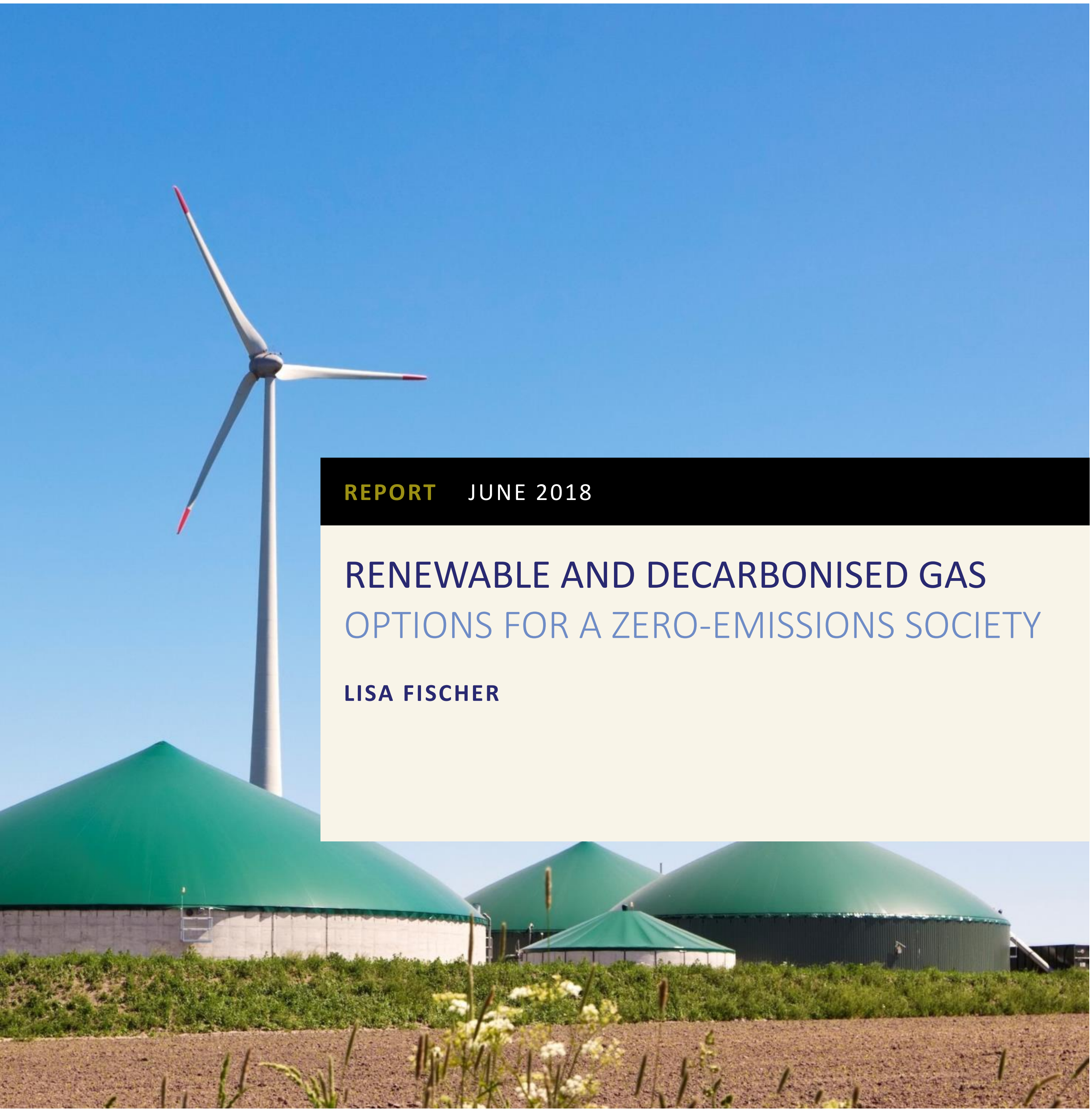
E3G



REPORT JUNE 2018

RENEWABLE AND DECARBONISED GAS
OPTIONS FOR A ZERO-EMISSIONS SOCIETY

LISA FISCHER

About E3G

E3G is an independent climate change think tank operating to accelerate the global transition to a low carbon economy. E3G builds cross-sectoral coalitions to achieve carefully defined outcomes, chosen for their capacity to leverage change. E3G works closely with like-minded partners in government, politics, business, civil society, science, the media, public interest foundations and elsewhere. In 2017, E3G was ranked the number three environmental think tank in the EU. **www.e3g.org**

Berlin office
Neue Promenade 6
Berlin, 10178 – Germany
Tel: +49 (0) 30 2887 3405

Brussels office
Rue de la Science 23
1040 Brussels, Belgium
Tel: +32 (0)28 93 92 12

London office
47 Great Guildford Street
London SE1 0ES, UK
Tel: +44 (0)20 7593 2020

Washington DC office
2101 L St NW
Suite 400
Washington DC, WA 20037
United States
Tel: +1 202 466 0573

REPORT JUNE 2018

RENEWABLE AND DECARBONISED GAS

OPTIONS FOR A ZERO-EMISSIONS SOCIETY

LISA FISCHER

CONTENTS

Summary

The deep decarbonisation of Europe's energy system changes the role of gas and the existing gas infrastructure. Achieving net-zero emissions does not leave room for unabated combustion of fossil gas.

In this briefing, E3G looks at the potential contribution of different options for 'renewable or decarbonised' gas to the decarbonisation of the energy sector. It assesses what each option means for gas infrastructure use and planning, alongside technical and economic potentials and compatibility with a net-zero economy.

It finds:

> **Europe should continue to innovate and explore different forms of renewable and decarbonised gas to test full potential and impacts**. However, not all forms of renewable or decarbonised gas are compatible with a net-zero emissions society.

> **The future prospect of renewable and decarbonised gases is no reason to slow down electrification or efficiency at this stage:** considerable levels of efficiency and electrification are needed in all scenarios that are compatible with the Paris Climate Change Agreement.

> **Big changes to gas networks are needed in the transition to a net-zero emissions society.** None of the Paris-compliant scenarios with renewable or decarbonised gas show increasing gas demand, and most of them show a sharp decline in gas volumes compared to today. This suggests there is no justification for the expansion of the gas networks, in particular not for imports.

> **Limited potential and – currently – unfavourable economics require defining where the use of decarbonised or renewable gases would be of highest societal value.** Focus should be concentrated on hard-to-decarbonise sectors.

> There is **currently no consensus on**

  - **which forms of renewable or decarbonised gas are most likely to succeed.** Each form of renewable or decarbonised gas comes with infrastructure challenges and choices of its own.
  - **which sectors would generate significant demand.** In many sectors, renewable or decarbonised gases would compete with alternatives such as fossil gas itself, electrification or demand side measures.

> **The EU's planning processes can become a guide for investors as to the future value of gas networks, by:**

  - giving sufficient granularity to distinguish between sources, production processes and end products for renewable and decarbonised gas, to reflect their differing infrastructure and climate impacts.

- developing scenarios that assess impacts of electrification, efficiency and renewable and decarbonised gases together to offer nuance between "all-electric" and "business as usual" scenarios.
- accounting for costs related to changes in infrastructure for the purposes of making the network fit for renewable or decarbonised gas.

Introduction

Political Context

Europe's demand for unabated fossil gas is set to decline drastically in the context of meeting its decarbonisation targets. Consequently, the focus for infrastructure development is shifting from gas to electricity. Several recent studies put forward the hypothesis of a future where renewable or decarbonised forms of gas replace fossil gas as an energy carrier[1]. They suggest that maintaining the significance of gas well into the future would enable the continued use of the existing network. Options to decarbonise gas could offer interesting potential for swifter decarbonisation of hard-to-electrify sectors, particularly in heavy industry.

However, there are large uncertainties on the technical and economic potential of renewable and decarbonised gas, the lifecycle emissions of these options and their infrastructure implications. Different studies demonstrated that there is no consensus on a future based on renewable or decarbonised gas yet:

- sources, processes or end products (e.g. methane or hydrogen) with very different climate and infrastructure impacts are considered.
- the same limited source of gas is allocated to different purposes (e.g. power sector, transport, heating or industry)[2].
- the competitiveness with alternatives such as fossil gas (all sectors), electrification (transport and heating) or demand side measures (heating, power sector) remains unexplored.

The assessment in this briefing seeks to expose choices for policy makers on sources and transition pathway based on the existing literature.

Methodology

To determine the potential contribution to a net-zero emissions society, we look at each form of renewable or decarbonised gas from the following angles:

a) **Is the technology compatible with a net-zero emissions energy system?** The EU has signed the Paris Climate Change Agreement and is currently adjusting its 2050 roadmap. The Paris Agreement envisages a net-zero emissions society by the second half of the century. This implies a faster pace of decarbonisation in the energy sector given the availability of technological solutions.

b) **What do we know about the technical potential compared to current level of gas supply?** Understanding resource constraints helps setting out the choices on

---

[1] For example, Eurogas, "The sustainability credentials for gas", 2018, available upon request on **http://www.gaswindandsun.eu/**, Pöyry, "**Fully decarbonising Europe's energy system by 2050**", 2018

[2] For example, the Eurogas study (Innovative Gas scenario) allocates more than 8 times of consumption to the transport sector compared to Ecofys' "Gas for Climate" study. Industry consumption of gas in the Pöyry study (Zero Carbon gas scenario) is about four times that of the Ecofys study.

highest value use of the resource. It also exposes what is needed to unlock the technical potential, e.g. in terms of research or strategic partnerships for imports.

c) **What do we know about the economic potential given competition from other energy sources?** The economic potential is determined by the competitiveness of renewable or decarbonised gases in the respective markets. For example, in the market for heating it competes with fossil gas or electrification, in the market for power flexibility with fossil gas, demand side response and interconnection amongst others. Understanding these markets will help develop an adequate policy framework.

d) **To what extent would the gas network need to change compared today?**

Gas network costs are a significant driver behind increasing gas prices for households.[3] At the same time significant investments in electrification, renewable energy and demand side measures are needed. Getting the decision about the future use and financing for infrastructure right is relevant for European citizens and industry.

This section looks at what the deployment of the different renewable or decarbonised gas options might mean for utilisation rates of the current network, for its shape and what changes to network planning might be required.

Benchmarks

Figure 2 Benchmarks for assessing decarbonised and renewable gas

	Green	Orange	Red
Net-zero emissions	Is or can become compatible with a net-zero emissions society.	Not compatible with zero emissions society but (potentially) substantial improvement on current carbon footprint of fossil gas.	No or little improvement on carbon footprint of fossil gas.
Technical potential	Production potential comparable to today's consumption of fossil gas.	Production potential not comparable to today's consumption of fossil gas but still considerable scale.	Production potential insignificant.
Economic potential	Competitive with fossil gas or other technical alternatives (depends on use).	Not competitive with fossil gas production or other technical alternatives (depends on use) but significant cost reduction potential.	Not competitive with fossil gas production or other technical alternatives (depends on use) and limited cost reduction potential.
Network impacts	Requires little to no modification of today's gas network.	Some modification of today's gas network required.	Large scale modification of today's gas network required.

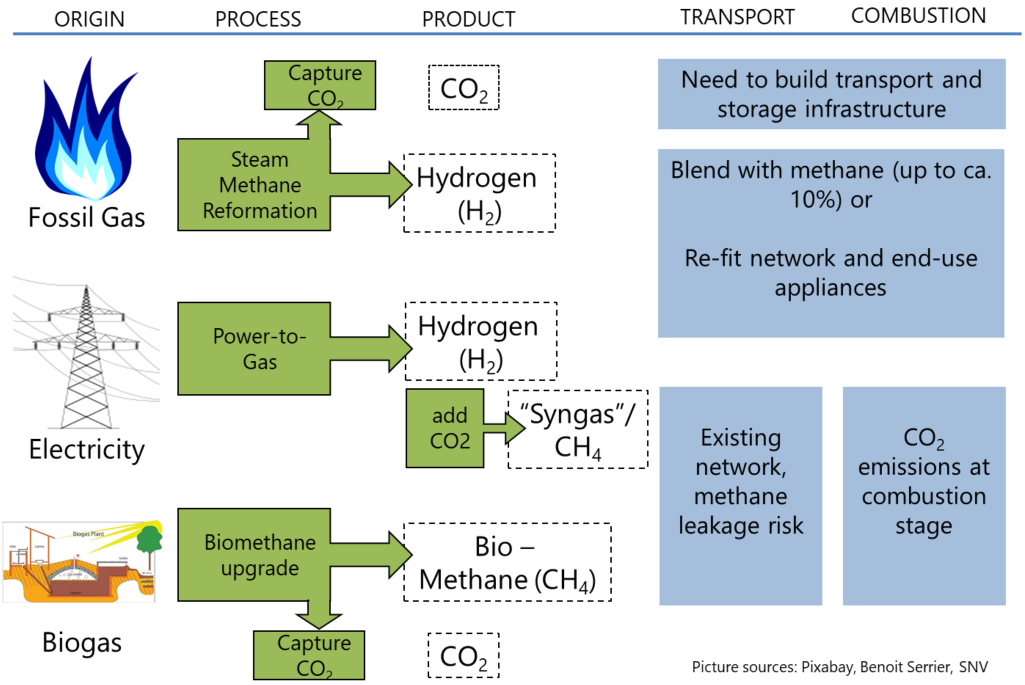
Source: E3G

[3] European Commission, **Energy prices and costs in Europe**, SWD(2016) 420 final, 2016

Defining ‘decarbonised or renewable’ gas

Several different terms are used to describe lower carbon gases – such as green gas, decarbonised or renewable gas. **Understanding the climate and infrastructure impact requires a close look at source and production process as well as at the end product.**

Figure 3 Forms of renewable and decarbonised gas



Source: E3G

Sources and production process

Steam Methane Reforming (SMR):

> Steam methane reforming chemically converts fossil gas into hydrogen (H2), thereby emitting CO_2.

> The product, hydrogen, is ‘decarbonised’ at the point of consumption but has residual CO_2 equivalent (CO_2e) emissions along the supply chain. Carbon capture and storage (CCS) technology can reduce some of the process emissions, but not those from fossil gas production and transport.

Biogas/biomethane:

> Biogas is produced from organic matter (e.g. farm and sewage wastes, wood pellets, energy crops) through anaerobic digestion. It can be upgraded to biomethane (CH4) by amongst others removing some of the CO_2, which needs to be offset or captured.

> There is also the pyro-gasification process, whereby biomass or prepared waste is converted into a synthetic methane via a thermochemical process. This is not yet used widely.

Power-to-gas (PtG) through electrolysis

> Can be produced from existing grid electricity or renewable electricity alone.

> Electrolysis uses electricity to split water into hydrogen and oxygen. The produced hydrogen can be used directly or converted into synthetic methane by adding CO_2 (*see box below*).

End products

The product of renewable and decarbonised gas can take the form **of hydrogen, synthetic methane or bio-methane**:

> Biogas can be upgraded to **biomethane** with the same characteristics of fossil gas, making it suitable for the existing gas grid. As it is methane, it still emits CO_2 at the point of combustion and carries the risk of methane leakage along the supply chain.

> SMR and PtG are both used to produce **hydrogen**. Hydrogen is a much smaller molecule than methane, meaning that pipeline networks, storage facilities and end-use appliances would need to be adapted for safe use.[4]

> Hydrogen can – technically - be converted to **synthetic methane** by adding CO_2. The methanation process reduces the need for network modification, but also efficiency (*see box below*).

Methanation of hydrogen

Methanation could remove the need for modifying the network infrastructure and end use appliances for hydrogen. Methanation brings efficiency losses of around 20% and significant additional costs.[5] The methanation process itself also requires large amounts of CO_2, which comes with significant drawbacks:[6]

(1) CO_2 sourced from industrial processes offers an opportunity to recycle a waste product. However, the CO_2 will eventually be emitted at the point of combustion, making it incompatible with a net-zero emissions society. To avoid building CO_2 transport infrastructure, methanation facilities would also need to be built near CO_2 production sites.

[4] A comprehensive analysis of the UK network: Dodds and Demoulin (2013), **Conversion of the UK gas system to transport hydrogen**

[5] Agora Verkehrswende (2018), **Die zukünftigen Kosten strombasierter synthetischer Brennstoffe**

[6] Bellona (2016), **Carbon Capture and Use in the EU ETS? – A risk of CO2 laundering preventing a permanent CO2 solution**

(2) The alternative, the use of "direct air capture", is at least currently a high cost technology with disproportionately high energy uses.[7]

[7] Evans, Simon (2017), **The Swiss company hoping to capture 1% of global CO2 emissions by 2025**, CarbonBrief. For cost reduction potential, cf. Ketih et al. (2018), **A Process for Capturing CO2 from the Atmosphere**

Assessment 1: Steam Methane Reforming (SMR)

Summary

Figure 4 Summary assessment of steam methane reforming in combination with carbon capture and storage

Steam Methane Reforming (SMR) + Carbon Capture and Storage (CCS)		
Net-zero emissions		CO_2 free end use if hydrogen, but emissions from fossil gas supply chain and reformation process that will be difficult to remove completely, even with CCS. Unlikely to be compatible with a net-zero emissions society.
Technical potential		Constrained by the availability of CO_2 storage sites.
Economic potential		Cheapest form of low carbon gas without CCS, but cost of CCS highly uncertain (current estimate at about 30% cost increase, i.e. not competitive with direct use of fossil gas)
Network impacts		• Hydrogen requires modification of network. • Requires addition of CO_2 transport infrastructure. • Utilisation rate of the network could remain high if enough carbon storage available.
Evidence needs Location and potential of CO_2 storage infrastructure.		

Source: E3G analysis

Detail

Compatibility with net-zero emissions

SMR is not a renewable energy source given it is based on fossil gas. The process of reforming fossil gas to produce hydrogen releases CO_2. This means that hydrogen from SMR without carbon capture and storage (CCS) has on average higher emissions (288 to 347 g CO2e/kWh) than from the direct use of fossil gas (230-328gCO2e/kWh).[8] First large scale SMR + CCS projects have capture rates of 80-90%, **falling short of a zero emissions objective**[9].

In addition, the production of fossil gas currently is characterised by **significant methane emissions along the supply chain. As a result, CCS alone is unlikely to bring emissions down to zero**. Upstream and downstream emissions from methane leakage would need to be managed during exploration and transport. Residual emissions for

[8] Sustainable Gas Institute (2017), **A greener gas grid – What are the options?**

[9] The two commercial SMR+CCS projects have capture rates between >80% (**Quest**) and 90% (**Port Arthur**).

steam methane reformers even with carbon capture and storage could range from 71 to 150 g CO_2e/kWh[10]. As such, **the compatibility of SMR - even with CCS - with a net-zero energy system is questionable.**

Technical potential

The technical potential of SMR with CCS is tied to availability of fossil gas reserves and the location and availability of storage for captured CO_2. Current estimates of the potential and location of CCS storage are indicative at best.[11] The availability depends on coordinated efforts among Member States to develop the storage.[12] It is likely to be a scarce resource in the EU which suggests a process is needed to identify the sectors for which the use of CO_2 storage is of highest societal value.

Economic potential

SMR in combination with CCS is the most cost-efficient option to decarbonise gas currently, but there are some clear limitations:

> **Using CCS adds to the cost of SMR** – early estimates indicate a price tag of ca 30%[13].

> **Given CO_2 storage is a scarce resource, its use should be prioritised towards the sectors where CCS is most needed**, e.g. where there are no other decarbonisation options. The use of SMR to produce hydrogen for industrial use or the maritime transport sector might be such a case, but the case is less compelling for residential heating or power generation. The economics can depend on local conditions, e.g. the proximity of CO_2 storage.

> **Converting to full hydrogen adds costs as it requires adaptation of the network.** Current regulatory frameworks apply limits to the amount of hydrogen in the system, in most places there is an upper bound of around 10%.[14]

> **While SMR is currently the cheapest form of low carbon gas, fossil-fuel based technologies are expected to have limited cost reduction potential** relative to the cost reductions estimated for electrolysis and biomass gasification.[15]

Gas network impacts

There is a choice between SMR and CCS closer to the point of production or to the point of consumption. In the case of the former, the gas network would be used to transport hydrogen, in case of the latter for the transport of fossil gas.

---

[10] Sustainable Gas Institute (2017), **A greener gas grid – What are the options?**

[11] Poulsen et al. (2014), **Assessment of CO2 storage potential in Europe**

[12] Littlecott, Attal (2012), **The CCS challenge - the practical potential for gas carbon capture and storage in Europe in 2030**

[13] Sustainable Gas Institute (2017), **A greener gas grid – What are the options?**

[14] Council of European Energy Regulators (2018), **Study on the Future Role of Gas from a Regulatory Perspective**

[15] Sustainable Gas Institute (2017), **A greener gas grid – What are the options?**

It can be more efficient to supply non-electrifiable heat demand with biomethane than to upgrade grids and end-use appliances across Europe to become hydrogen compatible.[16] In that context it would be best to concentrate hydrogen supply to sectors where it is currently without alternative, e.g. for industries that require high heat processes or segments of the transport sector that are difficult to electrify. In that case, the utilisation of the gas networks would be significantly reduced.

If hydrogen from SMR was to be transported through the existing gas network, this would require significant changes:

> **The use of hydrogen means the gas network needs to be converted to ensure safe use and transportation**.[17]

> To avoid additional CO_2 transportation infrastructure, **SMR plants would need to be located near CO_2 storage spaces of which potential and location are still to be determined.**

[16] Gasunie (2018), **Survey 2050**

[17] In Germany for example, the current regulation advises max 10% of the gas mix can be hydrogen for safety reasons.

Assessment 2: Biogas and Biomethane

Summary

Figure 5 Summary assessment of biogas/biomethane

Biogas/methane		
Net-zero emissions		• Requires strict definition of sustainability standards at plant and system level and clear rules for carbon accounting for biomass. • Emissions from upgrading process, transportation and combustion.
Technical potential		Estimated at 50-98 bcm by 2050, unless imported. This is about 10-20% of today's gas consumption. Higher estimates require intensification of agricultural use of land.
Economic potential		• Current cost (ca €100/MWh) is about 4 to 6 times higher than wholsesale gas prices. • Biomethane would only be able to compete with fossil gas if supported through specific policy instruments.
Network impacts		• Utilisation rate: it won't provide for the same utilisation of the network. • Depends on how much biomethane will be fed into the distribution and transmission grid at all instead of on-site consumption.
Evidence needs: • Cost reduction potential • Supply & consumption points compared to current network • Acceptable sustainability criteria and associated carbon balance and potential.		

Source: E3G

Details

Compatibility with net-zero emissions

The assessment of greenhouse gas emissions for biogas and biomethane is complex. Among the key determining factors at **plant level** are[18]:

> the choice of feedstock, its transportation and handling; for example, biomethane derived from energy crops has lower greenhouse gas saving than that from waste,

> the accounting of carbon sink effects from the product growth can cause big ranges in estimating CO_2 abatement potential,

> the specific production processes used including whether CCS is available,

> the amount of any methane leakage along the supply chain,

> any land use change effects from bioenergy crops used as a feedstock.

[18] Oxford Institute for Energy Studies (2017), **Biogas: A significant contribution to decarbonizing gas markets?**

In addition, **the systemic impacts** matter. For example, the Danish Climate Change Council stated that "Denmark already consumes much more biomass per capita than is likely to be sustainable if the rate were repeated on a global scale"[19]. In 2011, the UK's Committee on Climate Change identified that biomass use could cover maximum 10% of the UK's primary energy demand in view of global sustainability concerns and recommended to minimise imports.[20]

As a result, the range of estimates is huge; a literature review by the "Sustainable Gas Institute" cites estimates from -371 (in the case of combining it with CCS and accounting for carbon sink effects) to 504 g CO_2e/kW (beyond the average emissions of fossil gas).[21] **This highlights that sustainability criteria and accounting rules matter as well as a clear definition of which production models are truly in line with the Paris Climate Change Agreement**.

Technical potential

Estimating the technical potential for biogas and biomethane is similarly complex as estimating its greenhouse gas impact. The European Union estimates sustainable biogas production for the EU28 in 2030 at 28.8 to 40.2 Mtoe (ca 34 to 48 billion cubic meters/bcm).[22] For a time horizon until 2050, estimates only identify little additional potential: they range from around 50 bcm[23] up to 98 bcm[24] of biomethane if 35 bcm of synthetic gas from biomass pyrogasification are included. The potential of the latter is highly uncertain as it has so far not been deployed at commercial scale. It would have to compete with other uses for that sustainable biomass (i.e. biomass in the power sector or for heating).

Sustainability requirements play a key role in determining the potential for biogas. An early discussion of acceptability and criteria will both ensure public acceptance and help to determine the overall potential. For example, some reports suggest that in Germany two third of the sustainable potential is already exhausted.[25] Relying on waste products alone is likely to yield significantly better environmental credentials as there are no associated land use change impacts. However, the potential of waste alone is limited and will decrease with more efficient use of resources.[26]

Some studies identifying a strong role for biomethane in the future suggest a **double crop approach** – a study in France relies on increasing the use of "interseasonal" crops by more than 20 times[27]. This requires a significant intensification of agricultural use

[19]Klimaraadet (2018), **The Role of Biomass in the Green Transition**

[20] Committee on Climate Change (2011), **Bioenergy Review**

[21] Sustainable Gas Institute (2017), **A greener gas grid – What are the options?**

[22] European Commission (2016), **Optimal use of biogas from waste streams An assessment of the potential of biogas from digestion in the EU beyond 2020**

[23] Oxford Institute for Energy Studies (2017), **Biogas: A significant contribution to decarbonizing gas markets?**

[24] Ecofys (2018), **Gas for Climate**

[25] Fachagentur Nachwachsende Rohstoffe e.V., **BIOMASSEPOTENZIALE VON REST- UND ABFALLSTOFFEN Status quo in Deutschland**

[26] Sustainable Gas Institute, **A greener gas grid – What are the options?**, 2017

[27] Agence de l'Environnement et de la Maîtrise de l'Énergie (2018), **Mix de gaz 100 % renouvelable en 2050 ?**

and behavioural change. This scale of change is unlikely to come about without policy incentives and also needs to be considered from the point of view of sustainability.[28]

As an alternative, some studies suggest the import of biomethane[29]. This would bring the challenge of how to control and enforce sustainability standards, manage competition with food or habitats (cf. palm oil challenge), avoid double counting of carbon sinks or impact on the exporting country's decarbonisation efforts.

Economic potential

The use of biogas becomes cheaper if it is used directly instead of upgrading it to biomethane. The choice of feedstock and associated transport costs also play an important role. These can be negligible for readily available local waste, and substantial where energy crops are grown and transported over some distance.[30]

Some studies estimate the cost of biomethane production by 2050 around half today's cost (€50/MWh instead of €100/MWh).[31] This compares to current wholesale gas prices ranging from €15/MWh to €23/MWh in Europe.[32] The cost reduction in this case would come from technological development in thermal gasification alongside process and scale efficiency in anaerobic digestion. Current estimates suggest that a carbon price of €100/t CO_2e would be needed to provide competitiveness, with emissions trading prices until end of 2017 well below €10/t CO_2e.[33] **More generally, there is a need for further research into potential cost reductions and policy instruments to provide competitiveness with from fossil gas.**[34]

Gas network impacts

Biomethane – if upgraded from biogas – can be used in current gas networks, although some infrastructure modification may be needed. This could be to inject biomethane directly into transmission networks or to direct flows from distribution to transmission networks instead of the other way around. Agricultural centres that could supply large scale biogas are not always connected to the gas grid.

Upgrading to biomethane might make sense where this provides higher value to society than the additional costs from the upgrade. Currently, local use is prevalent

- from 2 to 49-52 MtMs

[28] Cf. the case of double-cropping adopted for electricity production in Italy https://www.researchgate.net/publication/305371248_Biogasdoneright_An_innovative_new_system_is_commercialized_in_Italy

[29] While not very specific on source and volumes, the Eurogas study relies on significant imports of biomethane and PtG. "The sustainable credentials of gas" (2018) http://www.gaswindandsun.eu/

[30] Oxford Institute for Energy Studies (2017), **Biogas: A significant contribution to decarbonizing gas markets?**

[31] Ecofys (2018), **Gas for Climate**

[32] For third quarter 2017 **https://ec.europa.eu/energy/sites/ener/files/documents/quarterly_report_on_european_gas_markets_q3_2017_final_20171221finalcover.pdf**

[33] ENEA Consulting (2017), **État des lieux du biométhane en France,** Business Green (2018), **Could Europe's €10 carbon price rise yet higher still?**

[34] Oxford Institute for Energy Studies (2017), **Biogas: A significant contribution to decarbonizing gas markets?**

to avoid additional costs and efficiency losses.[35] This might be outweighed where alternative decarbonisation options are hard to find such as for industrial use or in some cases for residential heating. It could also be the case where production potential exceeds local demand.

Biomethane alone however cannot guarantee a similar utilisation of gas networks as today. Based on current estimates, domestic biogas potential across Europe is at best a fifth of current gas consumption.[36] Some of it might be consumed locally instead of being injected into the gas grid. This could be complemented by imports, which will require a framework to ensure environmental integrity.

[35] Oxford Institute for Energy Studies (2017), **Biogas: A significant contribution to decarbonizing gas markets?**

[36] 2016 consumption in Europe was 510bcm (Eurostat). A study in France suggests that replacing all gas with biomethane is possible but relies on strong intensification of agriculture. Agence de l'Environnement et de la Maîtrise de l'Énergie (2018), **Mix de gaz 100 % renouvelable en 2050?**

Assessment 3: Power-to-Gas (PtG)

Summary

Figure 6 Summary assessment of Power-to-Gas from renewable energy

Power-to-Gas (from renewable energy)		
Net-zero emissions	H2 / CH4	*As hydrogen*: If based on entirely renewable energy, emissions from PtG are only from manufacturing processes of renewable energy. Extending the use of non-renewable electricity generation needs to be avoided. *If methanised:* CO_2 injected will eventually be emitted, even if sourced as waste product. Alternative sourcing process very energy intensive.
Technical potential	H2 / CH4	• It is linked to the scale of deployment of renewables and whether it uses "excess" or "dedicated" capacity. • So far, studies suggest limited domestic PtG potential, ranging from 24 to 30bcm, about 5-10% of today's gas consumption. Import volumes depend on renewable energy deployment outside Europe.
Economic potential	H2 / CH4	• PtG will compete against alternatives such as interconnection, demand side response or SMR+CCS. • The pace and scale of cost reduction will depend on dedicated policy measures to introduce PtG. *Methanation* would significantly add to the cost.
Network impacts	H2 / CH4	• Utilisation rate: PtG on its own will provide very low volumes of gas compared to today's gas consumption. • If used as hydrogen, the network would need to adapted to become hydrogen compatible. As *methane*, additional CO_2 infrastructure would need to be provided.
Evidence needs Where will the renewable capacity come from? Are deployment rates fast enought to avoid extended use of coal? What network adaptations need to be made for hydrogen (hydrogen storage, end use appliances)? Where would the CO_2 come from if methanation is considered?		

Source: E3G

Details

Compatibility with net-zero emissions

The carbon footprint of Power-to-Gas is largely a function of the carbon intensity of the source of electricity used.

> **Using grid electricity based on the current mix** (276g CO2e/kwh[37]) makes emissions comparable to using fossil gas directly - until grid electricity decarbonises.

> **Using renewable energy sources only** – either using "excess" electricity or by building dedicated renewable energy. Based on current manufacturing, CO_2e emissions from renewables electrolysis range from 25 to 178 g CO_2e/kWh.[38] As renewable energy manufacturing processes decarbonise, the carbon emissions of PtG from renewable energy are likely to reduce and become compatible with a zero-emissions energy system.

[37] EEA (2016), **CO2 emissions intensity**

[38] Sustainable Gas Institute, **A greener gas grid – What are the options?**, 2017

Technical potential

The potential for PtG from renewables is directly linked to the scale of deployment of renewables. If focused on using "excess electricity", it also depends on the level of interconnection and demand side response. For example, there is substantial benefit for the EU to foster interconnection, thereby reducing the amount of excess renewables for hydrogen production.[39]

So far, studies suggest limited domestic PtG potential, ranging from 24 to 30 bcm.[40] [41] Some studies suggest the possibility of importing significant quantities of hydrogen from outside Europe, e.g. North Africa.[42] This requires a fast acceleration of their own efforts to deploy renewable energy to avoid coming at the expense of their domestic decarbonisation.

Economic potential

So far, Power-to-Gas has not been deployed on a commercial scale in Europe, but several pilot projects are underway[43]. An analysis looking at the North Sea suggests electricity-based pathways are more attractive unless the price for hydrogen is high – at least in the medium term. [44] **The economics of PtG improve substantially if based on a continuous load rather than excess renewable production.**[45]

Without rapid cost reduction, PtG will only be able to compete if there are dedicated policy measures to introduce PtG.[46] PtG hydrogen would first and foremost compete with other ways of generating hydrogen, notably the much cheaper SMR. Costs depend on utilisation, the cost of renewable energy and the electrolysis process. PtG could benefit from the rapidly falling costs in renewables and economies of scale in if electrolysis deployment is scaled up.[47]

Gas network impacts

Like biomethane, PtG on its own is unlikely to achieve volumes of gas that are comparable to today's gas consumption. Import potentials are poorly understood but subject to the need of EU neighbours to decarbonise their own economies first.

[39] Newbery et al (2017), **Market design for a high-renewables European electricity system**

[40] Based on estimates from the Hydrogen Council (2017), **Hydrogen scaling up**: It expects that by 2030, 250 to 300 TWh (ca 30bcm) of renewable electricity could be stored in the form of hydrogen for use in other sectors. In addition, they expect that more than 200 TWh (ca 20 bcm) could be generated from hydrogen in large power plants to accompany the transition to a renewable electricity system.

[41] "Gas for Climate" talk about a potential equating to 24 bcm of hydrogen in methane energy equivalent by 2050

[42] Agora Verkehrswende (2018), **Die zukünftigen Kosten strombasierter synthetischer Brennstoffe**

[43] Among others: **Jupiter10000** - not constructed yet, **Falkenhagen**

[44] World Energy Council (2017), **BRINGING NORTH SEA ENERGY ASHORE EFFICIENTLY**

[45] Agora Verkehrswende (2018), **Die zukünftigen Kosten strombasierter synthetischer Brennstoffe**

[46] World Energy Council (2017), BRINGING NORTH SEA ENERGY ASHORE EFFICIENTLY & Agora Verkehrswende (2018), **Die zukünftigen Kosten strombasierter synthetischer Brennstoffe**

[47] Agora Verkehrswende (2018), **Die zukünftigen Kosten strombasierter synthetischer Brennstoffe**

The current network is not hydrogen compatible and would require potentially significant adaptations *(page 10)*. Given the limited potential a full conversion of the network for hydrogen compatibility might not be justified. Instead, electrolysis hydrogen could best be used directly for process heat or be blended in with biomethane.[48] If a world based on PtG from renewables is considered, a detailed mapping of renewable potential, sites for electrolysis (e.g. on- or offshore), most adequate storage and points of consumption would give a better understanding of the scale of the required infrastructure modifications.

The network impacts from PtG depend on whether it is produced domestically – either decentralised or centralised - or abroad. PtG production might be most obvious where it can feed from the regions of highest renewable energy potential in Europe close to hydrogen consumption points (e.g. industrial clusters on the shores of the North Sea). There is also the potential for hydrogen to be generated and consumed at local level, removing the need for transmission infrastructure to be adapted but losing economies of scale.[49] It could – in theory – also be imported from currently gas exporting countries with high renewable energy potential. Given the features of hydrogen it might be more likely to be transported via LNG tankers than via pipelines or after being converted to ammonia (NH3).

Methanation of Power-to-Gas hydrogen

Methanation of PtG hydrogen is possible theoretically and would remove the need to adapt the network for hydrogen. However, it requires large amounts of CO_2. The sourcing of CO_2 presents big barriers in terms of:

(1) infrastructure including developing dedicated CO_2 transport infrastructure,
(2) Direct Air Capture is at least currently a very high cost technology with disproportionately high energy uses.[50]
(3) compatibility with a net-zero emissions society (*see box on page 10*).

[48] Cf. the hydrogen plant planned next to Rheinland refinery, **http://www.itm-power.com/news-item/worlds-largest-hydrogen-electrolysis-in-shells-rhineland-refinery** or for steel manufacturing in Sweden **https://corporate.vattenfall.com/press-and-media/press-releases/2018/ssab-lkab-and-vattenfall-to-build-a-globally-unique-pilot-plant-for-fossil-free-steel/**

[49] A pilot in **Augsburg**, Germany is testing a closed-cycle project transforming excess rooftop solar into hydrogen and then methane. The efficiency of the methanation is expected to be higher (around 90%) because the heat from the methanation process can be used directly. The conversion to methane lowers efficiency but avoids the replacement or refurbishment of end-use appliances and storage facilities. The CO_2 from the use of the methane is captured and used to continue to produce methane from the hydrogen. There is no cost data available yet but ultimately this needs to be compared to alternative forms of decentralised electricity storage, such as batteries.

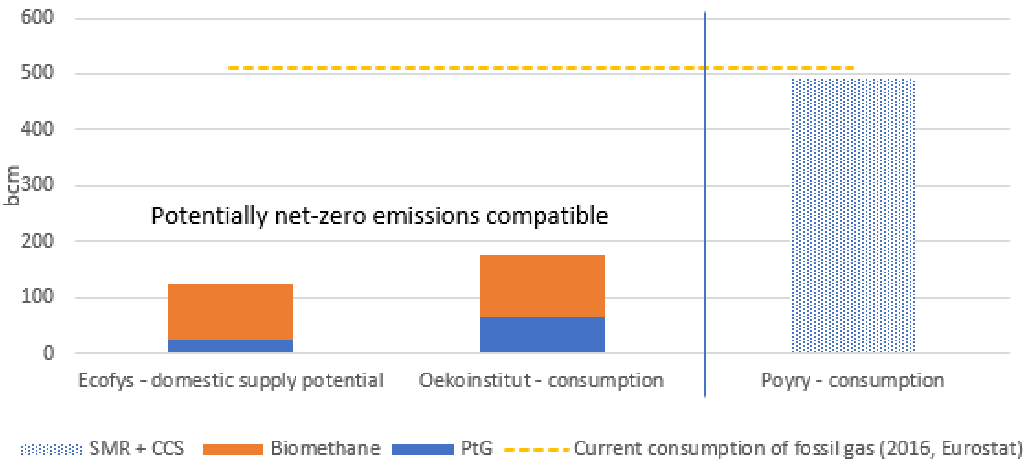
[50] Evans, Simon (2017), **The Swiss company hoping to capture 1% of global CO2 emissions by 2025**, CarbonBrief

Conclusions and Next Steps

There are several different options worth exploring on renewable and decarbonised gas. Yet, none of these are 'silver bullets' that allow business as usual to be continued.

The gas network will not face a further increase in utilisation rates even if decarbonised or renewable gas are developed at full potential. As a result, there is no need to further invest in the expansion of the gas network.

Figure 7 Renewable and decarbonised gas in 2050 (bcm)



Source: Ecofys, Ökoinstitut, Pöyry, Eurostat

It is worth noting that the inclusion of SMR+CCS might enable a transition to a significantly lower carbon, but not to a zero-carbon world. **Current estimates of the total potential of renewable gases that could in principle play a role in a net-zero society, i.e. excluding SMR+CCS, represent a fraction of the current fossil gas consumption, even in 2050.**

> Öko-Institut carried out a top down assessment for an energy system in line with the Paris Agreement. It estimates total hydrogen consumption 53 mtoe (ca 63 bcm) and biomass at 96mtoe (ca. 114 bcm), giving a total of 177 bcm of renewable gas.

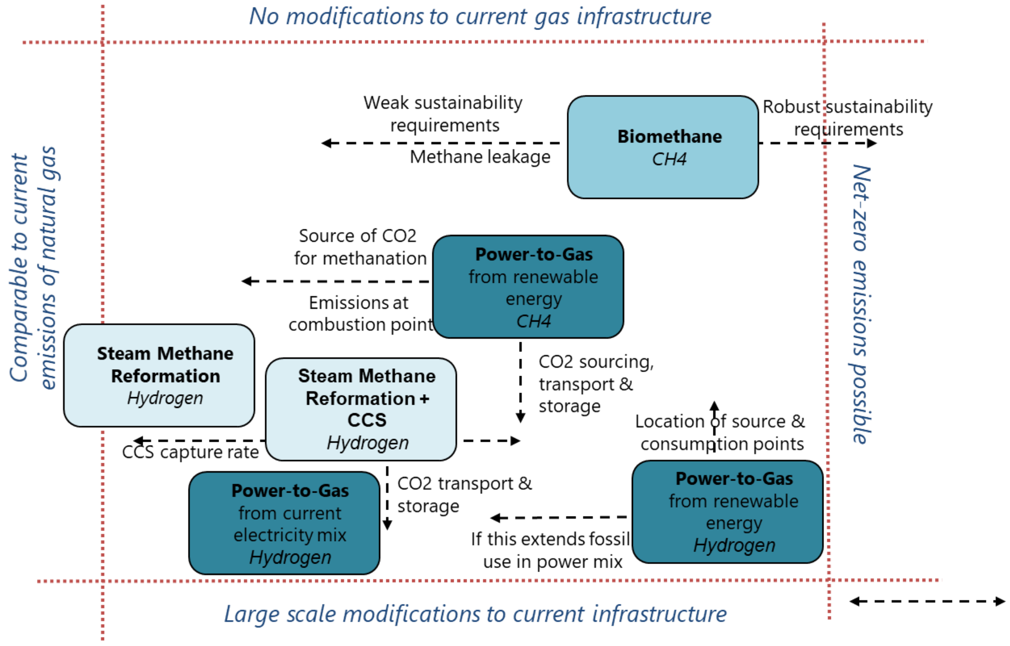
> The Gas 4 Climate study, also aiming at a net-zero energy system, estimates 98 bcm of biomethane and 24bcm from PtG, i.e. a total of 122 bcm total by 2050.

This compares to a current gross fossil gas consumption in 2016 at ca 510 bcm (17,903t TJ[51]), meaning that the gas networks could see a maximum of 30-40% of today's volume flow through if the option for full decarbonisation is pursued.

[51] Eurostat (2016)

The above estimates do not include potential volumes from imported biomethane or PtG. Imports would require cooperation mechanisms to ensure sustainability criteria are met in the case of biogas. For PtG, the currently gas-exporting countries connected to the EU via pipeline show little sign of large scale renewable energy development that would exceed their own decarbonisation needs. **Given current import facility capacities are already at twice the imported volume, the emergence of limited decarbonised gas import potential is unlikely to provide significant utilisation of import pipelines.**[52]

Figure 8 Clean and compatible?



Source: E3G

This shifts the focus towards decarbonised and renewable gas as a potentially important complement to electrification and demand side reduction rather than a separate pathway. Most of the renewable and decarbonised gas studies presented, even in their gas pathways, still rely on significant amounts of electrification, efficiency and demand side response.[53] Current developments indicate that a significant amount of electrification and demand side response will go ahead either way:

> Renewable electricity is expected to be consistently cheaper than fossil gas, let alone renewable or decarbonised gas before the end of this decade.[54]

[52] European Political Strategy Centre, **Nord Stream 2 – Divide et Impera Again?**

[53] Cf. Gas4Climate refers to an increase in the share of electricity in final energy consumption and “wide spread introduction of flexibility measures” Pöyry also foresees significant electrification in transport and to some extent in heating. Assumes considerable improvements in energy efficiency and much more flexible demand.

[54] IRENA, **Renewable Power Generation Costs in 2017**

> Cost projections for electric vehicles are on a steep downward trajectory[55] and residential heating is gradually being electrified. [56]

It is unlikely that points of production and consumption will match those of the gas network today. If the continued use of some of the gas infrastructure is considered, then the EU's and Member State network planning processes need to assess the following questions:

> *Point of production:* Is renewable gas expected to be produced locally, centralised (e.g. offshore wind resources) or even through imports. This will give an indication of the amount of gas entering the distribution and transmission grid and corresponding utilisation rates of transmission and distribution infrastructure.

> *Point of consumption:* Given the limited availability of renewable gas, which are the highest value sectors for consumption and where are they located? Which sectors do not provide for another decarbonisation alternative, e.g. through electrification? How does renewable and decarbonised gases compare with alternatives from electrification of heating and transport, or interconnection and demand side response in the power sector?

The end product matters - the suitability of the current network and the costs of the transition depend on whether hydrogen or methane are used. If hydrogen is used and stored for seasonal balancing, then the location and capacity of underground storage sites capable of storing hydrogen needs to be considered. End use devices will need to be upgraded as well as some of the compressor stations or transport infrastructure, the scale of that is yet to be assessed. The upgrade of hydrogen to methane means efficiency losses and added costs. It would need to be mapped against the availability of CO2 as a waste product from industrial production or consider the likelihood of Direct Air Capture becoming a feasible source of CO_2.

Cost effectiveness, cost trajectories and upscaling. While there is a steep downwards trend for some of the alternatives to renewable gas, e.g. battery costs or increased integration of electricity networks, the cost reduction trajectories for biomethane and PtG are speculative. With competition from both fossil gas and electrification it is unclear how decarbonised gas will achieve the scale suggested in the existing studies. Given renewable gasses are of significant value to some of the sectors hard to decarbonise, there is a value to continue pilots and research to improve the economic viability. Yet, this needs to be accompanied by an effort to minimise costs from maintaining extensive gas and electricity systems in parallel.

[55] Hodges, Jeremy (2018), **Electric Cars May Be Cheaper Than Gas Guzzlers in Seven Years**

[56] E.g. the Netherlands is moving to a fully electrified residential heating sector. Van den Ende, Eline (2017), **A revolution: The Netherlands kisses gas goodbye – but will it help the climate**, EnergyPost

Next Steps

To move from renewable and decarbonised gas as a hypothetical towards a deployable resource, the following questions need to be explored further:

> - **Understanding the suitability of the existing infrastructure**: Overall gas volumes will decline or stay the same at best, and points of consumption and future production will not be the same to today's network, including storage sites for hydrogen and carbon. This needs to be reflected in European and national network planning going forward to avoid unexpected drops in asset values. This also includes identifying infrastructure that may no longer be needed.
> - **From endpoints to pathways**: Most studies so far look at end points in either 2030 or 2050. Given the unfavourable economics and the infrastructure impacts of renewable and decarbonised gases, a next step is to map out policy and infrastructure pathways for the gas system. These would serve to define potential switch over of subsystems to hydrogen, decision points on when decommissioning of infrastructure is most efficient and market rules for the introduction and treatment of decarbonised gas.
> - **Understanding the choices**: As ultimately a scarce resource, renewable gas should be used in the highest value sectors. These need to be defined based on their social value, rather than the price of carbon alone. The guiding principle should be whether there are alternative options for decarbonisation or not. This means pathways alongside and not only instead of electrification should be explored in detail.
> - **Ensuring sustainability at plant and at system level:** Defining clear sustainability criteria for biogas/methane, application of best practice to minimise methane leakage along the value chain and developing methods for carbon accounting for biomass or potential methanation processes. For biogas and PtG from renewables there also needs to a consideration of land use and sustainability impacts at system level. Early dialogue and public debate of this will also pre-empt conflicts over the hierarchy of use of natural resources.