separation.**

Submitted data on upgrading technology

	Membrane separation	Pressure swing absorption	Chemical absorption	Water scrubbing	Cryogenic separation	Other
# of CAPEX submissions	56	4	16	0	0	4
# of OPEX submissions	43	3	18	5	0	4

05.

Biogas upgrading costs

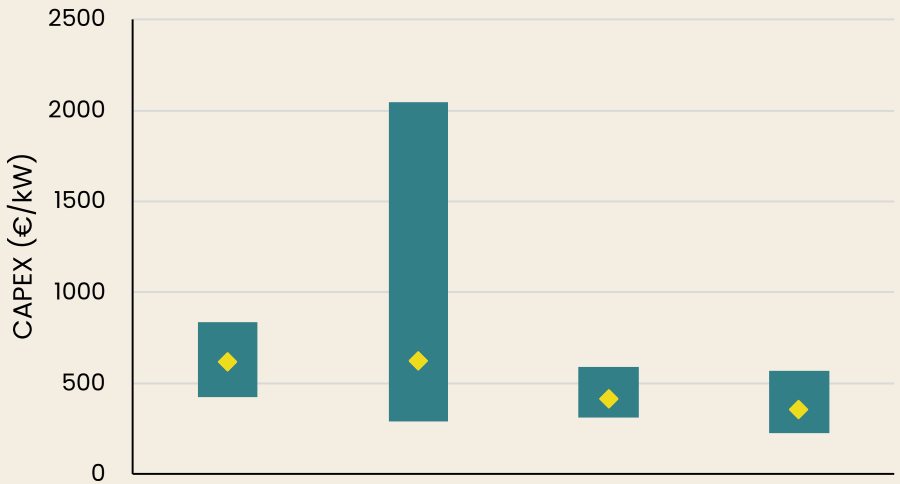
[1] Guidehouse & EBA 2023

Biomethane cost results

Biogas upgrading CAPEX investments show strong economies of scale

- The capital costs for upgrading show **a strong economies of scale effect**.
- Outliers remain for upgrading costs in the size category with public feedstock mixes.
- The average in size category 2 being near the bottom of the range shows that the high end of the range is indeed from an outlier/outliers.

Biogas upgrading capital costs



Size Category	1	2	3	4
Biogas (m3/h)	<500	500 - 1300	1300 - 2000	>2000
Biomethane (m3/h)	<300	300 - 780	780 - 1200	>1200
Biomethane (MW)	<3	3 - 8	8 - 14	>14
No. of plants	17	36	7	7

Biomethane cost results

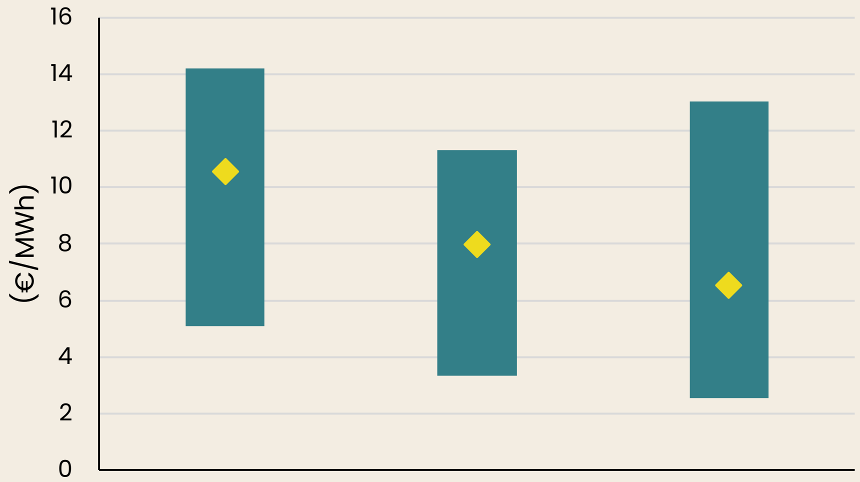
Biogas upgrading operational costs also decrease for larger facilities

- Operational costs for biogas **upgrading show strong economies of scale.**
- Here there are notably no outliers from size category 2 with public feedstock mixes, as can be expected, as the method of biogas production does not influence the costs here.

05.

Biogas upgrading costs

Biogas upgrading operational costs



Size Category	1	2	3	4
Biogas (m3/h)	<500	500 - 1300	1300 - 2000	>2000
Biomethane (m3/h)	<300	300 - 780	780 - 1200	>1200
Biomethane (MW)	<3	3 - 8	8 - 14	>14
No. of plants	17	36	7	7

Biomethane cost results

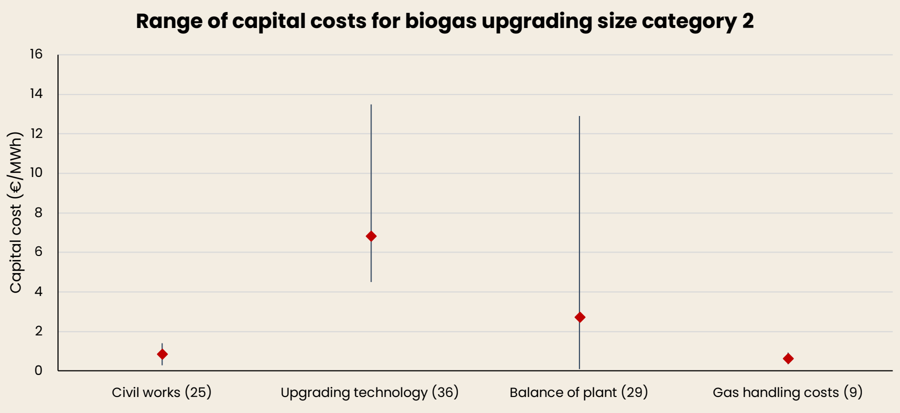
The upgrading technology is the dominant investment cost for an upgrading facility

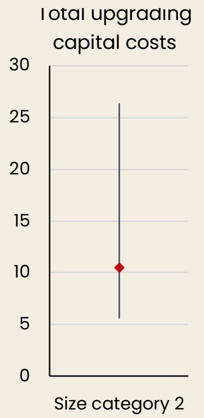
05.

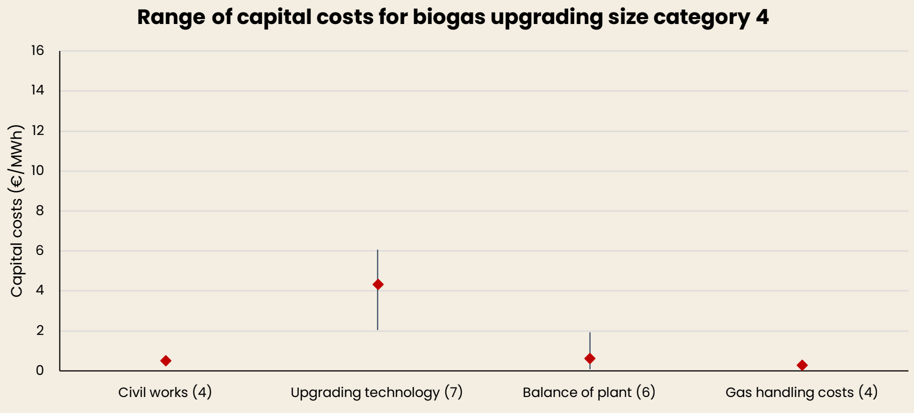
Biogas upgrading costs

- The upgrading technology itself is always the **largest investment costs for an upgrading facility**.
- Upgrading technology shows a ~33% cost decrease with increased facility size.
- Other costs almost always stay below €2/MWh$_{biomethane}$.
- Gas handling costs not always required as it can depend on the mode of distribution, but when present their influence on the cost is negligible.

Capital costs for biogas upgrading





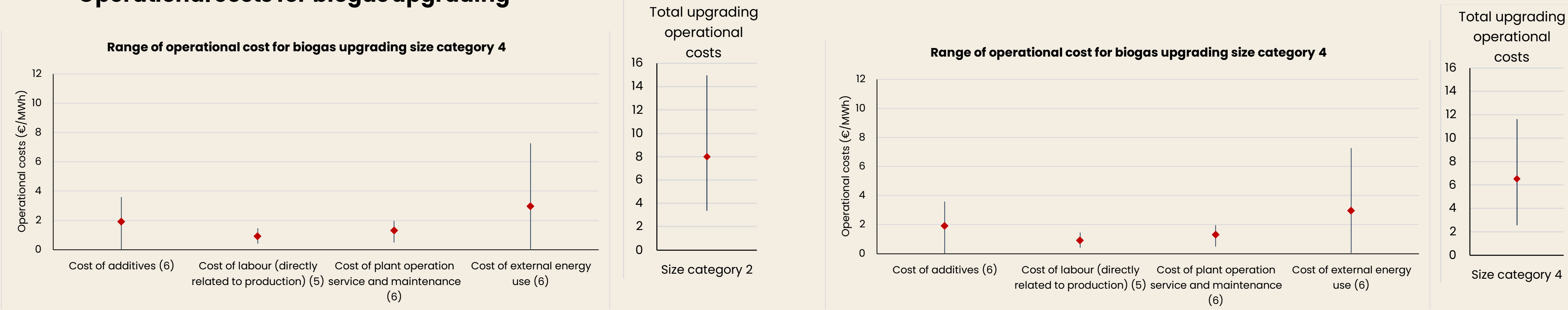


Biomethane cost results

Energy costs are the largest operational costs for upgrading, but internal energy must be accounted for

- Energy costs are the largest operational cost factor for biogas upgrading, however, the **shown energy costs are also likely on the lower end as the questionnaire did not capture the use of internal energy.**
- Other operational costs show a small economies of scale.
- The cost of additives appears to be independent of plant size, as these are higher per unit output for larger plants

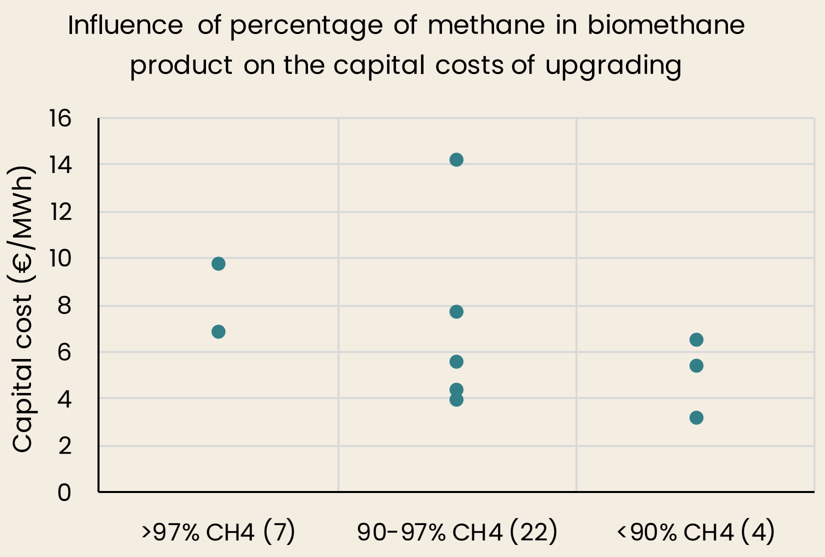
Operational costs for biogas upgrading

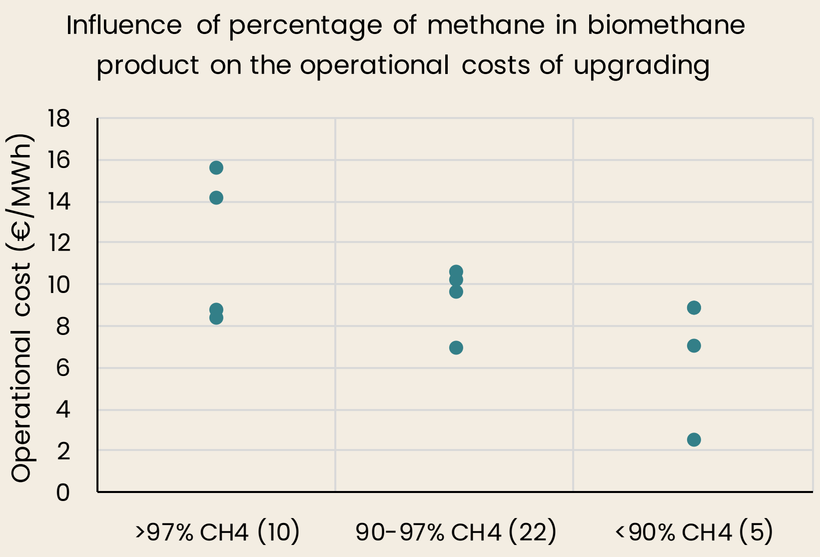


Biomethane cost results

Influence of the methane percentage in biomethane product on the cost of upgrading

- **The capital and operational costs of upgrading can be seen to generally decrease with a decreased percentage of methane in the final biomethane output.**
- The percentage of methane in biomethane can also influence downstream operations as biomethane for LNG production has to be ~99% methane to avoid CO_2 in the bio-LNG.
- Limited data restricts analysis for one set size, so some scale effects may be present in the data.





05.

Biogas upgrading costs

Increasing plant utilisation and decreasing internal energy use can increase output

- **Ensuring a higher capacity factor for biomethane plants is an important part of operations, to increase run time and output and thus decrease the costs of production**.
- **Participants reported that smaller facilities typically have lower capacity factors than larger plants** as here there are usually less spare parts, and there is less storage volume available in the plant, while larger plants are more likely to build in a redundancy.
- Not all biogas production is directed to upgrading, with some energy used internally to fuel the process with heat or power. Reducing internal energy use could also be a way for biomethane plant operators to increase their output, as the use of internal biogas cuts delivered volumes.
- Increasing plant utilisation can be an important factor to increase biomethane production from existing assets, but to also decrease the costs per unit biomethane produced.

	Size category 1	Size category 2	Size category 3	Size category 4
Capacity factor range from submissions	54-98%	83-98%	97%	82.5-96%

06.

Downstream biomethane costs

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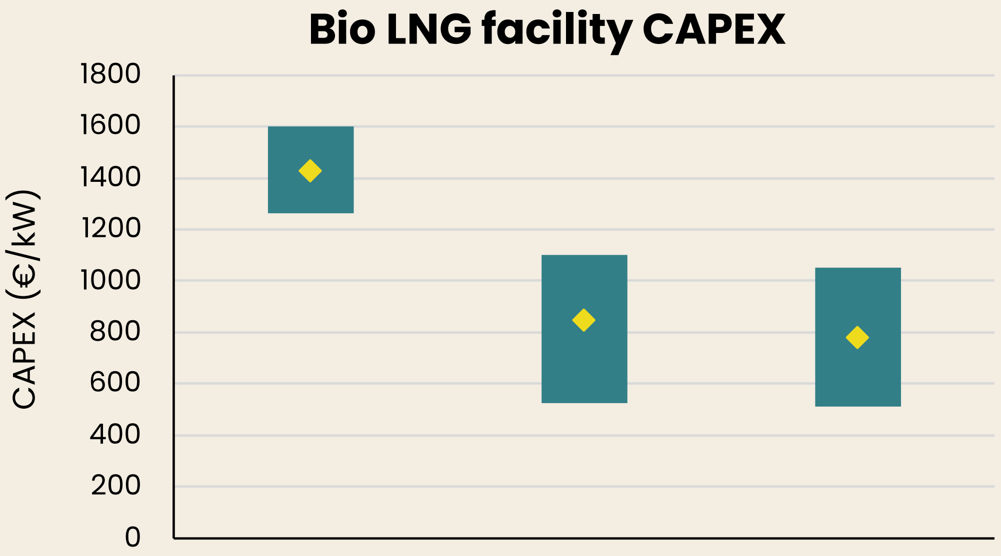
Biomethane cost results

Data limitations restrict analysis but some capital costs show economies of scale

- Data limitations reduce the opportunity for analysis here.
- Economies of scale are strong for capital investments preparing the biomethane for distribution.
    - **Bio-LNG facilities see an almost 2 fold cost decrease with an increase in size** from size category 2 to 4.
- Operational costs data limited and thus not shown

06.

Downstream biomethane costs



Size Category	1	2	4
Biogas (m3/h)	<500	500 - 1300	>2000
Biomethane (m3/h)	<300	300 - 780	>1200
Biomethane (MW)	<3	3 - 8	>14
No. of plants	18	27	4

07.

Other relevant costs

The costs of by-products are significant to production costs; Task Force 4.1's work will compliment this study

Digestate

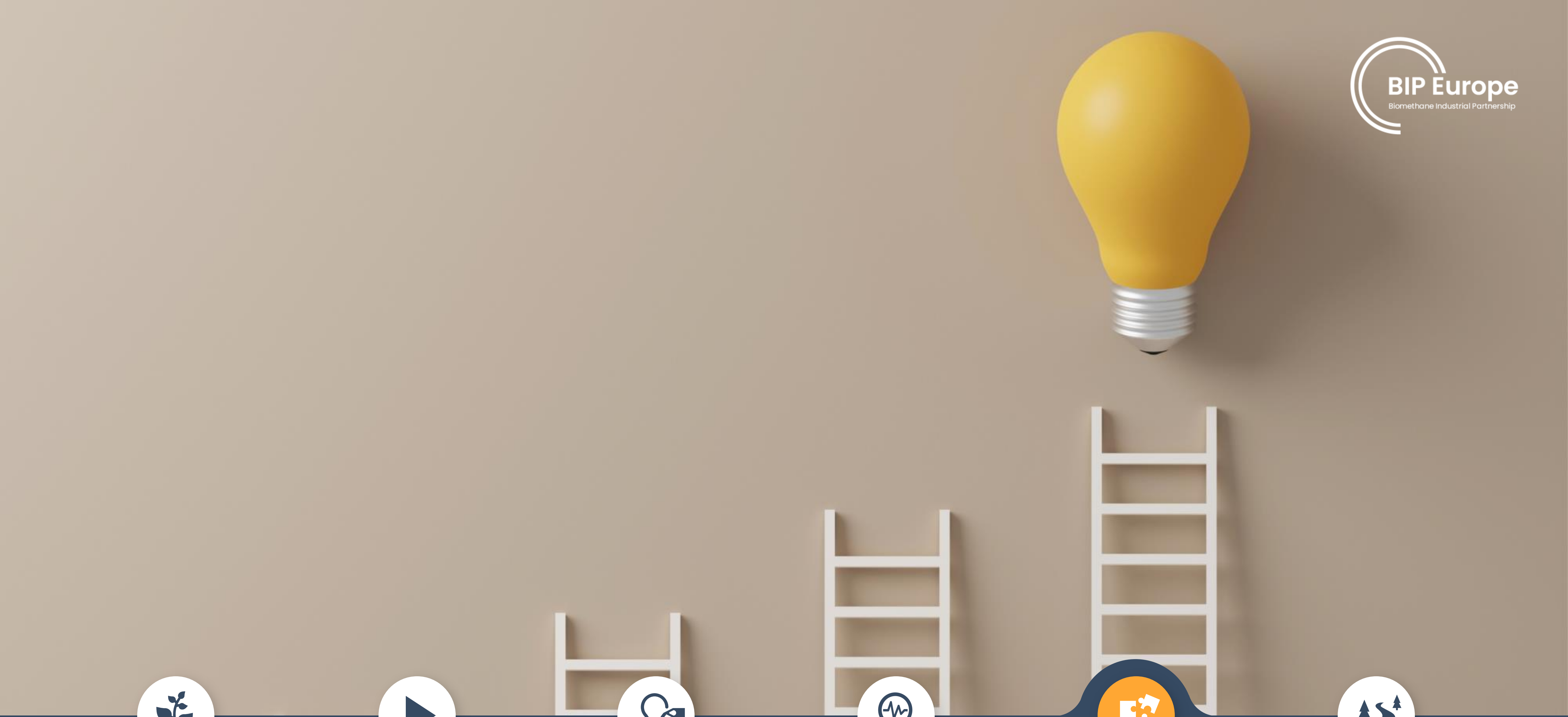
- As mentioned, digestate can be a notable cost to the supply chain if not valorised for use as an organic fertiliser, with Task Force 4.1 doing work on this.
- **With typically 90-95% of the feedstocks mass input to the digester coming out in the form of digestate** it is important to understand this part of the supply chain and the costs that come with it.
- Digestate can be in solid and liquid form, and when treated as a waste product **the costs of its transport and storage are reported by participants to range between €20-55/MWh.**

Biogenic CO_2

- Biogenic CO_2 is another important by-product, facilitating the replacement of fossil CO_2 wthe production of negative emissions with CCS, or the production of renewabl fuels of non-biogenic origin. Valorisation of this also falls under the scope of Task Force 4.1.
- In this questionnaire the **costs of valorising the CO_2 stream** was investigated and it was found to range between **€6-9/$MWh_{biomethane}$, equating to a cost of ~€45-68/t CO_2.**[1]

The valorisation of these by-products is acknowledged to be a part of creating the most value from biomethane production and can even lead to a production cost decrease as current operational costs can be divided across more than one product.

[1] Considering a gas with 55% CH4 and 40% CO2 (v/v), and a LHV for methane of 36 MJ/m3, and a capture rate of 90%



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Conclusions

Total feedstock related costs comparable across different feedstock mixes; clear economies of scale

Total feedstock related costs

- **Feedstock costs range between €-94 and €43/MWh**, changing based on feedstock mix types.
- Manure & industrial waste mixes tend to have the high costs
- While public feedstock mixes, e.g. WWTP sewage sludge and MSW, typically come with a received gate fee, reflecting the avoided cost of their disposal via other methods, and the added costs to the operator for its use as a feedstock.

Feedstock costs must therefore be viewed hand in hand with pre-treatment costs. **When considering the total feedstock related costs, the cost of these feedstock mixes are relatively comparable.**

Economies of scale

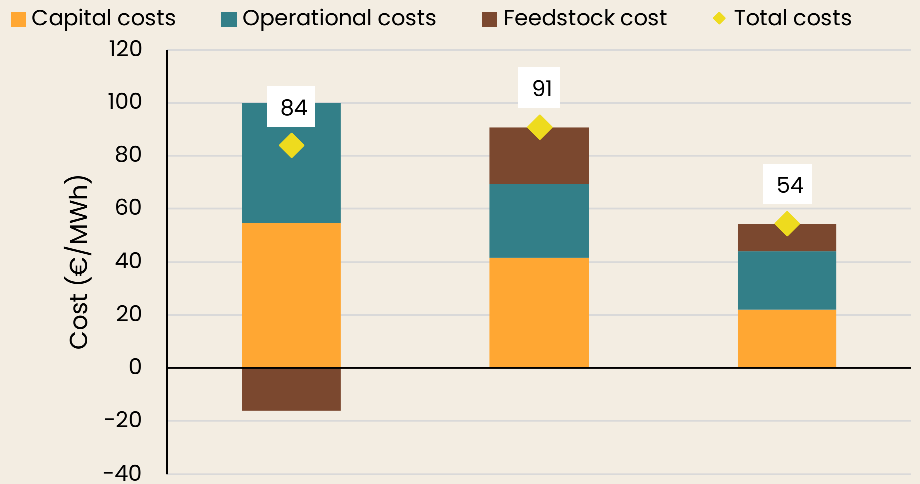
- **All parts of the biomethane production supply chain show varying degrees of economies of scale**, for both the capital and operational costs.
- **Biogas production investment costs show the strongest benefit from economies of scale**, with a 2-3 fold cost decrease with an increase in size of biomethane facility from ~5.5 MW to >14MW.

Conclusions

Biomethane production costs range from €54-91/MWh and show strong economies of scale

- A total average cost of **€54-91/MWh** is found **for production from facilities of at least 3 MW biomethane in this process.**
- The costs can be expected to be even higher for most producers with a capacity under 3 MW.
- Economies of scale are obvious in the biomethane supply chain.
- **Capital costs benefit the most from economies of scale** with a more than 2 fold reduction between size category 2 and 4.
- To simplify the total production costs and include the costs to prepare for distribution a grid connection and injection cost of~€5/$MWh_{biomethane}$ could be added, while ~€12/$MWh_{biomethane}$ could be added for bio-LNG.[1]
- It is important to note that **costs associated with digestate management were mentioned by participants to be significant and not fully captured in this analysis**. Some data from submissions indicates **€20-55/$MWh_{biomethane}$ for the transport and storage of this digestate.**

Total cost of biomethane production and upgrading



Size Category	2	2	4
Biogas (m3/h)	500 - 1300	500 - 1300	>2000
Biomethane (m3/h)	300 - 780	300 - 780	>1200
Biomethane (MW)	3 - 8	3 - 8	>14
Submission types	All feedstocks	Excluding public feedstocks*	All feedstocks

[1]Navigant 2019 – grid distribution cost of biomethane ~€5/MWh
DNV 2021 – liquefaction of biomethane cost ~€9-15/MWh

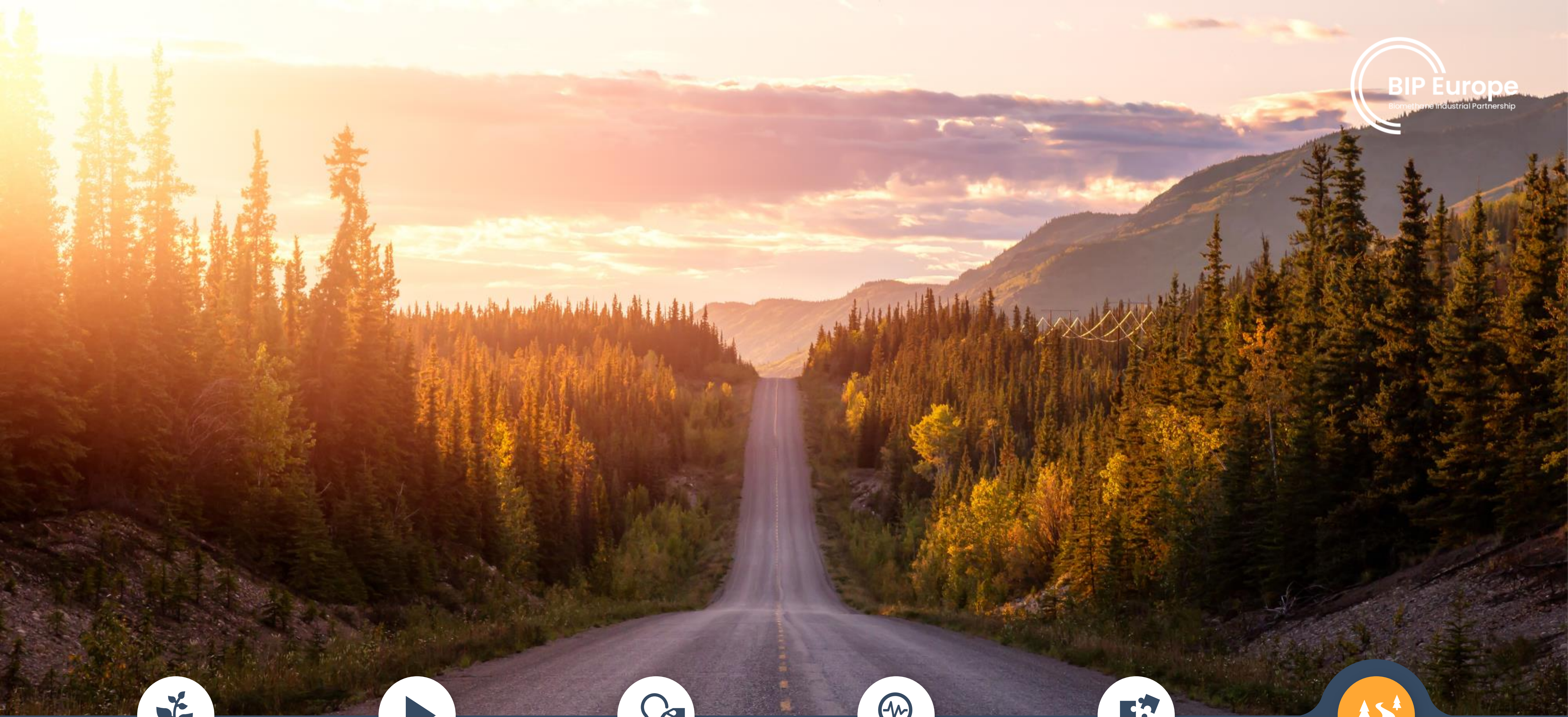
Conclusions

Biomethane costs on average higher than natural gas, but good market opportunities and positive externalities exist

Contextualisation of costs

- What alternative biomethane is compared to is important. **If natural gas from the grid and the EU ETS CO_2 price are considered, the comparator would be approximately €64/MWh.**[1] The €54-91/MWh cost of biomethane production found in this survey shows **currently biomethane would on average come at a higher price to the consumer than this natural gas, except for production from the largest plants where the costs could be comparable.** It is worth noting that for biomethane, a margin for the producer is needed, and for both biomethane and natural gas, distribution costs and a margin would be included in the end user price.
- **However, this cost comparison considers the valuation of the emissions reduction from the EU ETS, with the value of emission reductions in some hard-to-abate end uses bringing about a higher carbon cost.**
  - Examples of markets today where the value of emission reductions is above the EU ETS for hard-to-abate end uses are the **road transport market in Germany**, or **fuels for green gas blending for the built environment in the Netherlands**.
  - **These markets are strongly linked to national policy and the national market conditions however**, and as such EU wide implementation of a higher valuation of carbon emission reductions can improve the competitiveness of biomethane products.
- **When the price of carbon emissions is high enough, the alternative to biomethane shifts from natural gas to other green alternatives** such as green hydrogen, electric solutions, among others. A separate analysis is required to investigate competitiveness here.
- It must be noted that this **cost comparison does not consider the full benefit of biomethane, as it is not just an energy carrier, but an enabler of many important sustainable processes**, e.g. sustainable and circular agriculture, and can be considered an important part of investment into local rural economies.

[1] When compared with a natural gas price of €44/MWh (ICE "CAL 24" TTF future price) and an EU ETS price of €100/t CO_2 and an emission factor of natural gas of 56gCO_2/MJ, leading to €20/MWh_{NG}.



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Way forward

Outcomes can help with benchmarking for both industry players and policy makers

- This work can be used to provide a basic understanding of the cost structure of biomethane production to policy makers.
  - These results show that a "*one size fits all solution*" result for the cost of biomethane production is not possible as the costs depend on factors that may differ per region, or depend on policy choices.
- Policy makers can also use these outcomes on the costs of biomethane and its drivers to help with shaping future support schemes. This can come from creating some cost benchmarks and evaluating which parts of the supply chain can most effectively benefit from support or incentives.
  - E.g. support on CAPEX investments for smaller producers to counter economies of scale of bigger plants
- The results can also highlight key areas where costs will be expected to change, either increasing or decreasing, and the impacts of that on the total biomethane production cost must be assessed.
- The outcomes of this work can help industry players benchmark their production costs against those of others. This can potentially help with incentivising improvements within industry and the deployment of cost reduction measures.

Way forward

This process can be improved to increase its value to industry and the BIP

The data gathering process was first-of-a-kind, and the active participation by many companies has provided valuable lessons on how it can be further improved:

- Remove identified weaknesses/unclarities in the questionnaire itself and increase the data coverage on thinly covered sections of the supply chain e.g. operational cost of digestate processing and removal, cost of production with different feedstocks, etc.
- This could be done with a new round of a similar questionnaire with more participants.
- While this work is a crucial first step, the outcomes of this report can already be used valuably to create insights into how the industry sees these costs developing in the near future. A similar process could be undertaken to investigate foreseen future cost developments in the industry.

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