Biomethane –
factors for a successful sector development

Synthesis Report of WP1 of the IEA Bioenergy Intertask project
"Renewable Gas: Deployment, markets and sustainable trade"

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factors for a successful sector development

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of the IEA Bioenergy Intertask project
Renewable gas - deployment, markets and sustainable trade

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Executive summary

Renewable gases (RG) will be key components of a global energy system aiming at net zero greenhouse gas emissions by 2050 (IEA 2021). The IEA World Energy Outlook (WEO) indicates that global gas demand will be decreasing in emission reduction scenarios. The range of scenarios on future gas supply up to 2050 is large, though critical factors are not only the level of ambition to decarbonize but also energy efficiency, structural changes in demand and competition between gaseous fuels and electricity, among others. Yet, there is overall agreement that renewable gases, led by biomethane and hydrogen (H_2), have critical roles to play in a decarbonized global energy system. Biomethane is the largest contributor to low-carbon gas supply in IEA's WEO scenarios and a key component of future energy technology developments. Biomethane is nearly pure methane and can be used without any change in natural gas transmission and distribution infrastructure or end user equipment.

Biomass potential: Biomass based energy carriers have the particular restriction that masses available for provision of energy are limited and the access is subject to restrictions (as sustainability) and competition. In general, the energy equivalent of available sustainable biomass represents a limited fraction of the overall energy demand and, consequently, bio-based renewable gas can be a significant contribution but cannot completely satisfy the overall gas demand. Development targets based on these potentials have to be chosen with care and consideration of the details.

Substrates: The evaluation of a survey within selected countries revealed that almost all countries which support anaerobic digestion (AD) incentivise the use of manure and waste materials. The use of energy crops is not as much common and even when eligible for incentives they are not utilized everywhere due to conditions of the incentive system. Energy crops are costly, and the use is discussed controversially, with sustainability aspects and land use being the main issues. Catch crops or intermediate crops avoid some of the issues with energy crops but are considered as a separate case only in Switzerland. The trend is away from the use of energy crops.

Technology: Biomethane provision based on AD processes is a proven technology with numerous applications worldwide – with a variety of substrates used and technologies for gas production, upgrading and utilization. In recent years major progress has been accomplished in the reliability and efficiency of the upgrading technologies. When looking at technology used for upgrading, an increasing market share of membrane separation technology in regards of number of plants is apparent.

Cost structure: Since biogas plants are highly individual and represent a compilation of many components and contractors, and as they are limited in size due to substrate supply and digestate logistics, the future overall cost reduction potential based on higher efficiency of components is limited. With cost reduction achieved by wind and photovoltaics, the gap to electricity production costs from biogas is getting bigger. As an effect, biogas-based electricity is more expensive and only economic with higher feed-in tariffs than for wind and solar. Currently, biomethane use is dominated by applications where the gas is utilized in combined heat and power units. Since upgrading and grid injection is costly for sites with substrate potential for only low capacities, specific costs are too high, and CHP will remain the technology of choice for such sites. In these cases, CHP shall then have a high heat utilization and flexible electricity provision to balance market prices and electricity grid of the future energy system.

Support mechanisms: Under current market conditions, biomethane is not cost-competitive to most fossil energy carriers, e.g., natural gas. However, the basis of comparison for renewable energy carriers in the future needs to consider the necessary reduction of CO_2 emissions, and therefore, the long-term the transition to a decarbonized economy requires CO_2 pricing. The transition process will change the overall demand in energy forms and carriers as e.g., electricity, gaseous and liquid fuels. Up to 2050, competition of technologies for producing gaseous energy carriers will be driven by overall demand, production costs (including CO_2 price), and availability of technical alternatives. Any support should consider the availability of necessary infrastructure and technology options for gas utilization.

Due to the current lack of a comprehensive and cross-sectoral CO_2 pricing, support for developing renewable gas needs to balance the shortfall between the revenues for the product and the financial effort for the production. There are numerous systems and approaches to incentivise the production or the utilization of biomethane. The decision for or against the investment are made by weighing potential financial profit, positive co-benefits, legislative hurdles, and technical risks. Major driver for the success of a support scheme is the chance for the entrepreneur to make a profitable business case. Technical risk and legislative hurdles might have a certain impact but are usually to be overcome if interest of stakeholders to build plants is given. Besides the willingness of the operators to invest, an obligation to implement renewable energy options for the energy traders and sellers is also a strong instrument to enable a market. With an obligatory development target for renewable fraction of the market, set e.g., by a quota, a defined market share for renewables can force a development. Whereas unregulated competition between technologies and sectors in the early phase of the development would hinder technology development, competition is needed in the long-term to reduce costs for the consumers and increase production efficiency. A proper timing of the shift from protected technology development phase to competition is crucial to avoid an early choke of the development or long-lasting high costs. In order to avoid "lock in" effects by allocating gas to specific sectors effects, any support system shall be compatible to other sectors of use. In the long-term any support mechanism shall be replaced by a competitive market scheme. Since the future market will be highly influenced by CO_2 prices (and the way how they are applied) and the reduction targets, conditions and prices will need to be adjusted until the reduction target has been reached and then market conditions will have stabilized.

Strategies for biomethane sector development: Strategies and incentives to develop the sector need to reflect the available substrates for biomethane production, the specific costs for the improved access of substrates and gas provision. Since the investment has usually long amortisation periods, the duration of temporal guarantee of the incentive is highly important. Biomethane can contribute but not satisfy the demand for renewable gas completely. Therefore, the interaction and compatibility with other measures as for instance the development of Hydrogen sector is highly recommended. Further on technologies which can be combined with biomethane plants as Power to gas units need to be included in the development strategy to capitalize on synergies and enable most benefit in regards of green-house gas abatement. Last but not least, consideration of existing and needed infrastructure (e.g., natural gas grids) shall be part of the strategies.

On the one side, future infrastructure measures should aim to strengthen the diffusion of renewable gases than to keep fossil energy sources alive. On the other side, the availability of infrastructure has a significant impact on how fast a renewable alternative can be implemented to replace a fossil energy carrier.

In conclusion, the following main fields of action for developing renewable gases can be identified:

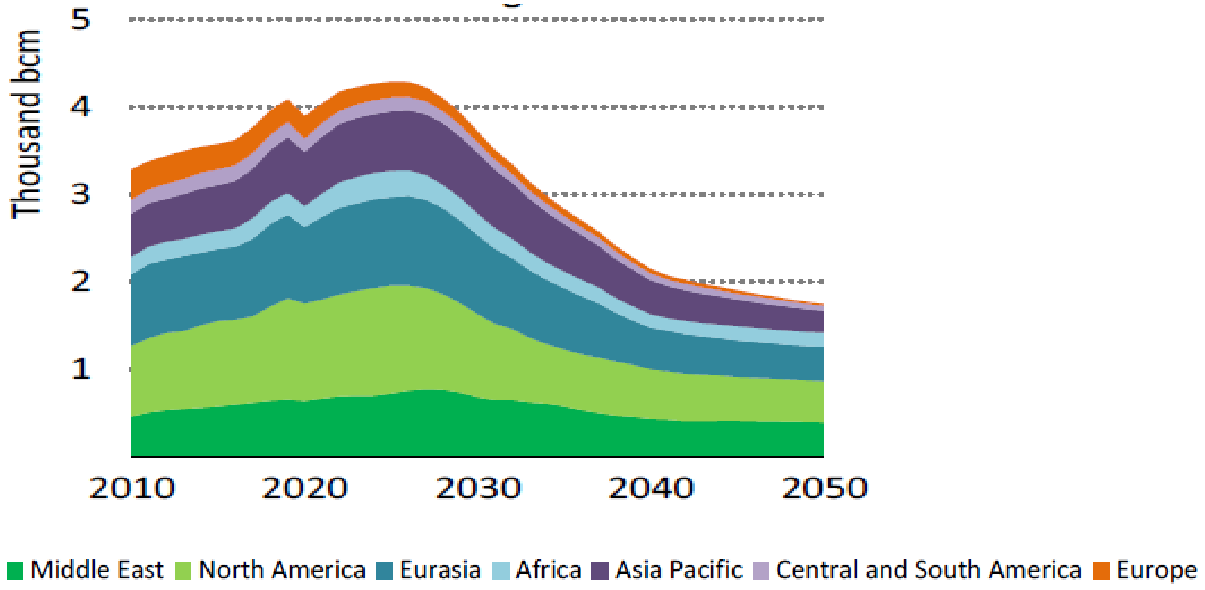
- Create strategies for biomethane sector development, including the consideration of available substrates and development costs, defined development targets and needed infrastructure
- Obligatory market implementation by means of a quota is the most effective way of introducing renewable gas under the current conditions
- Incentives which reflect costs and long-term operation (amortisation) conditions and provide a secure market environment for the run up of technologies
- Dismantling of inhibiting technical and legal regulations
- Compatibility with other measures to develop renewable gas and downstream technologies (e.g., PtG)

With all described complexity in sector-specific incentives and infrastructure considerations, it seems obvious that in the long-term, only a general system which sets a CO_2 price in all sectors will avoid many of the describes hurdles.

1. Introduction and background

Renewable gases (RG) will be key components of a global energy system aiming at net zero greenhouse gas emissions by 2050 (IEA 2021). With fossil gas supply peaking in the mid-2020ies and shrinking fast up to 2050 (Figure 1), RG will have to strongly increase.

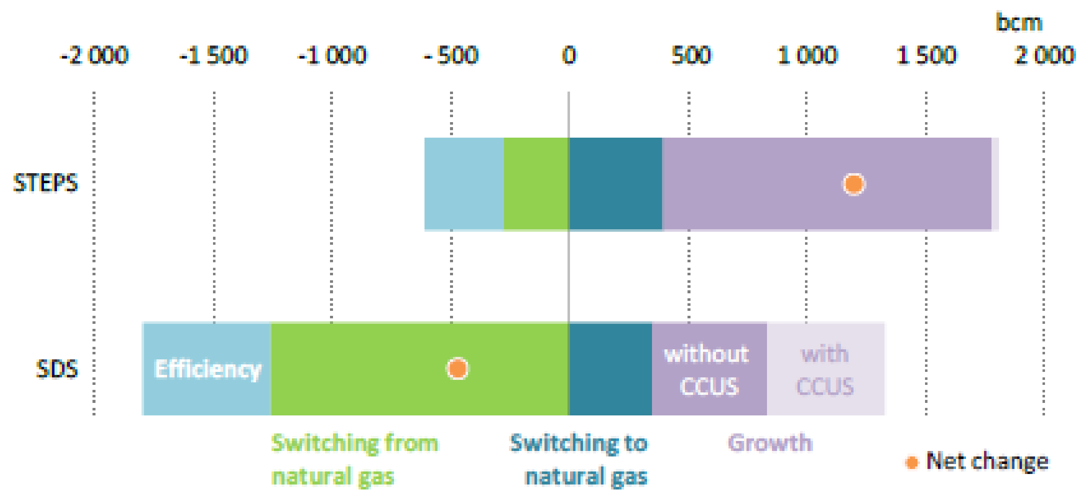
Figure 1 Global natural gas production in the IEA Net Zero Emission Scenario



Source: IEA (2021); bcm = billion cubic meters (approx. 40 PJ)

The IEA World Energy Outlook (WEO) provides scenarios up to 2040 (IEA 2020a), and also indicates that global gas demand will be decreasing in the "Sustainable Development" scenario (Figure 2), yet less prominently than in the more recent "Net Zero" case (IEA 2021).

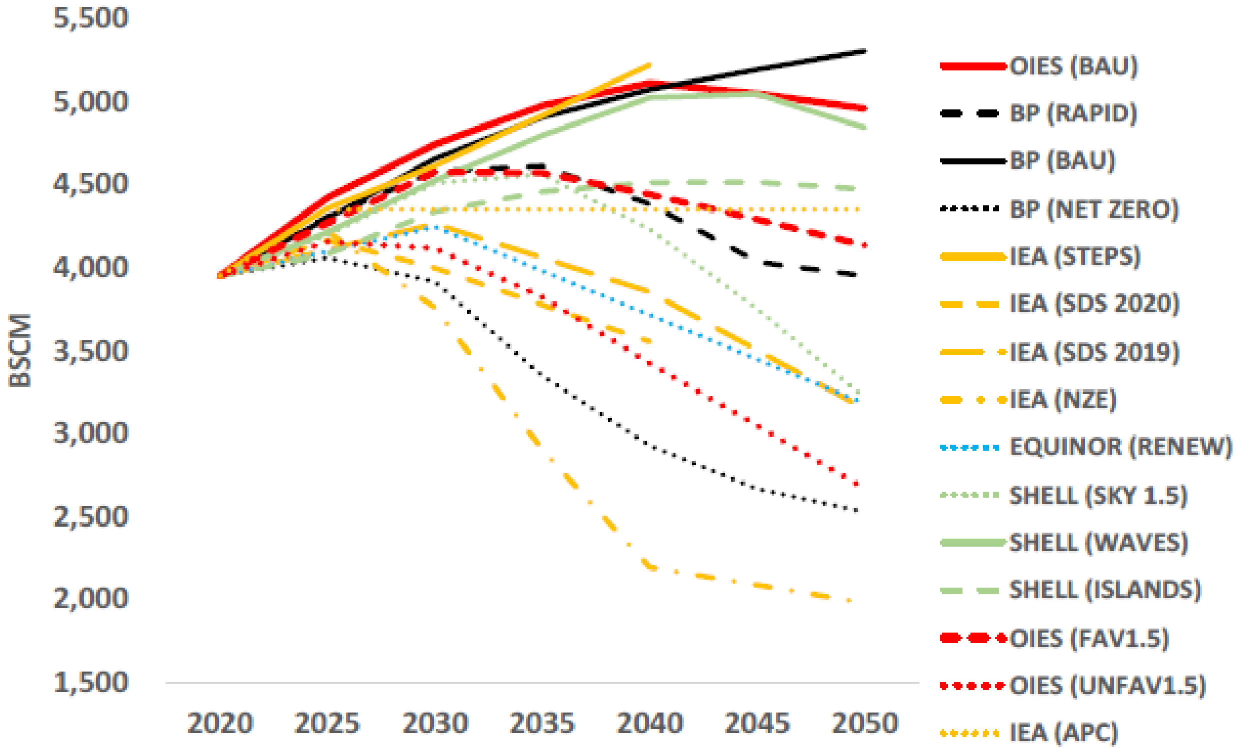
Figure 2 Changes in global natural gas demand from 2019-2040 according to WEO 2020



Source: IEA (2020a); STEPS = Stated Policy Scenario; SDS = Sustainable Development Scenario; bcm = billion cubic meters (approx. 40 PJ)

The range of scenarios on future gas supply up to 2050 is large, though (Figure 3) – critical factors are not only the level of ambition to decarbonize but also energy efficiency, structural changes in demand and competition between gaseous fuels and electricity, among others.

Figure 3 Selected Global Gas Demand Scenarios



Source: Fulwood (2021); BSCM = billion standard cubic meters (approx. 40 PJ)

Yet, there is overall agreement that renewable gases, led by biomethane and hydrogen (H_2)[1], have critical roles to play in a decarbonized global energy system (Harmse et al. 2019; OIES 2018 + 2021; Speirs et al. 2018).

Analysis from fossil fuel producers (e.g., GasNaturally 2019; Shell 2021) underlines that low-carbon gas use can also be achieved by applying carbon capture and storage (CCS), yet there are critical views to that (OIES 2021), and the share of CCS needed to achieve a net-zero energy system in 2050 is comparatively low (IEA 2021)[2].

Biomethane is the largest contributor to low-carbon gas supply in IEA's World Energy Outlook Scenarios (IEA 2020a) and a key component of future energy technology developments (IEA 2020b).

Currently, biogenic gases only play a small role in the global system, with Europe and China being the largest suppliers, followed by the US (Figure 4).

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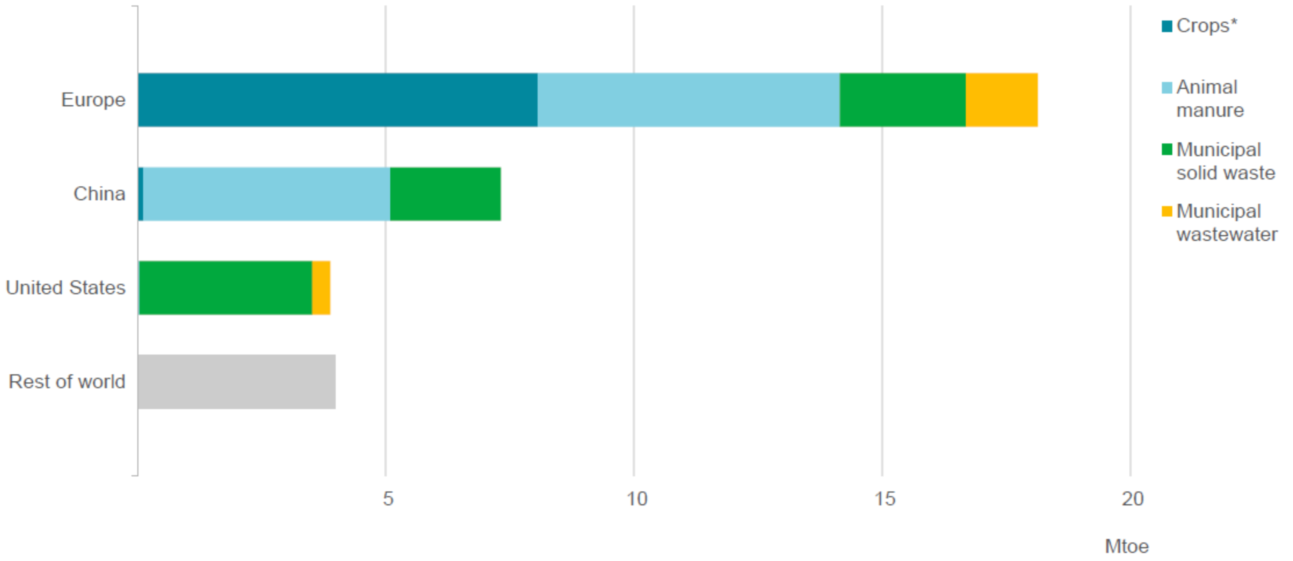
[1] The WP2 synthesis paper of the IEA Bioenergy Renewable Gas Intertask project deals specifically with hydrogen, see https://www.ieabioenergy.com/blog/task/renewable-gas-%e2%80%90-deployment-markets-and-sustainable-trade/

[2] There are many different views on the future role of CCS – and increasingly, "blue" H_2 from natural gas is discussed. This issue is covered in the WP2 synthesis paper on hydrogen (see footnote 1) and in Fritsche (2022).

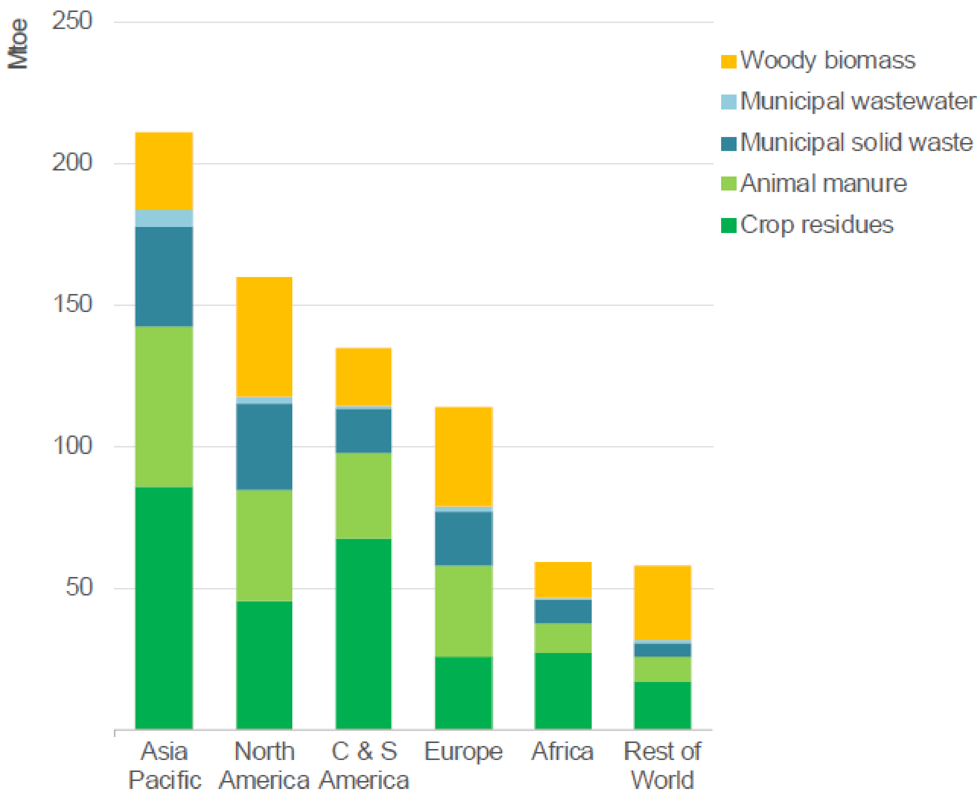
Figure 4 Biogenic gas production by feedstock type, 2018



*Source: IEA (2020c); Mtoe = million tons of oil equivalent (41.9 PJ); * = Crops include energy crops, crop residues and sequential crops*

The potential for biogenic gases, excluding dedicated annual crops, is shown in Figure 5 – Asian and American countries dominate, followed by Europe and Africa. More regionalized analysis on biogas is available (Dale et al. 2020; GBEP 2020).

Figure 5 Production potential for biogenic gases by feedstock source, 2018



Source: IEA (2020c); Mtoe = million tons of oil equivalent (41.9 PJ); C&S America = Central and South America. Woody biomass feedstocks are available only for biomethane production (through gasification or pyrolysis). Note that the potentials do not reflect mobilization restrictions, nor cost issues.

The two main options to decarbonize gas supply are biomethane[3] and low-carbon ("blue" or "green") hydrogen[4]. The latter received much interest in recent years, though currently, it is relatively expensive to produce (IEA 2019). Given that today there is not much infrastructure for dedicated H_2 transport, *existing* natural gas grids could be used to transport H_2 at much lower costs than those of new dedicated H_2 pipelines (IEA 2019).

Yet, unlike hydrogen, biomethane is nearly pure methane and can be used without needing any changes in transmission and distribution infrastructure or end user equipment (FE & IAEW 2019; IEA 2020c).

The following synthesis on the status and perspectives of biogenic renewable gases has thus a focus on the near- to medium-term and discusses the regulatory aspects of *biogenic* gas deployment.

2. Renewable gas and carbon intensity of gas

Renewable gases origin from a renewable source, such as biomass, wind or solar. They are energy carriers and the term includes a reference to gases for the purpose of utilization, which requires a defined quality standard (usually natural gas or hydrogen). In case of a combination of electricity-based hydrogen and CO_2 (for example to produce biomethane) the origin of the energy content of the gas defines if it is a renewable gas.

The impact on climate (resp. the carbon intensity) is a different characteristic and has to be looked at as an addition of contributions resulting from the source(s) of energy and the source of the CO_2. While carbon intensity can be calculated and is given in a number, the "renewability" has, so far, no such quantifiable criterion. The provision of biomethane (or synthetic natural gas (SNG) based on H_2 through electrolysis requires several processing steps and the energy supply to these process steps can also be a mix of renewable and not renewable.

3. Technologies for the production of renewable gases

Technologies for production of renewable gases in the sense of this document refer to Anaerobic Digestion processes, gasification and hydrogen production based on electrolysis. Hydrogen production from biomass is also included. However, the focus of the report is on biomethane based on upgraded biogas from Anaerobic Digestion, whereas the context of other options of renewable gases is considered.

4. Substrates

Biomass based energy carriers have the particular restriction that masses available for provision of energy are limited and the access is subject to restrictions (as sustainability) and competition. Therefore, any measure to access biomasses should – beside the overall potential of the biomass resource - consider the effect of the intended utilization in regards of sustainability, changes in the involved sectors (e.g., agriculture) and cost structure of accessing the biomasses to be used.

In general, the energy equivalent of available sustainable biomass represents a limited fraction of the overall energy demand and consequently biomass based renewable gas can be a significant contribution but cannot completely satisfy the overall gas demand. If biomethane provision is supported, countries give clear directions, which substrates are eligible for incentives.

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3 Biogas has a major role in replacing traditional fuels for cooking in developing countries and local cogeneration, see IEA (2020c) and IEA (2021).

4 Either as gaseous or liquefied H_2 or as renewable CH_4 from Power-to-Gas (PtG) schemes.

When looking at the energy potentials of the substrates it becomes obvious that the determination of masses and availability is dependent on many factors and assumptions and consequently the results of studies vary a lot.

In Table 1, several studies for Europe have been put together and key factors for the differing numbers are if gasification is included (European commission has not considered this) and the inclusion of sequential (only Gas for Climate) or intermediate (only Eurogas) cropping or energy crops (only European Commission).

More detailed factors of, such as the accessibility of substrates and related costs, are discussed for the example of manure in Liebetrau et al. (2021) and not considered here.

Consequently, development targets based on these potentials have to be chosen with care and consideration of the details.

Table 1 Europe's biogas and biomethane potential for 2030, 2040 and 2050, as calculated by the various studies

Study	Year	Biogas & biomethane production potential (bcm)	Biogas & biomethane production potential (TWh)	Biogas & biomethane potential production capacity (GW)
Current production	2019	18	193	33
Gas for Climate	2030	35	370	46
Eurogas	2030	35	375	47
European Comission	2030	44	467	58
Eurogas	2050	95	1,008	126
Gas for Climate	2050	95	1,020	128
IEA	2040	125	1,326	166
Cerre	No timeframe given	124	1,316	164

Source: EBA (2020)

The evaluation of the survey[5] with regard to which types of substrates are allowed to use in order to obtain incentives for the production of renewable gas (see Table 2), revealed that almost all countries incentivise the use of manure and waste materials.

The use of energy crops is not as much common and even when eligible for incentives they are not utilized everywhere due to conditions of the incentive system. Energy crops are costly, and the use is discussed controversially, with sustainability aspects and land use being the main issues. Catch crops or intermediate crops avoid some of the issues with energy crops but are considered as a separate case only in Switzerland.

Landfill gas is also not eligible in all countries for incentives. Substrates for gasification are also rather heterogenous incentivised.

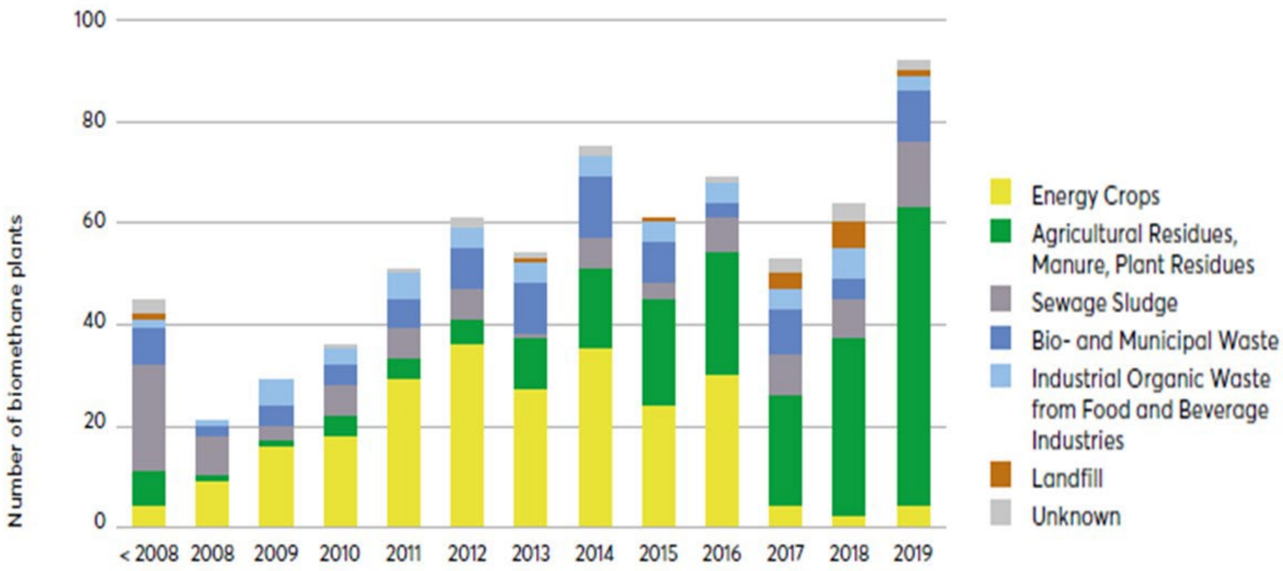
[5] Within an IEA Bioenergy Task 37 project, a questionnaire about the state of the art of renewable gases and biomethane has been send out. The following tables are based on the evaluation of the questionnaire responses.

Table 2 Substrates eligible within respective incentive systems

	Germany	Canada	China	Finland	Sweden	Norway	Estonia	Austria	Switzerland	India	USA	UK	Japan
energy crops	x	x		x		x	x	x				x	
catch crops (no main crop)	x	x		x		x		x	x			x	
agricultural residues and manures	x	x	x	x	x	x	x	x	x	x	x	x	x
municipal organic waste (separately collected)	x	x	x	x	x	x	x	x	x	x	x	x	x
organic industrial waste	x	x	x	x	x	x	x	x	x	x	x	x	x
landfill gas	x	x	x	x	x	x	x			x	x		
sewage sludge	x	x	x	x	x	x	x	x		x	x	x	x
Gasification: wood processing residues	x	x		x	x			x					
Gasification: waste materials	x		x	x	x			x					
Gasification: short rotation forestry	x			x	x			x					

Source: own compilation

Figure 6 Total numbers of newly installed biomethane plants each year, 2008-2019, overall and per main feedstock type



Source: EBA (2020)

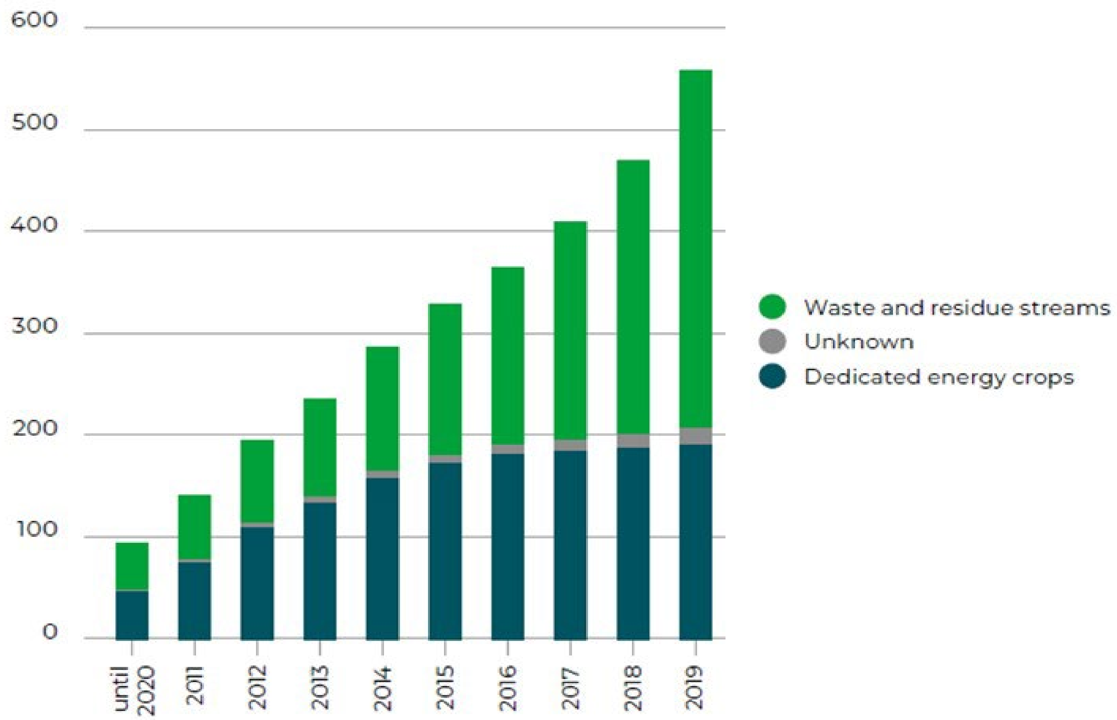
The controversy around energy crops resulted in change of incentive systems (in particular: in Germany) and this led to a trend away from the use of energy crops. This can be clearly seen in the share of energy crops on the substrate mix in plants in Europe (Figure 6).

On the other side, agricultural residues are gaining importance.

5. Technology for biomethane provision and utilization

Biomethane provision based on anaerobic digestion processes is a proven technology with numerous applications worldwide – with a variety of substrates used and technologies for gas production, upgrading and utilization. Figure 7 shows the growing number of biomethane plants in Europe and the share of substrates within these plants. Given the fact, that most of the 232 biomethane plants in Germany (EBA 2020) are based on energy crops, it is obvious that the European energy crop based biomethane productions is dominated by Germany.

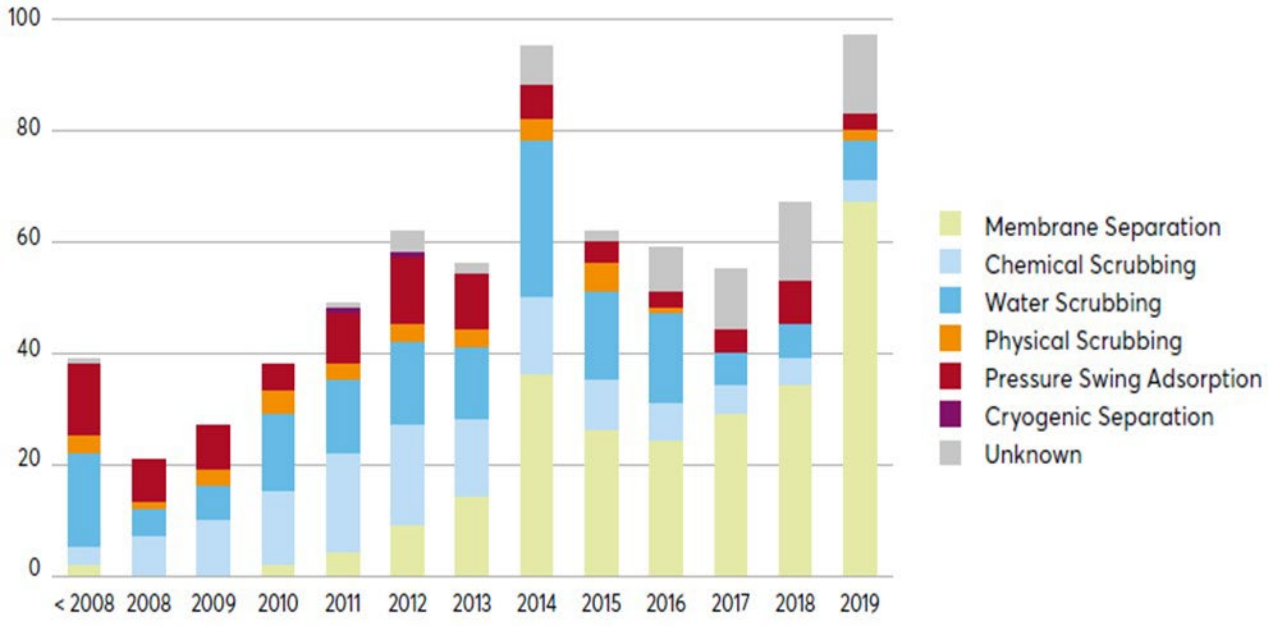
Figure 7 Number of biomethane production plants in the EU



Source: Wouters et. al. (2021)

In recent years major progress has been accomplished in the reliability and efficiency of the upgrading technologies. Figure 8 highlights the technologies which have been applied in the EU. The increasing market share of membrane separation technology in regards of number of plants is apparent.

Figure 8 Total numbers of newly installed biomethane plants each year overall and per upgrading technology (2008-2019)



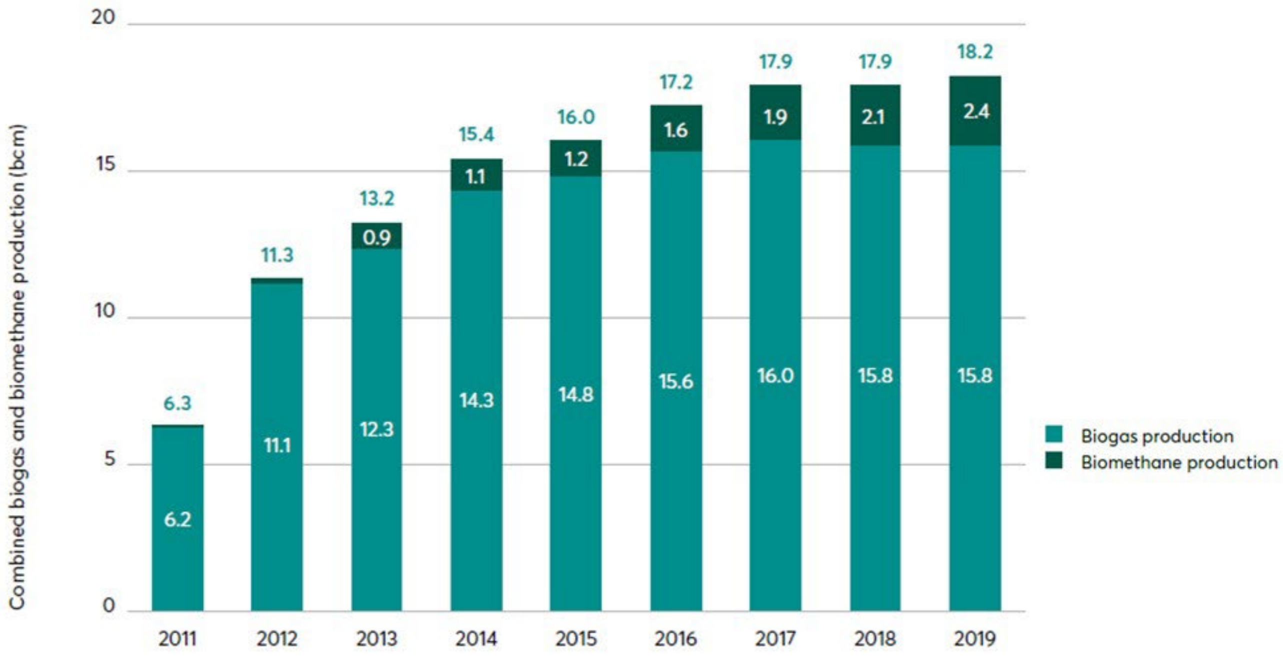
Source: EBA (2020)

Since biogas plants are highly individual and represent a compilation of many components and contractors, and as they are limited in size due to substrate supply and digestate logistics, the future overall cost reduction potential based on higher efficiency of components is limited.

With cost reduction achieved by wind and photovoltaics, the gap to electricity production costs from biogas is getting bigger. As an effect, biogas-based electricity is more expensive and only economic with higher feed-in tariffs than for wind and solar. Within the renewable gas sector, the situation is different, currently available alternatives are not necessarily cheaper and consequently the trend of biogas utilization is moving towards renewable gas applications. However, at the moment the sector is still dominated by applications where the gas is utilized in combined heat and power units (Figure 8). This has its reasons not only in the history of the development – biomethane as natural gas substitute has been incentivized later – but also in the fact that biomethane is more costly and therefore it was applied on sites with larger capacities to take advantage of economy of scale. Since the upgrading and grid injection is costly for sites with substrate potential for only low capacities specific costs are too high and the CHP will remain the technology of choice. In these cases, the CHP shall then have a high heat utilization and flexible electricity provision to balance market prices and electricity grid of the future energy system.

The share of biomethane capacities is increasing, illustrating the trend in most countries away from electricity provision towards renewable gas provision (Figure 9). For countries with a well-developed sector of plants equipped with CHP a major chance for the future is the transformation of suitable existing plants into biomethane plants.

Figure 9 Development of combined biogas and biomethane production in Europe 2011-2019



Source: EBA (2020)

The gas once upgraded to natural gas quality can serve as basis to provide transportation, electricity, heat or as material for chemical processes. The country-specific gas utilization depends on the target sector of the incentive system. Technically, in some regions the gas distribution grid limits the feed-in capacities due to low gas utilization in particular during times of low consumption of gas. In this case reverse flow stations could help to transport the gas from distribution to transportation grid level.

Due to different and in the course of time changing incentive systems, the development of the sector has been neither temporal steady nor evenly spread in the regions of the world. However, whenever conditions are in favour for biogas or biomethane sector, plants have been quickly built and the sector has been developing since experience and knowledge for reliable technology with a predictable constructions and operational costs are available.

6. Support mechanisms

Under the current market conditions the provision of renewable biomethane is not cost competitive to the provision of most fossil energy carriers, e.g., natural gas. However, the basis of comparison for renewable energy carriers in the future needs to be different than pure production costs for an amount of energy. The necessary reduction of CO_2 emissions requires additional instruments and therefore in the long-term the transition to a decarbonized economy requires a pricing of CO_2 of any kind.

The transition process will change the overall demand in energy forms and carriers as e.g., electricity, gaseous and liquid fuels. In a conceivable future competition of technologies for the production of gaseous energy carriers will be driven by the overall demand, production costs (including a CO_2 pricing) and availability of technical alternatives. It can be expected that this will lead to a completely new market for gases. For biomass-based gases the additional important restriction to be considered is the availability of resources. Last but not least, the development of the sector is highly dependent on political decisions how to organize the renewable energy provision.

The transition to a decarbonized gas sector will be gradually. Since the political decisions, prices, the demand and thereby the general development of the renewable gas sector are difficult to predict, firstly a selected variety of promising technologies should be supported to enable the run up of technologies and evaluate the progress of alternative technologies. Any support should also include the consideration of availability of necessary infrastructure and technology options for gas utilization. Due to the current lack of a comprehensive and cross-sectoral CO_2 pricing, a support for the development of a renewable gas sector needs to balance the shortfall between the revenues for the product and the financial effort for the production. There are numerous systems and approaches to incentivise the production or the utilization of biomethane.

Table 3 gives an overview over systems in selected countries – and the number of upgrading installations. It is obvious that a variety of support schemes are applied, and many countries apply several mechanisms – either specific to a region or an energy sector. Many countries have been developing successful biomethane applications - independent from the support mechanism.

Table 3 Overview over incentive systems in selected countries

	Germany	Canada	China	Finland	Sweden	Norway	Australia	Estonia	Austria	Switzerland	India	USA	UK	Japan
Feed in tariff	x		x	x					x		x			x
Feed in premium								x					x	
Quota/green certificates scheme	x	x						x			x	x		
Fiscal incentives		x		x	x	x		x	x	x	x			x
Investment support		x	x	x	x	x		x			x			x
Number of plants with upgrading and grid injection	219	11		4		13	0	1	14	39		109	113	several
Plants with upgrading, no grid injection	1		172	13	68	2	0	1	1	3		13		

Source: own compilation: x = yes

The support mechanism or incentive come into action at different points of the productions process - starting with the support of specific substrate utilization (e.g., incentives for manure utilization), the production process itself (investment support, feed-in tariff for the gas, quota systems for gas in the grid) and/or the final gas utilization (quota systems in specific sectors for gas utilization as transport, feed-in tariffs for electricity, tax exemption for target sector etc.). The support systems differ additionally in the resulting financial compensation, the one-time (mostly investment support) or operation related grant and in the latter case very important- the guaranteed period of the grant.

Beside many drivers to decide for or against a support system, the national specific energy supply situation drives the need to decarbonize specific sectors and leads to a national specific direction of biomethane utilization into varying sectors.

The decision for or against the investment are made by weighing potential financial profit, positive co-benefits, legislative hurdles, and technical risks. Major driver for the success of a support scheme is the chance for the entrepreneur to make a profitable business case. Technical risk and legislative hurdles might have a certain impact but are usually to be overcome if interest of stakeholders to build plants is given. Anyhow, most participants of the survey vote for economics when asked what hinders the market development most (see Table 3).

The vote within the survey is admittedly a subjective perception but the fact that all countries but one name financial reasons to be most hindering is a clear statement.

Combining this statement with the abovementioned incentive systems, it becomes obvious that for the development of a national industry the type of mechanism is not decisive, it is the fact if an economic business case is possible or not. In countries where the support for the installation is based on a realistic cost assessment and the legislative conditions do not represent a unbreachable obstacle, the sector develops.

Besides the willingness of the operators to invest, an obligation to implement renewable energy options for the energy traders and sellers is also a strong instrument to enable a market. With an obligatory development target for renewable fraction of the market, set e.g., by a quota, a defined market share for renewables can force a development.

Table 4 Major obstacles for further biomethane market development

	Germany	Canada	China	Finland	Sweden	Norway	Australia	Estonia	Switzerland	India	UK
Financial	x	x		x	x	x	x	x	x	x	x
Legislative (regulations regarding technology and plant operation)			x	x			x			x	x
Legislative (framework conditions other than financial and technological)	x	x	x	x			x				x

Source: own compilation: x = agreed

In the long-term any support mechanism shall be replaced by a competitive market scheme. Since the future market will be highly influenced by CO_2 prices (and the way how they are applied) and the reduction targets, conditions and prices will change until the reduction target has been reached and then market conditions will have stabilized. The run up of technologies to provide renewable gases needs to imply this transition into a market.

Whereas unregulated competition between technologies and sectors in the early phase of the development would hinder technology development, competition is needed in the long-term to reduce costs for the consumers and increase production efficiency. A proper timing of the shift from protected technology development phase to competition is crucial to avoid an early choke of the development or long-lasting high costs.

INCENTIVES AND UTILIZATION OF BIOMETHANE AND SECTOR SPECIFIC ABATEMENT TARGETS

Some countries decide to target - based on national, sectoral abatement targets - a specific gas utilization sector (e.g., transportation or electricity). The gas is directed with the incentive system and technical requirements to the desired sector. One aspect of the implementation is the certification or proof of eligibility measures – specific to the target sector, which are established on a national level. Due to the specific arrangement of these systems and a certain complexity, a quick redirection of produced biomethane to other sectors requires new procedures and conditions for eligibility – although technically the gas can be applied in many sectors. In order to avoid “lock in” effects, any certification system shall be compatible to other sectors of use.

7. Strategies for sector development

Many countries have recognized the high need for renewable gas as a major energy carrier for future energy systems. Currently the major focus seems to be rather on hydrogen than on biomethane, although many countries overwork or adjust their incentive systems for biomethane as well. In all countries the potential of available biomass (energy crops not considered) exceeds the currently used sustainable substrates by far, which means that there is room to increase biomethane production.

Strategies and incentives to develop the sector need to reflect the available substrates for biomethane production, the specific costs for the improved access of substrates and gas provision. Since the investment has usually long amortisation periods, the duration of temporal guarantee of the incentive is highly important.

Biomethane can contribute but not satisfy the demand for renewable gas completely. Therefore, the interaction and compatibility with other measures as for instance the development of Hydrogen sector is highly recommended. Further on technologies which can be combined with biomethane plants as Power to gas units need to be included in the development strategy in order to capitalize on synergies and enable most benefit in regards of greenhouse gas abatement.

Last but not least a consideration of existing and needed infrastructure (e.g., natural gas grids) shall be part of the strategies. On the one side, future infrastructure measures should aim to strengthen the diffusion of renewable gases than to keep fossil energy sources alive. On the other side, the availability of infrastructure has a significant impact on how fast a renewable alternative can be implemented to replace a fossil energy carrier.

With all described complexity in sector specific incentives and infrastructure considerations, it seems obvious that in the long-term only a general system which sets a price for CO_2 in all sectors will avoid many of the describes hurdles.

8. Major requirements to further develop the biomethane sector

Concluding the abovementioned statement, the following main fields of action for the development of renewable gases can be identified:

- Create strategies for biomethane sector development, including the consideration of available substrates and development costs, defined development targets and consideration of needed infrastructure
- Obligatory market implementation by means of a quota is the most effective way of introducing renewable gas under the current conditions
- Incentives which reflect costs and long-term operation (amortisation) conditions and provide a secure market environment for the run up of technologies
- Dismantling of inhibiting regulations on technical and regulatory level
- Compatibility with other measures to develop renewable gas sector and downstream technologies (e.g., PtG)

In the long-term the technology and sector specific support schemes need to be transferred into an overall market scheme resp. an economy where CO_2 emissions have a monetary value. According to reduction targets and technology development the price for CO_2 will develop and drive the transformation.

Such a system will include competition of technologies and shifts between energy sectors and consequently the phase out of specific incentives. Any incentive system set today shall be scrutinized for transferability into such a future economy.

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