Production of Biomethane from Diverse Sources:
Capture and Utilisation Systems

GAS NETWORKS IRELAND
GAS INNOVATION FUND
MARCH 2022

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Document Title
GNI Gas Innovation Fund – 2020-011 – Report: Production of Biomethane from Diverse Sources: Capture and Utilisation Systems
Project Reference Number(s)
20-001 – GNI R&D Review of Capture and Utilisation
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Version	DATE	REASON FOR ISSUE	PREP. BY	CHK. BY	APP. BY
1	01/08/2022	NVP Energy Final Report	TG	CH	DK

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Abbreviations

AD	*Anaerobic Digestion*
CAPEX	*Capital Expenditure*
CH_4	*Methane*
COD	*Chemical Oxygen Demand*
DAF	*Dissolved Air Floatation*
DM	*Degassing Membrane*
HRT	*Hydraulic Retention Time*
OPEX	*Operational Expenditure*
TOTEX	*Total Expenditure*
UASB	*Upflow Anaerobic Sludge Blanket*
UWWD	*Urban Waste Water Directive*
WW	*Wastewater*
WWTP	*Wastewater Treatment Plant*

1.0 Executive Summary

The anaerobic digestion process offers the opportunity to produce renewable biogas from waste organic material, be that solid waste or wastewater. The potential waste to produce such biogas has grown due to technological advancements in the recent decade such has co-digestion of manure or sewage sludge and municipal organic waste, as well as the significant development of low-temperature anaerobic wastewater treatment allowing more dilute wastewaters to be treated.

Despite these strides technologically they have not been translated at commercial or full-scale and thus the benefit to the environment from offsetting fossil fuels has yet to be seen.

This desktop report for GNI Innovation details 'new' and diverse sources of substrates not yet utilised in Ireland via anaerobic digestion, solid and wastewater.
Furthermore, we outline some key limitations and technology to overcome these gaps in the areas of biogas capture and utilisation methods for isolated, relatively smaller, wastewater treatment plants (WWTPs) across Ireland.

The report focuses on the following strands.

- Potential Biogas Production in Ireland
    - Diverse and new substrates
- Biogas capture from wastewater
    - Especially difficult extraction scenarios (e.g. low temperature)
- Biogas utilisation
    - Off-site Use: e.g. pressurisation and transport possibilities

2.0 Grant Objectives

The project aimed to achieve the following objectives:

1. Identification of bands of volumes for WWTPs with AD plants or potential biogas production.
2. Engage with the above AD community and potential AD customers to determine how they currently deal with or plan to deal with biogas generation on their sites.
3. Develop and review a block-process flow identifying potential technologies possibly including but not limited to Gas Stripping; Methane Concentration; Gas Compression, Bottling and Transportation options.
4. Complete report for Gas Networks Ireland and wider AD community of stakeholders including a next-step description taking this to an experimental strategic project.

3.0 Introduction

The anaerobic digestion (AD) process is a natural process that has several positive impacts namely the production of biogas, a renewable fuel that can offset fossil fuels and simultaneously the degradation of wastes.

The AD process can be implemented across a range of wastes including but not limited to manures, sewage sludge (primary and waste activated sludge) and food / 'brown-bin' wastes. It can also be implemented to clean wastewaters both heavily contaminated and warmer food and beverage wastewaters.

While the process has been well developed internationally across all sectors, the Irish sector remains underdeveloped with only c. 10 sites across the Republic of Ireland. In the future decarbonisation of the gas grid and indeed the country as a whole the production of biogas could play a significant role.

This report targets the previously underutilised sources of biogas through solid-AD and anaerobic wastewater treatment as the larger scale systems deployed in Ireland and internationally offer economies of scale for solid-AD systems which can deploy gas-to-grid systems etc. to ensure use of the gas. Larger food and beverage sites also have a direct use for the gas produced from anaerobic wastewater treatment to offset fossil fules onsite in boilers etc.

Smaller scale production of biogas through smaller solid-AD systems or more dilute wastewater streams (food and beverage or sewage treatment)

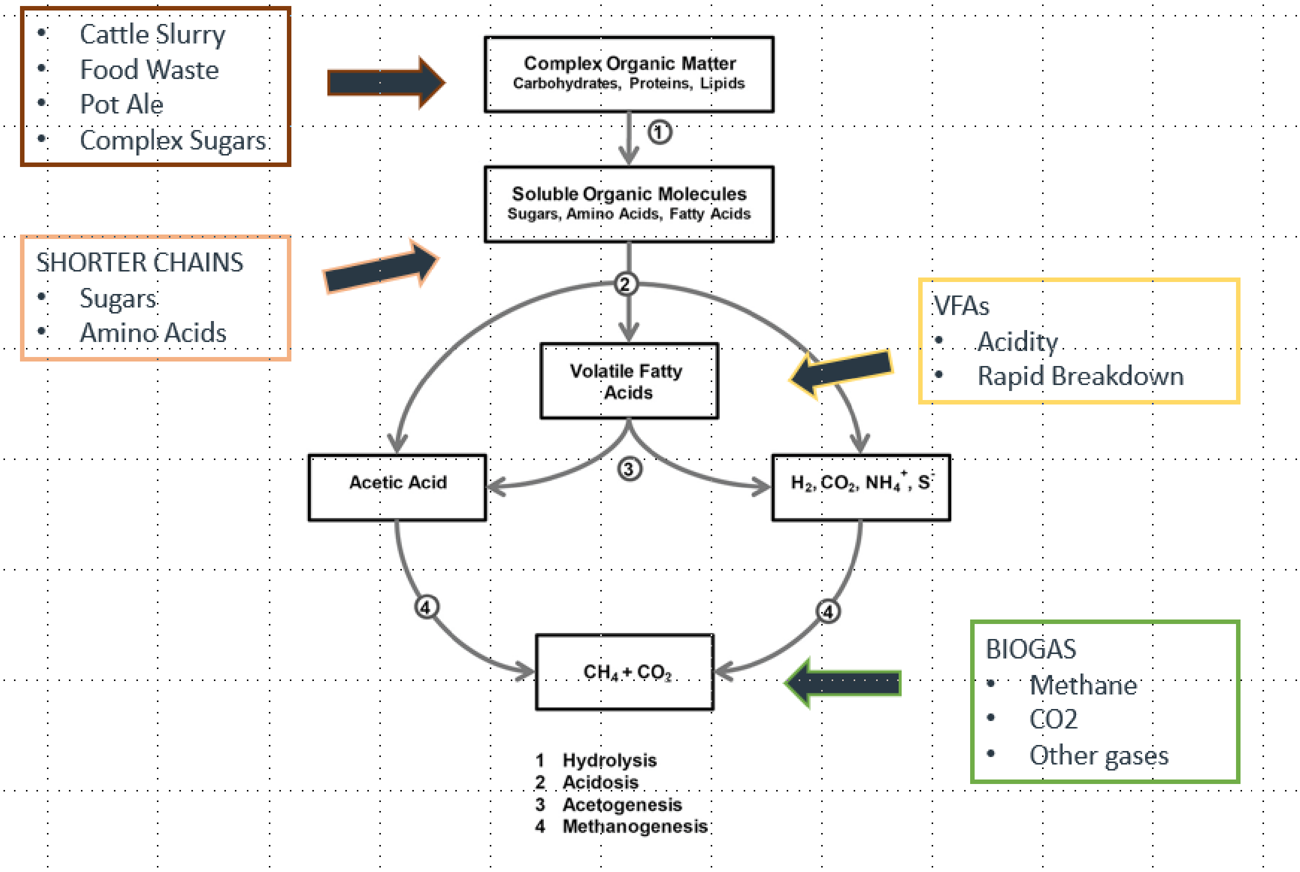
To ensure the direct offsetting of fossil fuels the production of biogas needs to avoid unnecessary flaring or discharge of the biogas and the use of the renewable gas to offset previously used fossil fules, not to use the gas in a parasitic manner.

However, it requires the strict capture and worthwhile use of the biogas to avoid unnecessary and damacingmethane or carbon dioxide releases to the atmosphere.

3.1 Anaerobic Treatment - How it Works

3.1.1 Anaerobic Digestion

The step-wise but interlinked microbially driven process of anaerobic digestion, outlined in Figure 1. Has 4 keysteps that allows microbes to break down complex organics into simple monomers and further convert them into methane and carbon dioxide (biogas).



3.1.2 Anaerobic Wastewater Treatment Technology

Anaerobic wastewater treatment allows for the retention of biomass and the removal of organics from wastewater through their conversion to biogas. The process is normally an upflow process that allows the biogas to bubble off at the top.

Often the systems operate to a short Hydraulic Retention Times (HRT).

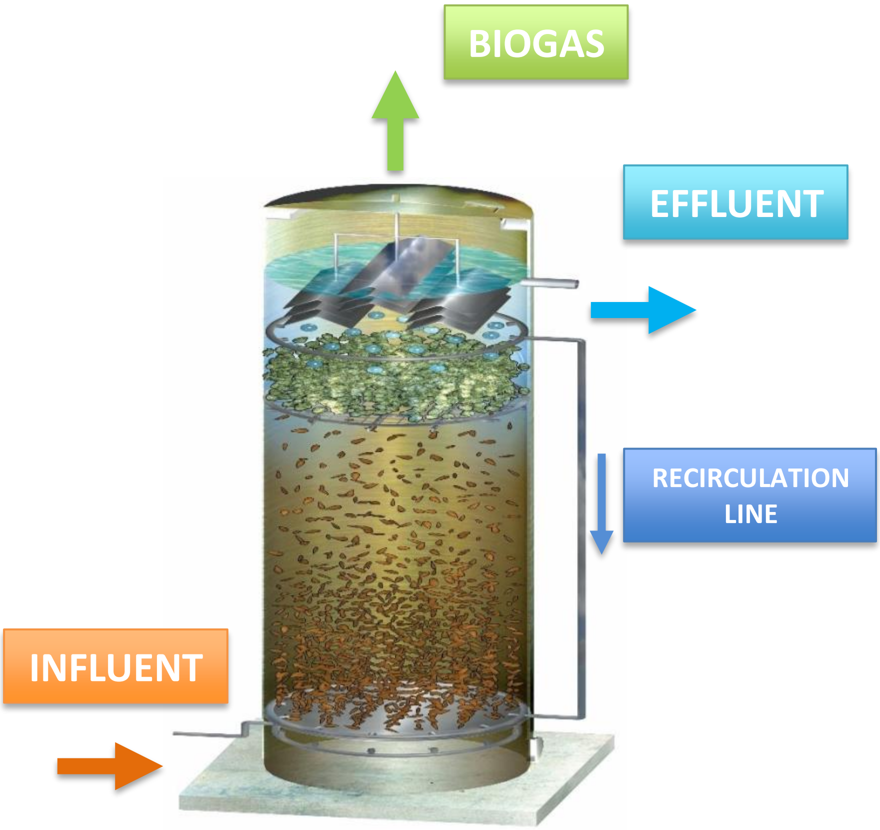
The process is as follows:

- Pumping influent through a fluidised bed of anaerobic microbes where the organic components are converted into methane and carbon dioxide.

- Effluent is then passed through a patented fixed film filter, which acts as a polisher to generate effluent of high quality in terms of COD removal efficiencies.

- **80% COD Removal with Biogas Production (0.42 m^3/kg COD)**

- Continuous recirculation of liquid to achieve optimum up-flow velocities for treatment. Methane gas naturally separates from the liquid and is removed at the top of the module and utilised on/off-site (see Section 5 for further information)



3.2 Integration of Low-temperature anaerobic wastewater treatment

An Irish Case Study – NVP Energy Arrabawn Dairies.

The anaerobic system provided by NVP Energy treats wastewater streams post screening and Dissolved Air Flotation (DAF is usually required to pre-treat Food and Drink wastewater such as Dairy as it contains fats, oils, and greases).

The system is installed on a simple concrete plinth as illustrated in Figure 1 below, and the main anaerobic reactor is typically constructed using a glass lined steel tank with a fiberglass standpipe for mixing and pH correction (if required). The AMBI-ROBIC system is generally manufactured offsite, along with the containerised pumping and panel systems ensuring a rapid build time and a compact footprint.

The technology removes up to 80% of the remaining COD load (post DAF), resulting in both a reduction of load on the Aerobic unit but more applicable to this project, biogas is produced, and this can be directly piped back to the Production facility for use on-site or bottled and transported elsewhere (see Section 5 for possible options). One of the benefits of AMBI-ROBIC occupying a neat footprint is that it allows as much room as possible for biogas infrastructure to turn the biogas into biomethane if required.

Figure 1: NVP Energy Anaerobic Treatment Plant at Arrabawn Co-op, Kilconnell, Co. Galway

4.0 Biogas Production from Wastewaters

a) Sewage Potential – Irish Water

Irish Water Biogas Potential		Variables	Notes	PE Bands						WW treated per day by IW*	Unit
				499	5,000	10,000	25,000	50,000	100,000		
Volume for Treatment		0.2	1PE = 0.2m^3/day (Henze)	100	1,000	2,000	5,000	10,000	20,000	**1,600,000**	m^3/day
Typical COD Load		0.5	Same as municipal WW that was trialled	50	500	1,000	2,500	5,000	10,000	**800,000**	kg/day
Theoretical MAX	Potential Biogas Generation	80%	COD removed								
		0.42	m^3 **biogas** per kg COD removed	6,120	61,320	122,640	306,600	613,200	1,226,400	**98,112,000**	m^3/year
		365	no. of days p.a.								
	Potential Energy Value of Biogas	**7**	Calorific Value of **Biogas**	**43**	**429**	**858**	**2,146**	**4,292**	**8,585**	**686,784**	**MWh/year**
	Irish Water Data		No. of plants per PE band	526	**TBC**	**TBC**	**TBC**	**TBC**	**TBC**		
	Potential Energy of Biogas per PE Band			**22,533**	**TBC**	**TBC!**	**TBC**	**TBC**	**TBC**		**MWh/year**
Theoretical MIN	Potential Biogas Generation	80%	COD removed								
		0.18	m^3 **methane** per kg COD removed	2,623	26,280	52,560	131,400	262,800	525,600	**42,048,000**	m^3/year
		365	no. of days p.a.								
	Potential Energy Value of Biogas	**10**	Calorific Value of **Methane**	**26**	**263**	**526**	**1,314**	**2,628**	**5,256**	**420,480**	**MWh/year**
	Potential Energy of Biogas per PE Band			**13,796**	**TBC**	**TBC**	**TBC**	**TBC**	**TBC**		**MWh/year**

Table 1 (**See Appendix B for these figures which are taken from Irish Water's Business Plan to 2021)*

5.0 Complementary Biogas Technologies & Solutions

5.1 Gas (methane)stripping/removal from low-temperature wastewater

It is a known phenomenon that the solubility of methane increases as the temperature of water/wastewater decreases as is depicted in the below graph, Figure 2 (See Appendix D.a. for a table that presents a more detailed breakdown of the solubility of methane for varying temperatures and pressures). Discharge of residual dissolved methane in the effluent of WWT reactors contributes to an increase in atmospheric methane, which is 21 times more potent than CO_2 as a greenhouse gas (Hartley and Lant, 2006). In addition, the dissolved methane discharge represents a loss of energy that is generated in anaerobic WWT processes.

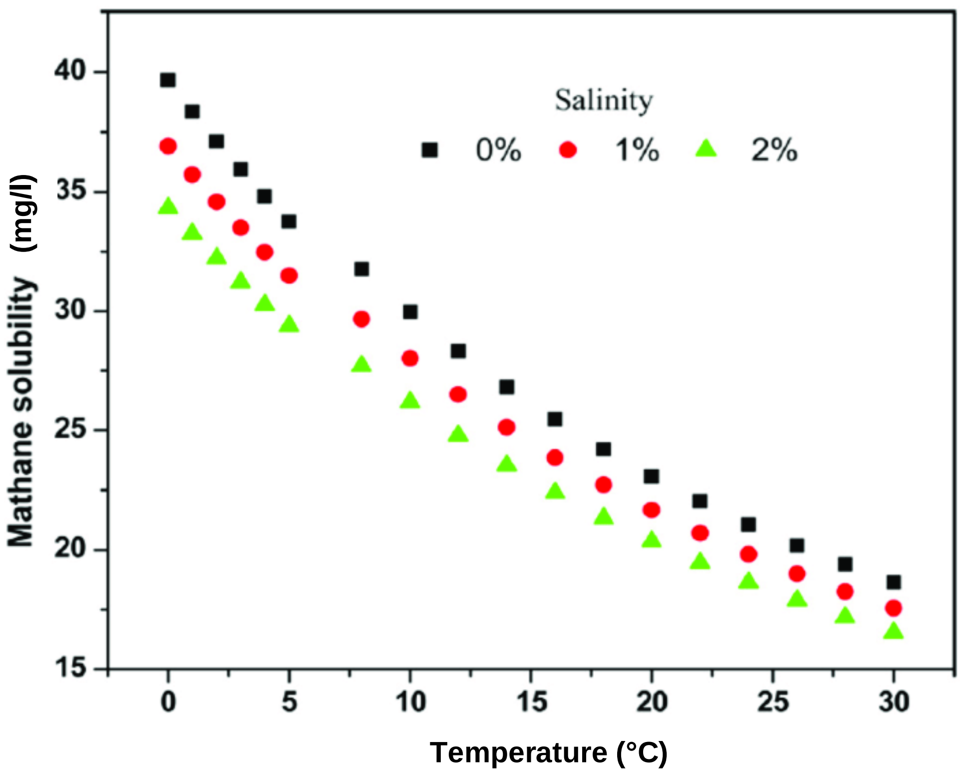


Figure 2: Solubility of Methane at Varying Temperatures

As the fundamental design of the sustainable AMBI-ROBIC technology is that it treats municipal wastewater at low/ambient temperatures, it is imperative that the increased solubility of methane at low temperatures is addressed through a complimentary technology in order to maximise the biogas yield and minimise methane emissions to the atmosphere.

5.1.1 EloVac – Vacuum Degassing Solution

Through our research on this project, NVPE have been in communication with Eliquo Technologies who have designed and manufactured a methane capture technology known as EloVac which is a compact, skid-mounted vacuum degassing solution. It extracts residual methane that has remained solublised in the treated effluent. Figure 3 below illustrates the process flow that takes place within EloVac.

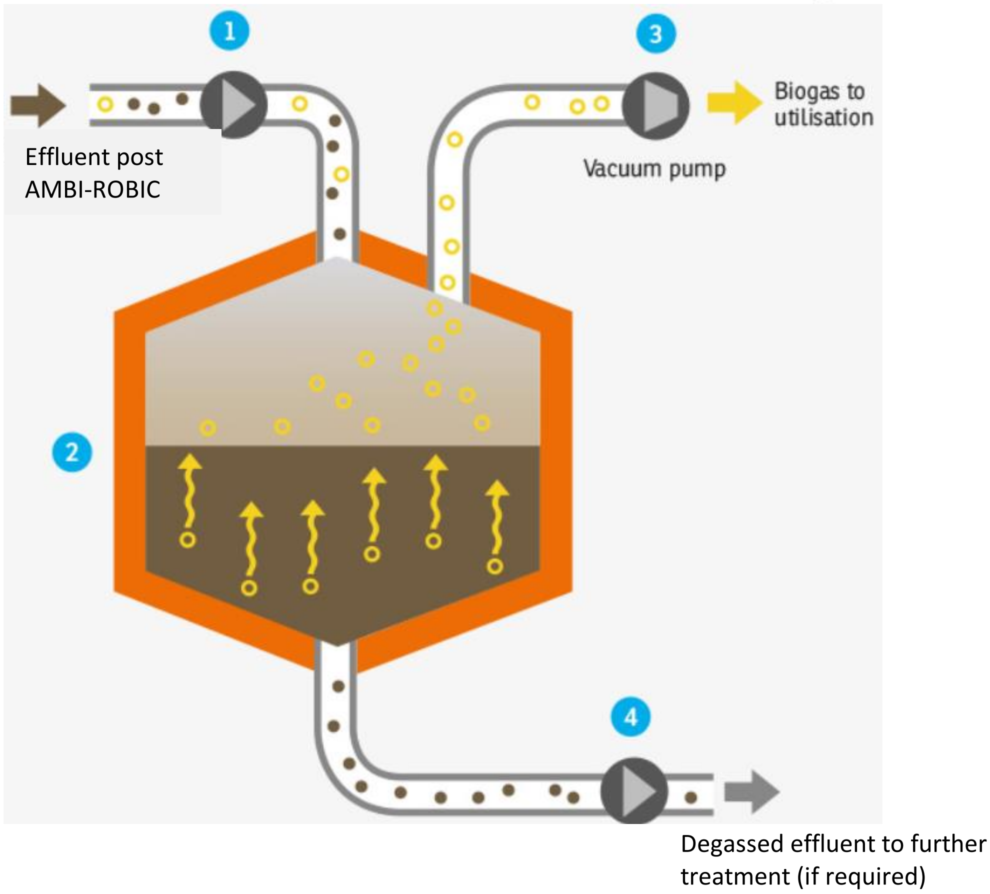


Figure 3: EloVac Process Flow Diagram

1. Effluent is fed continuously to the degassing reactor tank via a control valve or a pump.
2. In the degassing tank, a vacuum is created by a pump, and pressure and filling levels are controlled to predefined values. The gas present in dissolved form and as bubbles is withdrawn under vacuum from the effluent.
3. The vacuumed gas enables an energy-positive operation by capturing additional biogas that can be combined with the biogas collected during the AMBI-ROBIC process

and used as a source of renewable energy, while consequently reducing greenhouse gas emissions.

4. The degassed effluent is continuously discharged from the degassing tank (HRT < 15 mins) to further (tertiary) treatment downstream (if required).

NVPE have deemed EloVac to be a very cost-efficient process, which, as a stand-alone system, does not require extensive process conversion or a large footprint (<10m^2) and so will work well in tandem with AMBI-ROBIC.

5.1.2 Degassing Membrane Reactor

Another possible solution for degassing the wastewater that was discovered through this project is a degassing membrane (DM) reactor which was trialled post an Upflow Anaerobic Sludge Blanket reactor using low-strength WW at low temperatures (Bandara, W. et al, 2011) which is extremely comparable with AMBI-ROBICs operational remit.

A hollow-fibre membrane module (a multi-layered composite hollow-fibre membrane) was installed in the DM reactor. The DM reactor was completely filled with the WW treated by the UASB reactor. The dissolved biogas diffuses into the lumen of the hollow fibres of the DM under vacuum generated using a vacuum pump. Although gas molecules can pass through the non-porous layer of the membrane, liquids cannot. Therefore, the DM effectively separates dissolved gas from the liquid. The DM reactor was operated at the same temperatures as the UASB reactor (Transmembrane pressures were set at 50 kPa and 80 kPa (absolute pressure) by using a vacuum gauge).

It was found that the dissolved methane was successfully collected by degasification with the DM. Under lower temperatures or shorter HRTs, the dissolved methane concentrations increased (as explained in section 6.1); therefore, the dissolved methane collection efficiencies increased. Moreover, the particulate COD concentration (calculated by subtracting the dissolved fraction of COD from the total COD) was decreased by degasification. The results indicate that degassing membranes are a promising technology for not only improving methane recovery, but also particulate COD removal efficiencies post low temperature AD processes treating low-strength wastewater.

5.1.3 Summary of Different Methane-Recovery Technologies

Research carried out by Melbourne Water in Australia (Melbourne Water, 2013) in relation to methane-recovery technologies on the market, corroborates NVPE's research that vacuum degassing and degassing membranes are the two most efficient methods for recovering the maximum amount of dissolved methane from wastewater, see Table 3 below.

	CAPEX ($m)	OPEX (Excluding Energy)	Energy Use	Maximum CH4 Recovery (from 30mg/L)	Process Notes	Other Notes
Vacuum	High (~$18 million)	Medium (packing may need replacement)	Medium	95%	Fouling may be an issue, need to backwash/scour packing.	
Sparging	Medium-High (less than vacuum?)	Low	Medium-High	99%		Gas stream will be diluted by sparge gas
Membrane	Medium-High ($11 million)	High (need to maintain/ replace membrane)	Medium	100%	Fouling likely to be an issue, may be severe with higher solids.	
Ultrasonic	V. High ($119 million)	Low	V. High (Electricity for ultrasound)	88%		
Agitation	Low-Medium ($0.5-5 million)	Low	Low-Medium	<50%		
Heat	Medium-High (Not costed)	Low	V. High (Gas for heating)	50%		

Table 3: Summary of key data for different methane-recovery technologies

Vacuum and membrane methods recover up to 95% and 100% of the dissolved methane respectively. Although Sparging also has a high recovery value (99%), the recovered methane will consist of the gas used for sparging. This prevents the recovered methane from being utilised unless the sparging gas can be separated and the methane enriched making this recovery method impractical and cost prohibitive.

It is noted in the above table that vacuum and membrane methods are susceptible to fouling, however, this is only an issue if being employed on poorly treated wastewater which would not be the case here as the chosen gas-stripping method would be installed post NVPE's highly efficient AMBI-ROBIC wastewater treatment solution.

5.2 Biogas Storage

NVP Energy approached Storetec in the UK who are specialists when it comes to biogas handling and storage. They suggested that their smallest stand-alone BIODOME which stores in the region of $100m^3$ (see Appendix D.b. for technical data relating to this BIODOME mode) would be appropriate for small wastewater treatment plants generating biogas. They can provide site specific quotations once we provide the following details:

- Where is the project located?
- What storage volume we are looking for?
- What is the max flow rate into the Gas Holder?
- What is the max flow rate out of the Gas Holder?
- What is the operating pressure of the Gas Holder?

5.3 Biogas Pre-Treatment: H_2S Removal Technologies

Hydrogen sulphide (H_2S) is always present in biogas, although concentrations vary depending on the feedstock. It has to be removed in order to avoid corrosion in compressors, gas storage tanks and engines. H_2S is extremely reactive with most metals and the reactivity is heightened by concentration and pressure, the presence of water and elevated temperatures. Due to the potential problems H_2S can cause, it is recommended to remove it early in the process of biogas pre-treatment.

Due to the wide range of H_2S expected (500-1500ppm) *Higgins & Hewins* recommended their twin vessel Lead/lag arrangement as per Figure 4. It includes 2 No. 1.2m diameter vessels each containing 2 No. bulk bags (907kg each) of SulfaTreat 410 CHP media (see Appendix D for more information)

The quotation for the vessels and media is as follows (assuming all pipework, valves and instrumentation will be provided by others):

Capital Cost: 2 No. Size STS 201/1, 2m diameter vessels c/w 1st fill of media

Price: *€39,344 Ex-Works*

Operational Cost: Replacement media per vessel, i.e. 2 No. Bulk Bags (1814kgs)

Price: *€3,084 Ex-Works*

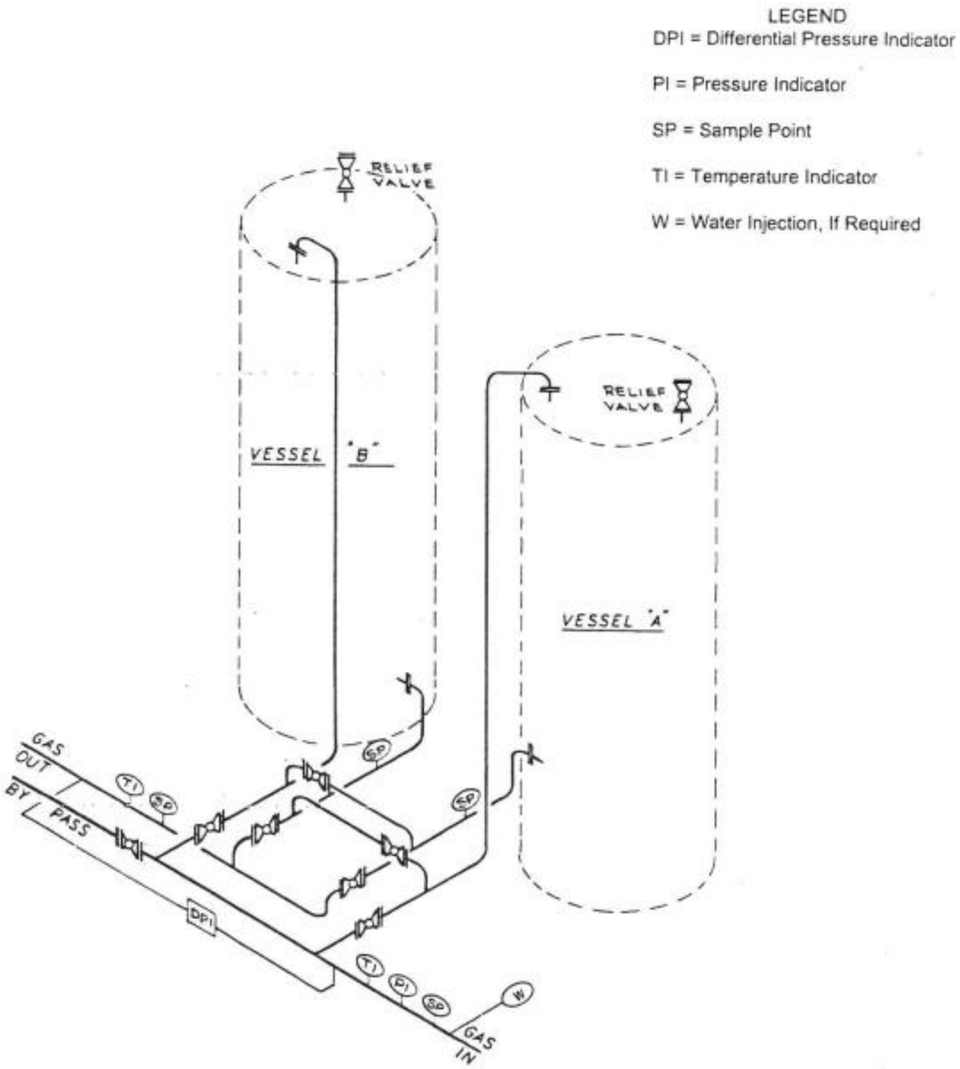
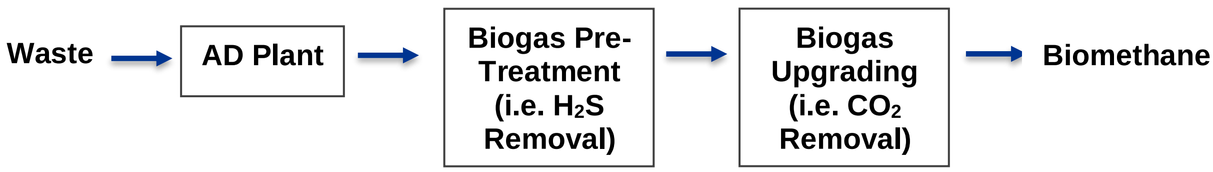


Figure 4: Gas Purification System

Another technology that offers H_2S removal but also compression and filling is discussed in a subsequent section – 6.5 Gas Compression & Bottling Systems

5.4 Biogas Upgrading to Biomethane: CO_2 Removal Technologies

Biomethane, also known as Renewable Natural Gas (RNG), is biogas that has been upgraded to a quality similar to natural gas through the removal of CO_2. Removing CO_2 increases the heating value of the gas allowing it to be added to the natural gas grid.



There are several different commercial methods for reducing CO_2 and consequently upgrading biogas to biomethane:

- Water wash scrubbing
- Amine wash absorption
- Pressure swing adsorption
- Membrane separation

Of the above methods, Membrane separation is preferred as it allows for CO_2 capture (see Figure 5 below). On the contrary, Water wash uses air to flush the CO_2 out of the water meaning the CO_2 cannot be captured as it is in an N_2 stream. Whilst Amine technology is efficient at separating CO_2, it requires 120°C heat to regenerate the amine and so is only appropriate if there is a high-grade heat source available.

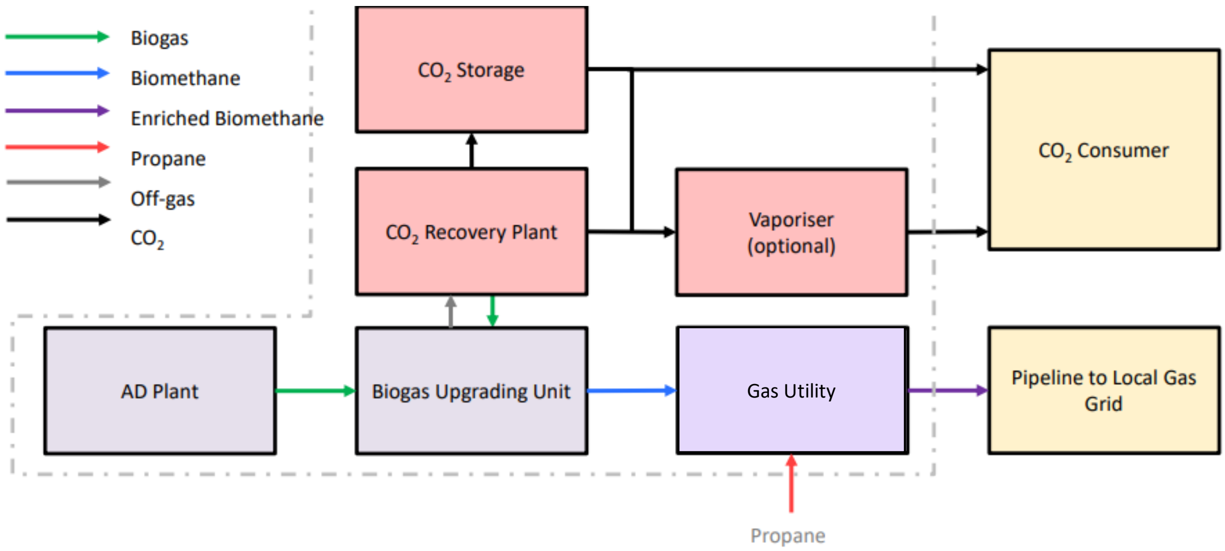


Figure 5: Membrane separation and CO_2 Capture

5.5 Gas Compression & Bottling Systems

An alternative to utilising biogas onsite in a gas boiler/CHP, is to purify the biogas and compress it into gas bottles for onward distribution, see Figure 6 on the following page.

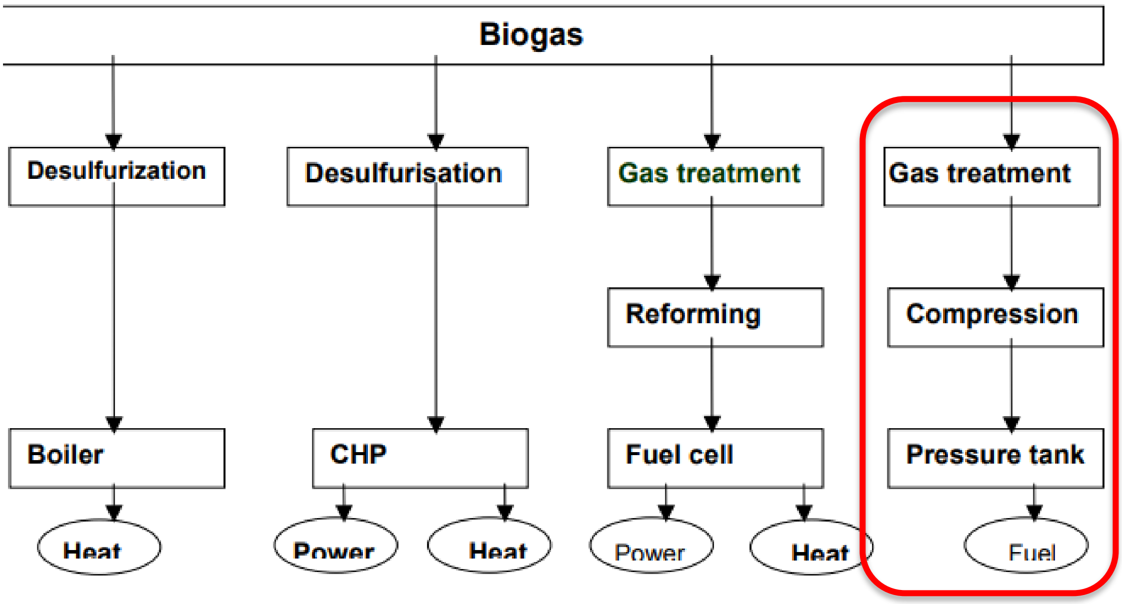


Figure 6: Biogas Upgrading Options

A company that provides such a service is Carbon Masters. Their process involves 3 major steps (see Figure 7 for the Process Flow Chart):

1. **Purification**: First the methane is enriched to > 92% by removing CO_2, moisture, H_2S and other impurities.
2. **Compression:** Next the enriched methane is compressed to high pressure of c 200Bar.
3. **Filling:** After compression, the purified gas is either bottled for storage and onward distribution as 'CARBONLITES' or it can used to fill a CNG compatible vehicle directly.

Figure 7: Process Flow Chart of the Raw Biogas

A large-scale Carbon Masters system takes up approximately 350 sq metres, see Table 4 below.

Sl No	Description	Area in Sq Mtrs
1	Purifiction Unit	150
2	Compressor Area	100
3	Bottling Area	100
	Total	350

Table 4: Approx. Area required for a 150 Cum/Hr Carbon Masters system

As many small sites would not have that amount of available space, Carbon Masters have proposed a smaller Proof of Concept (POC) scheme for NVP Energy that would purify and compress the biogas for CNG vehicles only (i.e. there would be no bottling area), see the process flow schematic in Figure 8 below.

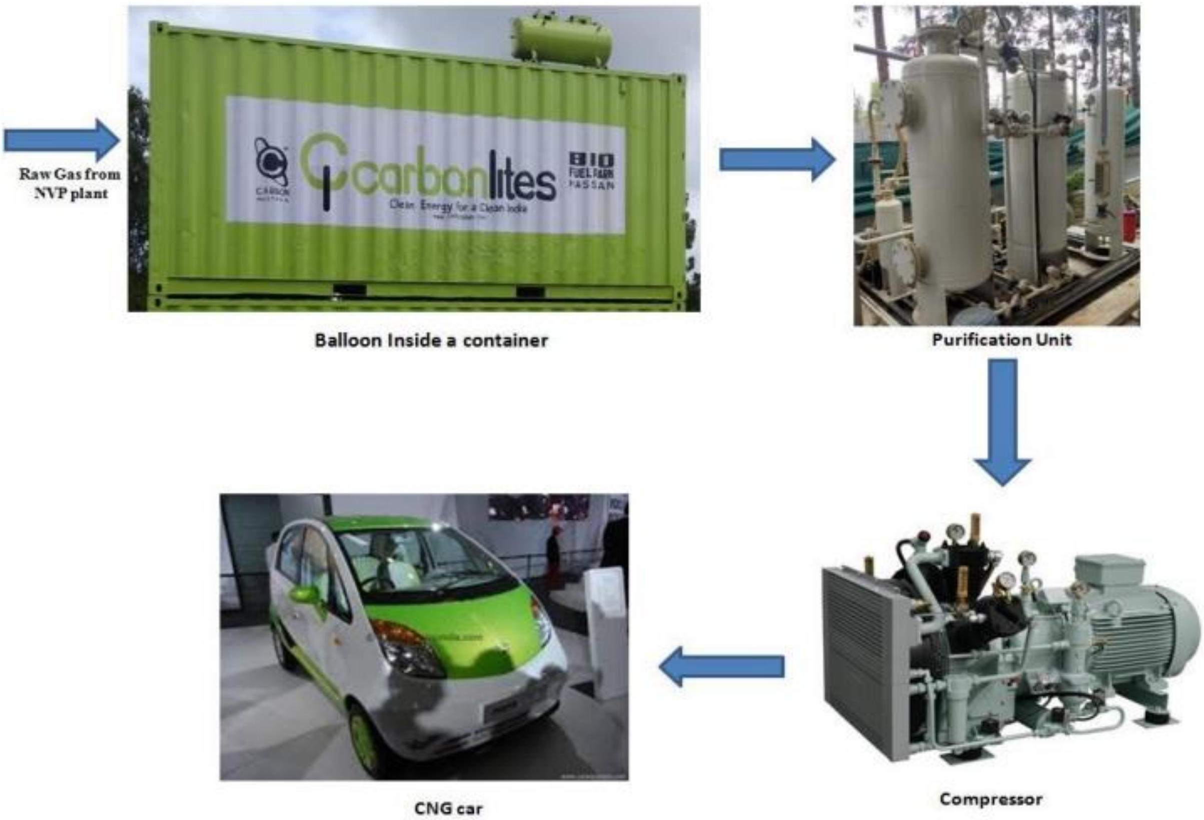


Figure 8: Carbon Masters Bio-CNG POC for NVP Energy

The benefits of the above POC, are that it is a small-scale solution which is portable and requires less than half the space (approx. 170 sq metres) of a large-scale system. See Appendix D.d. for further information about the proposed POC.

5.6 Collection and Delivery potential to Gas Grid Injection Centres

During the course of this study, NVP Energy engaged with CNG Services who provide consultancy support in relation to the development of new anaerobic digester projects including a range of utilisation options for the biogas. One part of our discussions related to the collection and delivery of biogas from production sites. They provided us with a detailed quotation from a 3rd party for a self-carrying road tanker for CNG transportation, see Figure 9 below. The major benefit of this road tanker is that the manufacturing company can modify the tank so that untreated biogas can also be transported within it. Appendix D.e. outlines the cost of a CNG road tanker followed by modification costs to adapt the tanker in order to carry biogas depending on the level of H_2S present in the biogas.

Figure 9: Self-carrying road tanker for CNG transportation

6.0 Next Steps

The companies referenced in this report are very interested in collaborating with NVP Energy as they offer utilisation solutions that are appropriate for isolated wastewater treatment plants that generate lower biogas volumes from our smaller AD reactors.

NVPE are in the process of reviewing current and potential future AD projects in Ireland with a view to combining a number of these complementary biogas usage technologies and incorporating them into an experimental strategic project downstream of NVP Energy's AMBI-ROBIC technology.

7.0 Conclusions

As per the preceding sections, this feasibility study investigated the possibility to develop biogas capture, upgrade and subsequent utilisation methods for AD sites nationwide, generating biomethane for the gas network.

The project outputs and outcomes correspond with what was outlined in Section 2 – Grant Objectives. In summary, the following has been achieved:

- Identification of 'bands' of volumes of biogas per potential sites.
- Identification of Irish stakeholders
    - Including list of plants and associated contacts that would be feasible utilisers of such technologies
- Complementary biogas technologies and their associated process flows
    - From production through 'processing' to its utilization
- Future 'next steps' (inc. possible pilot or technology trial)

The research from this project has the potential to propose a circular biogas production, offering a greater feasibility for industries and municipalities to invest in AD that 'traditionally' would not have been the case. For example, municipal WWTPs that offer a consistent stable source of organics in every community now have the potential to become a reliable biogas/biomethane source. If this was put into action, it would help achieve the Irish Government's aims on four fronts:

1. Offsetting further fossil Carbon with a renewable fuel
2. Increasing viability of Biogas projects – value of biogas/biomethane
3. Increasing volume of biogas into GNI grid.
4. Creating a varied, dynamic source of biomethane

Therefore, implementation of this research will potentially assist Ireland in its move towards a lower carbon economy and can help the country achieve its legally binding target of net-zero GHG emissions no later than 2050 and a reduction of 51% by 2030.

8.0 References

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A. Map of WWTP Plants in Ireland

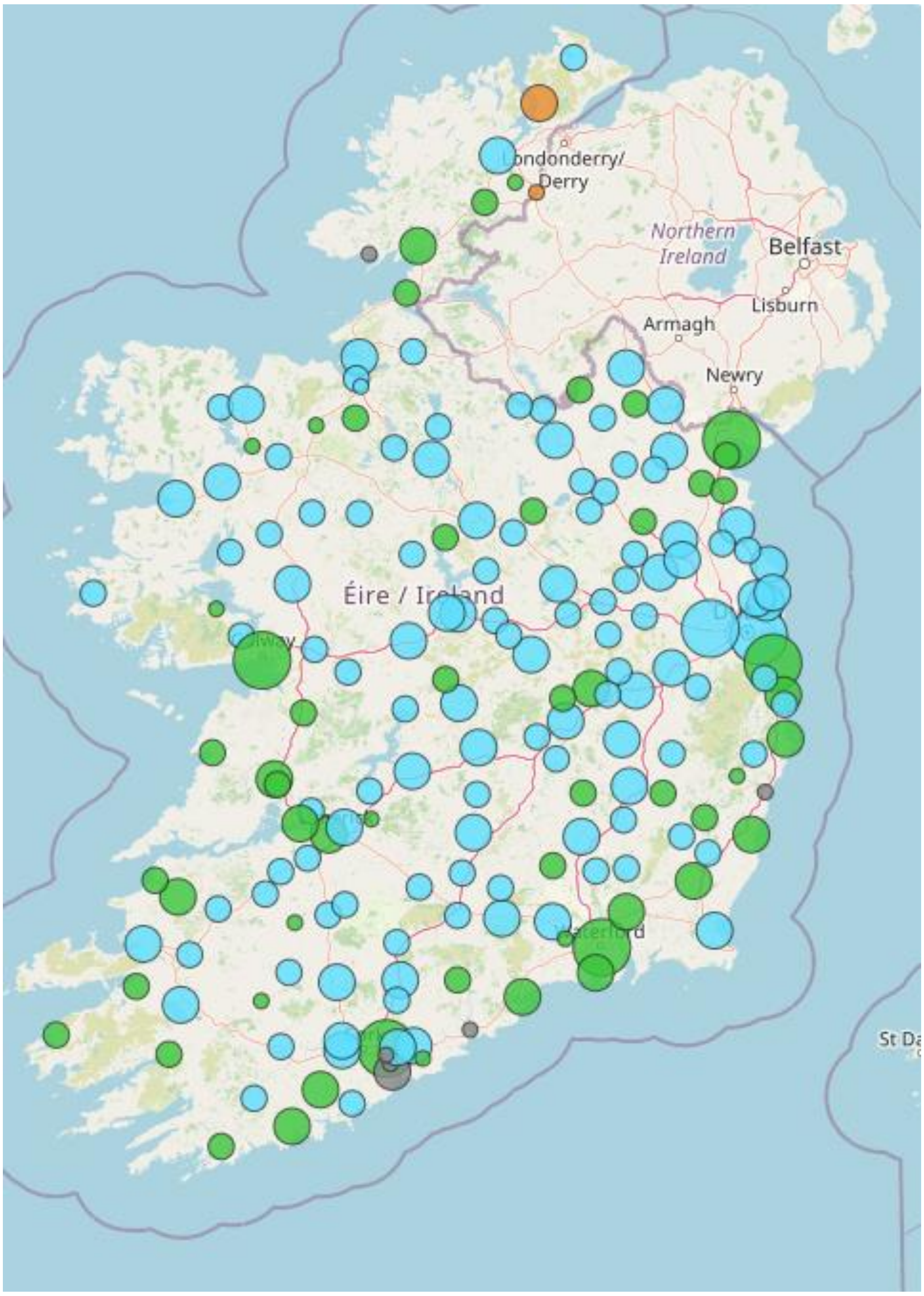


Figure: Outlining the WWTPs in Ireland, from the Urban Wastewater Directive EU.

B. Potential Biogas Production per 'Band'

Irish Water's Business Plan to 2021: https://www.water.ie/__uuid/8a0d383d-d696-4a29-a374-e8f9708372e6/Irish-Water-Business-Plan.pdf

Water and wastewater network assets

On its establishment, Irish Water assumed responsibility for a large portfolio of fragmented and disjointed water and wastewater assets (treatment plants, network pipes, etc.). **It should be noted that at present a comprehensive and detailed database of water and wastewater assets is not available.** Irish Water is in the process of collating the available data from the 31 Local Authorities and all outstanding information not recorded heretofore. A summary of the estimated scale of Irish Water's operations is set out in Table 2.1.

Irish Water assets and operations	
Assets:	
Water abstraction and treatment points all sizes (no.)	856
Water treatment plants >1 million litres per day production (no.)	235
Water pipelines mapped (km)	58,000
Treated water reservoirs all sizes (no.)	1,347
Wastewater treatment plants all sizes (no.)	1,074
Licensed wastewater treatment plants (no.)	385
Certified wastewater treatment plants < 500 PE* (no.)	526
Wastewater network mapped (km)	15,000
Wastewater network estimated (km)	25,000
Operational Activities:	
Customer base (no.)	1.56m (1.36m** domestic and 200k non-domestic)
% of population supplied with drinking water	>80% (3.3m)
Public water zones (no.)	c. 1,000
Drinking water treated per day (litres)	1,670m
Agglomerations where wastewater is collected (no.)	>1,000
Wastewater treated per day (litres)	1,600m

* PE - Population Equivalent **full service equivalent to account for customers with only one service

Table 2.1 Irish Water - water and wastewater assets and operational activities

Irish Water's operations include several thousand water extraction points, treatment plants, pumping stations and wastewater discharge points, approximately 58,000km of mapped water pipelines and an estimated 25,000km of wastewater pipelines.

Irish Water supplies drinking water to approximately 80% of the public (3.3m people), with the remainder supplied by group water schemes and private wells. This is delivered through some 1,000 separate water supply areas (public water supply zones) and involves the abstraction, treatment and delivery of 1,670 million litres of drinking water each day.

Irish Water collects wastewater from over 1,000 separate communities connected to the wastewater network (wastewater zones known as "agglomerations") and treats 1,600 million litres of wastewater daily, before it discharges it back into our rivers, harbours and coastal areas.

The origins of the fragmented nature of the Irish water and wastewater network can be traced back to the 19th Century and the early formation of public water supplies, based on individual urban council areas and river basins. The origin of the current system dates from the 1878 Public Health Act and the role of each Sanitary Authority. With expansion and development water services remained fragmented given the sparse rural nature of a significant part of the Irish population and the development of water and wastewater services within individual Local Authority boundaries. This is one of the key factors that has lead to higher costs of operations in Ireland compared to peer utilities in Europe.

C. Calculations Appendix

Average Annual Domestic Gas Usage		11,000	kWh
1 plant	20	*m^3/hr*	generated
	8	*kWh/m^3*	calorific value
	160	*kW*	Energy per hour
	3,840	*kWh/day*	
	1,401,600	*kWh/year*	
	127	*Households*	
5 plants	7,008,000	*kWh/year*	
	637	*Households*	
10 plants	14,016,000	*kWh/year*	
	1,274	*Households*	
100 plants	140,160,000	*kWh/year*	
	12,742	*Households*	
GNI Target	12	*TWh/year*	
	11,500,000,000	*kWh/year*	
Plants	**kWh**	**Households**	**% Target**
1	1,401,600	127.42	0.012%
5	7,008,000	637.09	0.061%
10	14,016,000	1,274.18	0.122%
50	70,080,000	6,370.91	0.609%
100	140,160,000	12,741.82	1.219%
200	280,320,000	25,483.64	2.438%

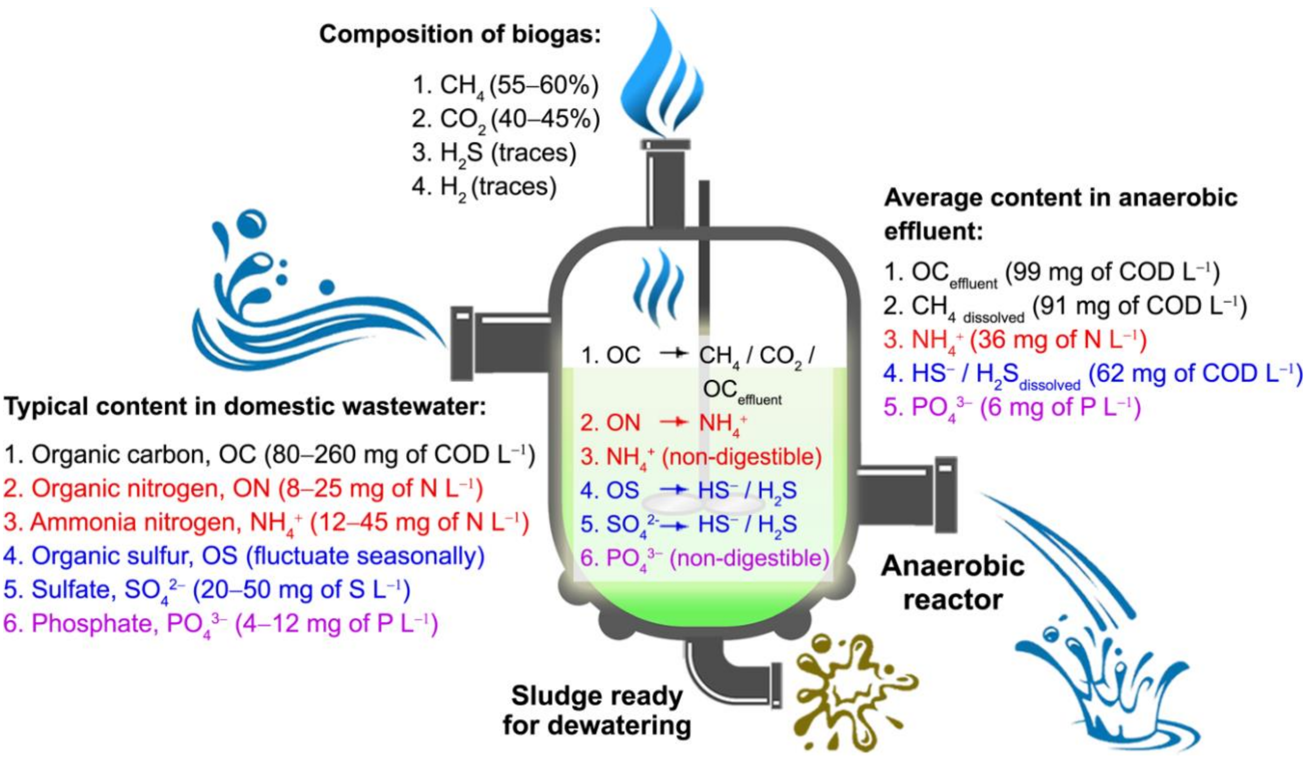
D. Complementary Biogas Technologies & Solutions

a. Gas (methane)stripping/removal from low-temperature wastewater

The following table presents a more detailed breakdown of the solubility of methane for varying temperatures and pressures.

Pressure (bar)	Temperature of Water in Degrees C					
	0	5	10	15	20	25
1	39.8	34.4	30	26.4	23.7	21.6
2	79.6	68.8	60	52.8	47.4	43.2
3	119.4	103.2	90	79.2	71.1	64.8
4	159.2	137.6	120	105.6	94.8	86.4
5	199.0	172	150	132.0	118.5	105
6	238.8	206.4	180	158.4	143.2	129.6
7	278.6	240.8	210	184.8	165.9	151.2
8	318.4	275.2	240	211.2	189.6	172.8
9	358.2	309.6	270	237.6	213.3	194.4
10	398	344	300	264	237	216
ppm/bar	39.8	34.4	30.0	26.4	23.7	21.6

Solubility of Methane (mg/l) for Varying Temperatures & Pressures



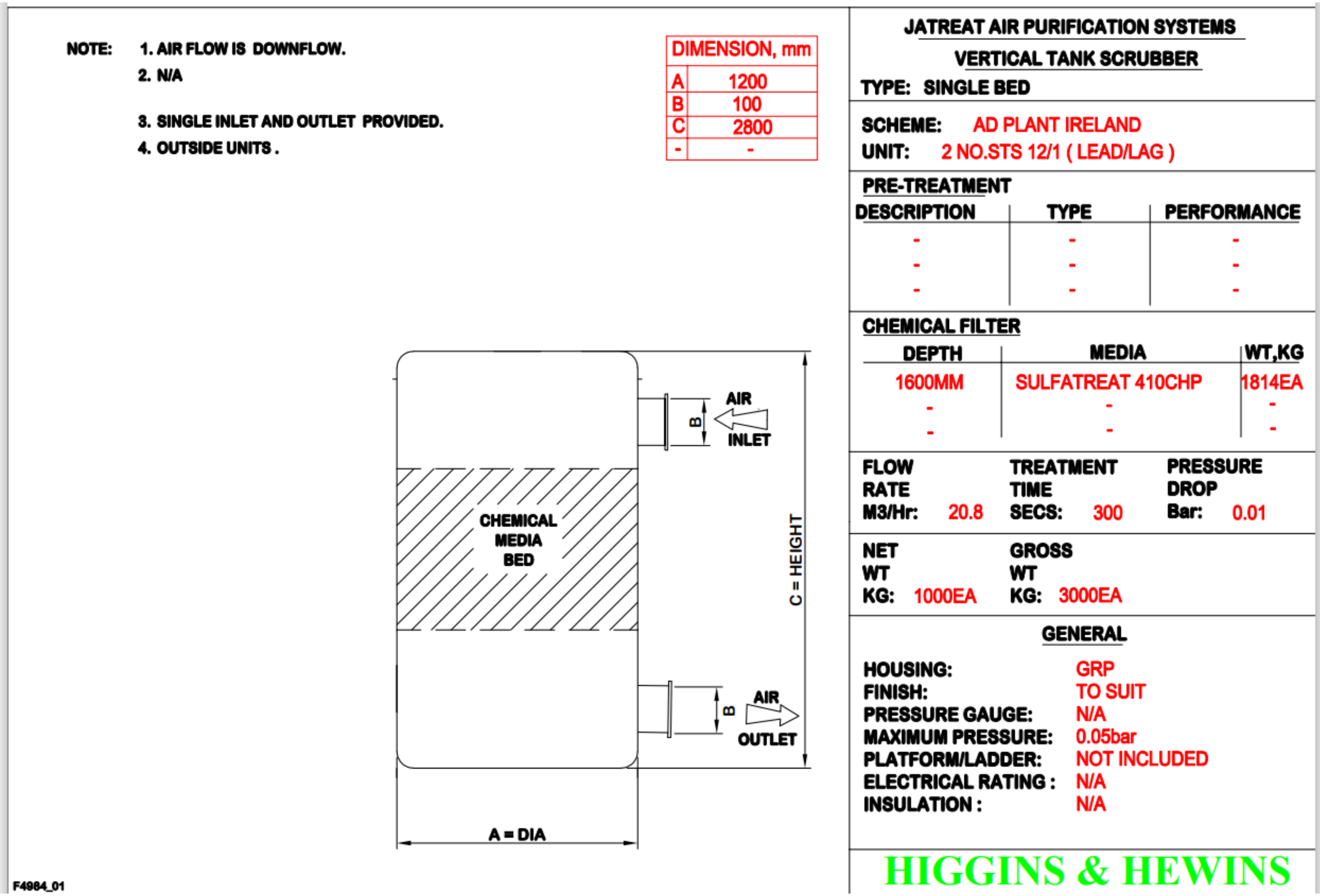
b. Gas Storage

TECHNICAL DATA

BIODOME MODEL GMB 08

Inner & Outer Membrane Type	Type 2
Outer Membrane Colour	White
GEOMETRICAL CHARACTERISTICS	
Inner & Outer Membrane Strength	4000 N/5cm
Height of BIODOME®	4.703m
Overall Diameter of BIODOME®	6.270m
Diameter at the Anchoring Point	5.430m
Volume of the BIODOME®	$100m^3$
Gas Pipe Connection Diameter	100mm
WORKING CHARACTERISTICS	
Design Operating Pressure	6mbar (+ / - 2mbar)
Over Pressure Valve Blow-Off Pressure	8mbar (+ / - 2mbar)
Max Biogas Temperature	55°C
Max Gas Flow	$100m^3/h$
Max Snow Load	$46kg/m^2$
Max Wind Load	140km/h

c. H_2S Removal Technologies



Air and Gas Purification Systems

TYPE: SULFATREAT- 410 CHP

AIR & GAS PURIFICATION MEDIA

GENERAL DESCRIPTION

SulfaTreat-410CHP safely and irreversibly removes Hydrogen Sulphide and other sulphur type odours from any air stream. SulfaTreat-410CHP is a non-corrosive, granular material that selectively treats Hydrogen Sulphide and light mercaptans (methyl and ethyl) in a batch type process. This high capacity product is unique in that it reliably and predictably functions in partial to fully humid air. SulfaTreat-410CHP is easy to handle and environmentally safe in both its un-reacted and reacted forms for easy disposal. All concentrations of Hydrogen Sulphide can be treated to virtually any outlet concentration desired. SulfaTreat-410CHP systems are extremely flexible, maintaining treatment during variations encountered in normal operation without operator adjustment. This product is also ideal for treatment of biogas (digester and landfill) and other streams that benefit from the very low pressure drops characteristics of SulfaTreat-410CHP.

APPLICATION

SulfaTreat-410CHP can be used in common drum, box, or tank type vessels. Entrained or condensed liquids should be removed in a separator, knockout, or drip pot, just prior to entering the vessel(s). SulfaTreat-410CHP is applied in fixed bed reaction vessels operated, preferably, in down-flow mode(helps prevent accumulation of condensed liquids). Bed depths can range from 450 mm, with good inlet distribution and outlet collection design, up to 12 meters deep. Larger flows may be best treated in multiple parallel flow operation. Higher concentrations of Hydrogen Sulphide may be best treated in lead/lag or reversible series flow. Computer aided design will specify the appropriate system and bed design, and process results, such as pressure drop, days to operate, etc.

PHYSICAL PROPERTIES

SulfaTreat-410CHP can be kept for an indefinite period of time under normal storage conditions without loss of effectiveness. Product can be stored outside if protected from weather elements. No special handling or environmental inventory is required being non-hazardous and non-toxic.

HANDLING

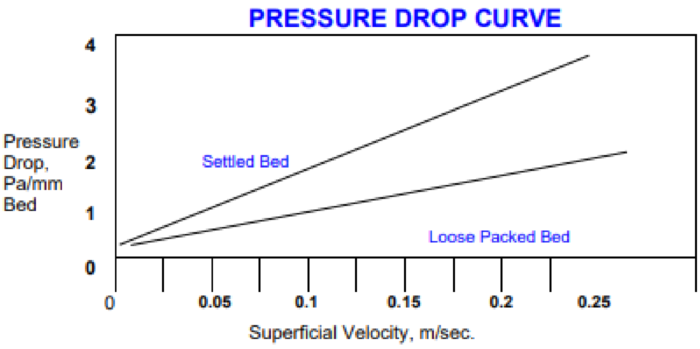
Shipping .... DOT Non-Hazardous

Apparent Density............... 1.0g/cc

Graded Granular Size....... 4 to 16 mesh

H_2S Removal Capacity...... Up to 25% by weight

Appearance & Odour....... Black Granular, Odourless



DISTRIBUTION & HANDLING

SulfaTreat-410CHP is available in 907 kg (2,000 lb.) super sacks from our Warehouse in Stourbridge, West Midlands. Higgins and Hewins will assist owners and contractors by specifying the appropriate SulfaTreat-410CHP system. Higgins and Hewins offer 320 ltr. odour control drums or pre-assembled drum packages that include blowers, in 11 and 23 L/sec flow capacity ideal for low flow "wet well" applications. Large systems can use custom design SulfaTreat Odour Control Units with a built-in separator/saturator section available for flows ranging from less than 1,700 to over 6,800 m³ /hr per unit, depending upon specified operating conditions. These low profile units are specifically designed for low pressure drop and even distribution across the beds.

Higgins and Hewins Limited

Titan Works, Stourbridge, West Midlands, DY8 4LR
Tel: 01384 397700 Fax: 01384 397701
Web site: www.handhltd.co.uk
E-mail: sales@handhltd.co.uk

MI SWACO

SulfaTreat - A Business Unit of M-I L.L.C. - 17998 Chesterfield Airport Road - Suite 215 - Chesterfield - Missouri - 63005 - USA
Tel: 636-532-2189 - Toll Free: 800-726-7687 - Fax: 636-532-2764 - info@sulfatreat.com

SULFATREAT ESTIMATED PERFORMANCE SHEET ('EPS')

CUSTOMER INFORMATION

Company:	HIGGINS AND HEWINS LIMITED		
Lease Name:	Nucleus V.P.		
Contact:		**Lease City:**	n/a
Phone:		**Lease State:**	
Fax:		**Lease Country:**	Ireland

OPERATING CONDITIONS

Gas Flow Rate (Nm3/hr):	20.8	**Gas Pressure (barg):**	0.03
Inlet H2S (ppm):	1,000.0	**Gas Temperature (C):**	30.0
Max. Outlet H2S (ppm):	10.0	**Water Saturation:**	100%
CO2 (Mole %):	35.0	**O2 (Mole %):**	0.00

REACTOR INFORMATION AND CONFIGURATION

Total Number Of Vessels:	2	**Inside Diameter (m):**	1.2
System Design*:	LeadLag	**Bed Height (m):**	1.6
Estimated Pressure Drop (bar):	0.01	**Min. S/S Height (m):**	2.8
		Vessel Loading (Kgs):	1,814.4

*Vessels are in trains of two

PREDICTED RESULTS		PRICE ESTIMATES	
Days to Max. Outlet H2S:	265**	**Product Selection:**	SulfaTreat 410 CHP
Sulfur Removed (Kgs):	200	**Product Price (USD/ lb):**	
Sulfur Removed (Kgs/day):	0.8	**Product Cost/Vessel (USD):**	
Gas Volume Produced (MMNm3):	0.13	**Cost/M Nm3(USD):**	
Gas Velocity (m/min):	0.32	**Cost/Kg Sulfur Removed (USD):**	

NOTES & SPECIAL CONDITIONS

Application County:	n/a	**Contact Email:**	

**Change one of the two vessels and reverse vessel sequence

ASK ABOUT OUR PRODUCT WARRANTY

Any Questions? Call

HIGGINS & HEWINS LIMITED
AIR & GAS PURIFICATION SYSTEMS
TITAN WORKS, STOURBRIDGE
WEST MIDLANDS
DY8 4LR, ENGLAND
Tel No. 01384 397700
Fax No. 01384 397701
E-Mail: sales@handhltd.co.uk

MI SWACO

SulfaTreat - A Business Unit of M-I L.L.C. - 17998 Chesterfield Airport Road - Suite 215 - Chesterfield - Missouri - 63005 - USA
Tel: 636-532-2189 - Toll Free: 800-726-7687 - Fax: 636-532-2764 - info@sulfatreat.com

SULFATREAT ESTIMATED PERFORMANCE SHEET ('EPS')

CUSTOMER INFORMATION

Company:	HIGGINS AND HEWINS LIMITED		
Lease Name:	Nucleus V.P.		
Contact:		Lease City:	n/a
Phone:		Lease State:	
Fax:		Lease Country:	Ireland

OPERATING CONDITIONS

Gas Flow Rate (Nm3/hr):	20.8	Gas Pressure (barg):	0.03
Inlet H2S (ppm):	500.0	Gas Temperature (C):	30.0
Max. Outlet H2S (ppm):	10.0	Water Saturation:	100%
CO2 (Mole %):	35.0	O2 (Mole %):	0.00

REACTOR INFORMATION AND CONFIGURATION

Total Number Of Vessels:	2	Inside Diameter (m):	1.2
System Design*:	LeadLag	Bed Height (m):	1.6
Estimated Pressure Drop (bar):	0.01	Min. S/S Height (m):	2.8
		Vessel Loading (Kgs):	1,814.4

*Vessels are in trains of two

PREDICTED RESULTS		PRICE ESTIMATES	
Days to Max. Outlet H2S:	532**	Product Selection:	SulfaTreat 410 CHP
Sulfur Removed (Kgs):	200	Product Price (USD/ lb):	
Sulfur Removed (Kgs/day):	0.4	Product Cost/Vessel (USD):	
Gas Volume Produced (MMNm3):	0.27	Cost/M Nm3(USD):	
Gas Velocity (m/min):	0.32	Cost/Kg Sulfur Removed (USD):	

NOTES & SPECIAL CONDITIONS

Application County:	n/a	Contact Email:	

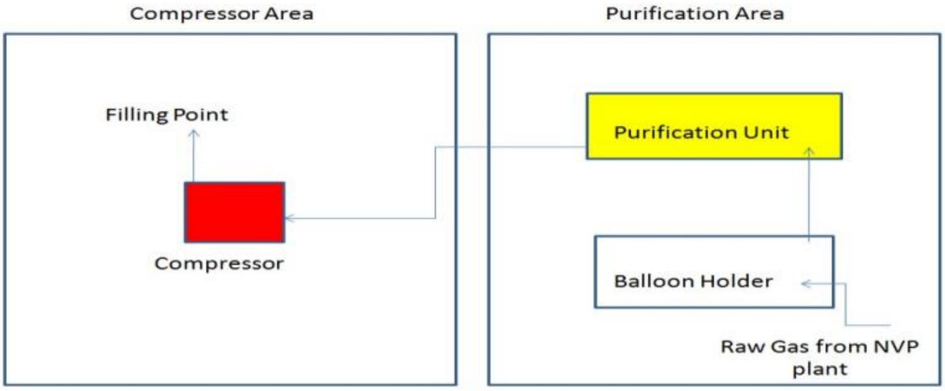
**Change one of the two vessels and reverse vessel sequence

ASK ABOUT OUR PRODUCT WARRANTY

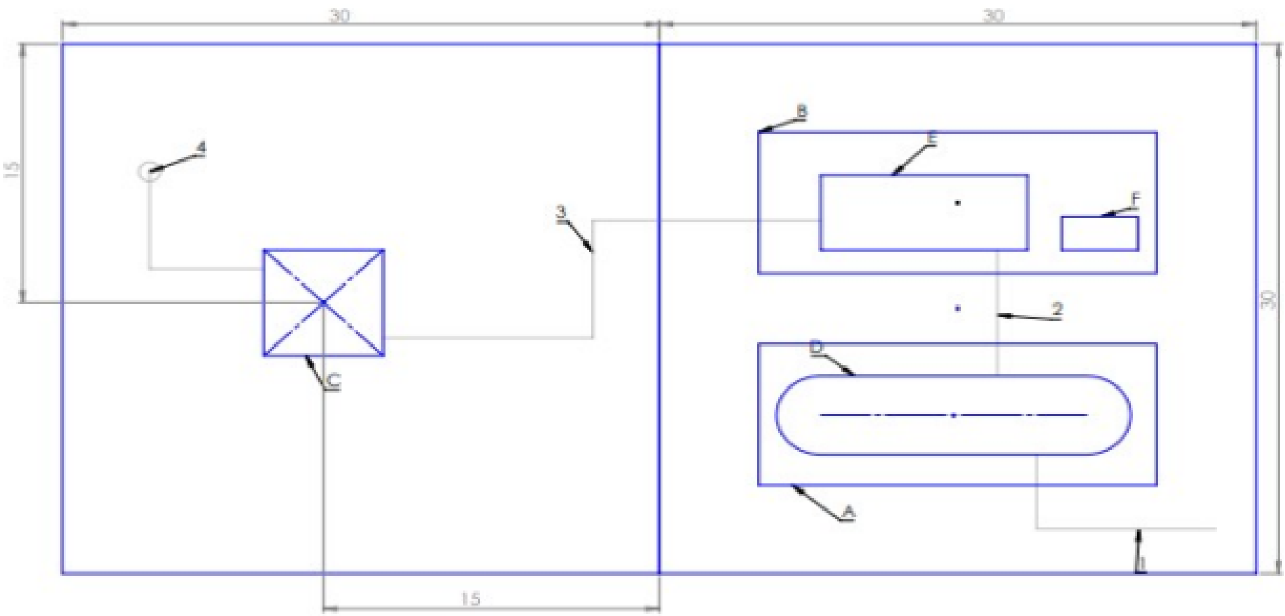
Any Questions? Call **HIGGINS & HEWINS LIMITED**
AIR & GAS PURIFICATION SYSTEMS
TITAN WORKS, STOURBRIDGE
WEST MIDLANDS
DY8 4LR. ENGLAND
Tel No. 01384 397700
Fax No. 01384 397701
E-Mail: sales@handhltd.co.uk

d. Gas Compression & Bottling Systems

Flow Diagram of POC



POC Space Requirement

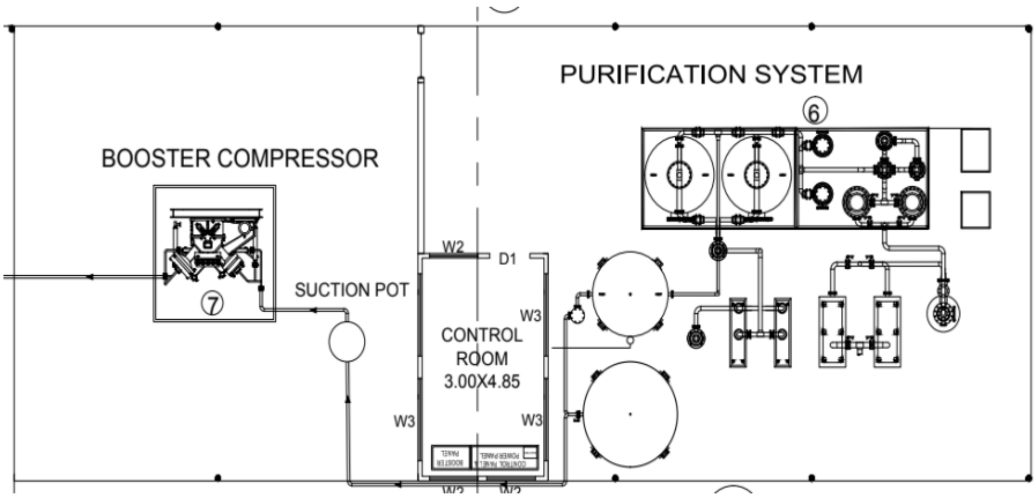


ITEM.	DESCRIPTION	QTY.
A	Container 1	1
B	Container 2	1
C	Booster Compressor	1
D	Bio-gas ballon	1
E	Purification Unit	1 Set
F	Control Panel	1 Set
1	Raw Gas Input line	1
2	Raw Gas line to Purification	1
3	Purified Gas line to Compressor	1
4	Filling Point	1Set

ITEM	DESCRIPTION	AREA in Sq Ft
A+B	Purificaion Area	900
C	Compression Area	900
Total		1800

1800 Sq Ft is approx. 170 Sq Metres

Layout of the Carbon Masters System




DESULPHURISER
AFTER COOLER


MPSA TOWER A
DRYER TOWER

e. Collection and Delivery potential to Gas Grid Injection Centres

Ti APM Technoimpianti apm

TECHNOIMPIANTI APM s.a.s.
: Via Lombardia, 8 - 24030 Medolago (Bg) – Italy –
Tel. +39(0)35.4948222 fax 4933535 C.F.e P.I. 02569840164
Visit our website: www.tiapm.it E-mail: info@tiapm.it

LPG/LNG/CNG/CO2 AND AIR GASES TANKS – ROAD TANKERS – ISO CONTAINERS

a) Design / Manufacturing

Volume :	52.500 litres (nominal)(*)
Design/Manufacturing code :	ADR2021 – EN14025 (tank will be π marked)
Testing agency :	Italcert (TPED Notified body #0426)
Outside diameter :	2.425 mm.
Total length :	12.900 mm.
Construction material :	P460NL1 Mod.
Shell thickness :	37,0 mm.
Heads thickness :	37,0 mm. a.f.
Tare weight Kg. :	33.400 Kg.
Natural gas payload :	≈2.600 Kg.
Semitrailer max height	3.950 mm.

b) Tank features

Cylindrical shape with elliptical heads
The tank is manufactured and approved according a code that foresees t :

- Drawing approval
- Checks of steel plates and materials
- 100 % radiographies
- Hydraulic test at 97.5 bar (working pressure at 65 bar)

c) Valves and accessories

The semitrailer is equipped with:

- N.2 safety valves setting at 90 bar with relative outlets upwards
- N. 2 fire-safe isolating valves DN 32 PN 100 for loading and un loading placed in a way to allow the operations on both sides of the semitrailer
- N.1 manometer
- N. 1 thermometer
- N. 1 flange DN 25 PN 100 placed in the rear head – upper side for venting
- N. 1 draining cap
- N. 1 manhole
- The supply includes a manifold for the unloading . On the manifold no. 4 valves 1" in parallel will be foreseen.

(*) tank dimension shall be optimized for road transport when fully laden, this value is valid for CNG with average density 0,75 kg/Nm3. In case of different value or biogas, capacity will be adjusted accordingly

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LPG/LNG/CNG/CO2 AND AIR GASES TANKS – ROAD TANKERS – ISO CONTAINERS

d) Semitrailer self-supporting chassis
Self-supporting chassis 3 fixed axles SAF Intradisc (9 Ton. per axle) in steel with high elasticity limit . Pneumatic suspensions , complete with :

- All fixed axles
- King pin 2" - Jost
- Rear protection guard complete with incorporated sizing lights
- Landing legs Jost Modul , 25 ton dynamic, 50 ton static
- EBS + RSS (Electronic Braking System + Anti reverting Braking System)
- Parking brakes
- Electrical plant as per ADR 2021
- Side lights
- N. 6 bright light alloy discs with n. 6 tires Continental 385/65 R22,5
- N.1 powder extinguisher 6kg in closed holder
- PVC tools box
- Warning labels and plates

Finishing
Inner tank cleaned and dryed with hot nitrogen
Tank outer surface:

- shot blasting grade SA 2,5"
- Primer coat and final polyurethanic coat
- Tank colour : white RAL 9010

Chassis colour : as per customer choice

Unit price Free Carrier Medolago (BG) – Italy	**€**	**182.000**

OPTIONALS FOR BIOGAS TRANSPORT
Modification of unit composed by inner tank coating for corrosion protection due to H_2S / CO_2 / humidity presence in gas mixture. Composed by (to be chosen among option 1 or option 1+2 – for raw biogas option 1 is strictly required):

Option #1 - Internal coating for corrosion protection (NEEDED FOR H_2S PRESENCE UP TO 2.000ppm)
Inner surface treatment:

- Degreasing with appropriate cleaner
- Sandblasting Sa3-SSPC-SP5 with anchoring profile 40÷50µm, using abrasives either synthetic or natural "Iron & Chloride Free"

ISO 9001 ISO 10014 Ti Apm *"Engineering in transport"*

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Tel. +39(0)35.4948222 fax 4933535 C.F.e P.I. 02569840164
Visit our website: www.tiapm.it E-mail: info@tiapm.it
LPG/LNG/CNG/CO2 AND AIR GASES TANKS – ROAD TANKERS – ISO CONTAINERS

- Ibrid nanotechnologic product "DuraPol UCR - DURAPOL" in one coat reaching a DFT 300÷400 µm
- After coat, the tank will be placed in a hoven at 100°C for curing
- Final checks:
  - Final aspect with non-destructive machinery Fischer Dualscope
  - Porosity absence test according NACE SP 0188 with spark test

Option #1 unit price	**€ 53.000**

Option #2 – Internal coating for corrosion protection (NEEDED FOR H2S PRESENCE UP TO 10ppm)
Sandblasting SA 2.1/2 (as per ISO 8501-1)
Ebonite type AP0030 installation, thickness 5mm ± 10%
N.B.: OPTION #2 INVOLVES UNIT TAREWEIGHT TO RAISE BY 900kgs

Option #2 unit price	**€ 32.000**

SALE CONDITIONS	
OFFER VALIDITY:	*30 days*
DELIVERY TERMS:	*FCA Medolago – BG – (Italy) – acc. INCOTERMS*
PAYMENT COND.:	*35% downpayment, balance by irrevocable confirmed L/C*
DELIVERY TIME:	*280 days from downpayment+L/C rec. (+30 days biogas opt.)*

We remain at your disposal for any further clarifications or requests.

Best regards.

TECHNOIMPIANTI A.P.M.
Ing. Marco Amantia

TECHNOIMPIANTI A.P.M. S.A.S.
ING. MARCO AMANTIA

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E. Potential Irish Stakeholders

a. Prospective Food & Drink AD Customers

Company	Industry	Location	Contact	Anaerobic Plans
ABP Food Group	Meat Processing	Armagh	Mr. John Durkin	Full Scale pilot in operation for several years
Arrabawn Group	Dairy	Galway	Mr. Conor Ryan	Full Scale pilot in operation for several years at Kilconnell. Reviewing anaerobic treatment for HQ, Nenagh.
Kerry Group	Dairy	Kerry	Dr Sean Pender	Reviewing onsite expansion of anaerobic wastewater treatment. CHP Onsite
Carbery	Dairy	Cork	Mr. Pat McCarthy	Onsite anaerobic treatment for high strength. Reviewing treatment for lower strength WW.
Glanbia	Dairy	Kilkenny	Mr. John Finlay	Tendering for anaerobic wastewater treatment.
Lakeland Dairies	Dairy	Cavan	Mr. Rory Farrell	No anaerobic, no plans in motion.
Dairygold	Dairy	Cork	Mr. John Bourke	Onsite anaerobic treatment implemented on one site but not 2 others.
Pepsico	Food and Drink	Cork	Mark Pettigrew	Anaerobic treatment reviewed but not impemented.

Table 2: Prospective Food & Drink AD Customers

b. Prospective Municipal AD Sites