Greening your Biomethane Production Chain

A best practice guide for reducing greenhouse gas emissions

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Biomethane can be used in the same efficient and versatile manner as natural gas – for transportation, heat and electricity and in addition to this, the feeding of upgraded biogas, biomethane, into national gas grids offers a flexible energy solution to meet European renewable energy targets. Due to these advantages biomethane is becoming increasingly important on the political agenda and also as a business opportunity in Member States across the European Union (EU).

In several EU countries including The Netherlands, Germany and Austria, the use of biomethane has been in practice for several years and respective policy schemes are already in place. Other Member States are now following suit, however, developments are slow and strong support is still needed due to the complexity of the long value chains, lack of cooperation between involved stakeholders and cross-border trade barriers.

A successful European cross border biomethane market relies heavily on environmentally and economically sustainable production across the entire biomethane lifecycle. In addition to this, the biomethane market requires support in finding solutions to market barriers, bringing together potential business partners and most importantly, the promotion of biomethane into the mainstream by positioning it on the agenda of key EU gas/energy bodies.

The focus of this report is to outline the relevant sustainability criteria regarding biomethane production, the methods by which this can be assessed and thus evaluate methods of best practice in sustainable biomethane production.

The last section of the report highlights the recent changes from the European Commission regarding how Members should implement emissions from indirect land-use change (ILUC).
The rapid development of the global biofuels and bioliquids\(^1\) market has led to concerns over the environmental, economic and social sustainability of the industry. As a consequence, sets stringent criteria for assessing the sustainability of biofuels and bioliquids have been developed.

**RENEWABLE ENERGY DIRECTIVE**

The Renewable Energy Directive (RED)\(^2\) sets out in Article 17, 18, 19 and Annex V the sustainability criteria for biofuels and bioliquids. The legally binding criteria apply across the European Union (EU) and do not allow for additional criteria to be imposed by Member States.

All biofuels and bioliquids produced within the EU must comply with the sustainability criteria specified in the RED in order to receive government support or count towards mandatory national renewable energy targets. This includes the delivery of the Directive’s twin targets for 10% of EU transport fuels and 20% of EU energy needs to be sourced renewably by 2020.

The sustainability criteria aims to promote biomethane production in a sustainable form by focusing on several key areas;

- **Reduction in GHG emissions**
  - GHG emissions savings from the use of biofuels and bioliquids to be at least 35% compared to fossil fuels.
  - Rising to 50%, January 2017.
  - Rising to 60%, January 2018.

- **Biodiversity**
  - Raw material may not be obtained from land regarded/classed as having high biodiversity (after January 2008).
  - May include: primary forest, designated nature protection areas, highly biodiverse grassland.

- **Land of high carbon stock**
  - Raw material may not be obtained from land with high carbon stock (after January 2008).
  - May include: wetlands or highly forested areas.

**VOLUNTARY SCHEMES**

In order to facilitate the single market, the European Commission (EC) can assess existing voluntary schemes monitoring sustainability.

The EC selection process for Voluntary Schemes has been made on the compliance of the Certification Schemes (listed below) and whether or not they meet the mandatory sustainability requirements of the RED. In addition to the seven currently approved and recognised schemes listed below member states are also able to use their own Voluntary Schemes providing the EC’s requirements are met.

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\(^1\) Biofuels means ‘liquid or gaseous fuel for transport produced from biomass’. Bioliquids means ‘liquids fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass’.

• ISCC (International Sustainability and Carbon Certification);
  - Covers all types of biomass and biofuels;
  - Recognition for all criteria of the RED;
• Bonsucro EU (a standard for sugarcane based ethanol);
  - Focus: Brazilian sugarcane production;
  - Recognition for all criteria of the RED, except provision on highly biodiverse grasslands;
• RTRS EU RED (Roundtable for Responsible Soy);
  - Focus: Argentinean and Brazilian Soy Production;
  - Recognition for all criteria of the RED;
• RSB EU RED (Roundtable on Sustainable Biofuels);
  - Recognition for all criteria of the RED;
• 2BSvs (Biomass Biofuels Sustainability Voluntary Scheme);
  - Recognition for all criteria of the RED, except provision on highly biodiverse grasslands;
• RBSA (Abengoa RED Bioenergy Sustainability Assurance);
  - Recognition for all criteria of the RED;
• Greenenergy Brazilian Bioethanol Verification Programme;
  - Focuses on Brazil;
  - Recognition for all criteria of the RED, except provision on highly biodiverse grasslands.

BIOENERGY SUSTAINABILITY CRITERIA

SOLID AND GASEOUS BIOMASS SUSTAINABILITY

In order to comply with Article 17(9) within the RED the Commission was required to report on sustainability schemes for the use of solid and gaseous biomass for energy other than biofuels and bioliquids. The recommendations broadly follow the criteria in the RED focusing on several key areas.

• Protection of biodiverse land
• Protection of high carbon stock land
• GHG emissions savings (in % terms) as stated in the RED
• Differentiation of national support schemes in favour of installations that achieve high energy conversion efficiencies
• Monitoring of the origin of biomass

Despite initial indications of a potentially EU wide binding sustainability criteria for solid and gaseous biomass in electricity, heating and cooling, the criteria is still assessed solely through non-mandatory voluntary schemes.
All energy systems emit greenhouse gases (GHG) and thereby can contribute both directly and indirectly to climate change. It is now widely recognised that GHG emissions resulting from energy generation need to be quantified over all stages of production in order to monitor emissions, and in this instance promote sustainability. While accurate calculations of GHG emissions per kilowatt-hour (kWh) are often difficult, sound knowledge of lifecycle emissions can be an important indicator for mitigation strategies and identifying potential methods of best practice.

**LIFECYCLE ASSESSMENTS**

A Lifecycle Assessment (LCA) comprises of both environmental impacts and impacts on resource consumption, as well as covering the utilisation and end use of the product. This method allows every component of biomethane production to be assessed in terms of GHG emissions and resource depletion and thus helping to evaluate the sustainability of the entire process from feedstock production to biomethane injection.

**LIFECYCLE ASSESSMENT IN BIOMETHANE PRODUCTION**

A LCA of biomethane production has the potential to provide several benefits for the biomethane industry:

- Stops the problem of shifting environmental impacts
- Helps to minimise secondary effects if used in conjunction with design
- Helps to reduce environmental pollution and resource use
- Enables understanding of true and total costs
- Environmental management techniques (including LCA) may improve profitability.

Biomass is increasingly becoming a priority resource to substitute fossil fuels in the energy and transport sector, as is the need to ensure the process is sustainable.

Figure 1 briefly outlines each stage of biomethane production, the areas of potential GHG emissions and resource use associated with a range of inputs.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizers</td>
<td>Emissions to air</td>
</tr>
<tr>
<td>Herbicides and Pesticides</td>
<td>Emissions to water</td>
</tr>
<tr>
<td>Fuel</td>
<td>Emissions to land</td>
</tr>
<tr>
<td></td>
<td>Resource Consumption</td>
</tr>
<tr>
<td>Fuel</td>
<td>Emissions to air</td>
</tr>
<tr>
<td></td>
<td>Resource Consumption</td>
</tr>
<tr>
<td>Electricity</td>
<td>Emissions to air</td>
</tr>
<tr>
<td>Heat</td>
<td>Resource Consumption</td>
</tr>
<tr>
<td>Electricity</td>
<td>Emissions to air</td>
</tr>
<tr>
<td></td>
<td>Resource Consumption</td>
</tr>
</tbody>
</table>

Figure 1: Sources of GHG Emissions in Biomethane Production
The level of GHG emissions produced during biomethane production may vary according to the scale of the inputs (e.g. the amount of machinery or fertiliser used), as well as reflecting the sustainability of the methods of practice in place.

Figure 2 provides theoretical estimates to the GHG associated with each stage of biomethane production. As illustrated in this scenario (based on the use of maize as a feedstock) cultivation is the largest source of GHG emissions, accounting for between 10-60% of total GHG emissions. It is important to note that these are purely theoretical values for representation only.

Other sources of emissions relate to the biogas production process. The modern designs of anaerobic digestion (AD) plants attempt to ensure the ‘anaerobic’ nature of the fermentation process and minimise GHG emissions; both biogas production and biomethane upgrade are also significant sources of emissions. Emissions at these stages relate directly to the problem of methane slip (emission). It has been suggested that a methane slip of more than 2% is sufficient to reverse the positive environmental savings of biomethane when compared to other fossil fuels.\(^3\) Methane slip is a key concern for a number of reasons; the chemical properties of methane enable a longer atmospheric lifetime compared to CO\(_2\) (approximately 23 years) and mean it is more efficient at trapping heat in comparison to other GHG. For these reasons there is a strong focus on reducing methane slip through the implementation of different technologies, this not only has the potential to increase the overall sustainability of biomethane production but also minimises the impact on economic returns.

**EUROPEAN UNION RED LIFECYCLE MODEL**

Stages of biomethane production are detailed in terms of emissions by the European Union’s RED Lifecycle Model, as shown below:

\[
E_{\text{feedstock}} = e_{\text{ec}} + e_{\text{i}} + e_{\text{p}} + e_{\text{td}} + e_{\text{u}} - e_{\text{sca}}
\]

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\(^3\) BioGasMax. ‘Naturemade Biomethane Label’, 2010.
E = total emissions from the use of the product

e_{ex} = emissions from the extraction or cultivation of raw materials

e_{c} = annualized emissions from carbon stock change caused by land-use change

e_{p} = emissions from processing

e_{td} = emissions from transport and distribution

e_{u} = emissions from fuel in use

e_{sca} = emissions saving from soil carbon accumulation

Using the EU RED Lifecycle Model enables generators and other stakeholders to assess the emissions associated with biomethane production across the bio-energy lifecycle from cultivation to processing and grid injection.
CARBON BENEFITS OF BIOMETHANE PLANTS

The sustainability of biomethane plants is directly related to the potential GHG savings that biomass feedstocks offer in comparison to other fossil fuels. At present, the most common use of biogas is for electricity generation. However, it is argued that this will not be the case in the future, as the sustainability of biogas use will have a greater impact and therefore biomethane injection will be favoured.

Although biomethane production is a more efficient method of using biogas compared to electricity only production, due to the EU’s relatively carbon intensive electricity grid, biomethane gas injection has a lower carbon saving impact than using biogas for electricity generation.

Maximising the GHG savings from the use of biomass demands that it is converted as efficiently as possible into heat and/or power. Modelling has shown biomass feedstocks are able to demonstrate a range of GHG savings under “good practice” conditions.

In order to meet the EU sustainability criteria on biomass outlined in the RED, electricity generating facilities must achieve a GHG reduction of 35% or greater compared to the current European electricity mix. In some countries, such as the UK this target has increased to 60% (Figure 3). To meet EU criteria on biomethane, electricity-generating facilities must reach a GHG reduction target of 35%, in the UK, again, increasing to 60%.

Using the RED methodology modelling has demonstrated that AD plants are able to achieve a GHG reduction of at least 72% for biogas to electricity production, when acting under best practice. Further to this, with a heat recovery unit such as an Organic Rankine Cycle engine (ORC), electricity efficiency can increase further offering a reduction in GHG of over 80%. For biomethane plants the expected GHG emissions are approximately 60kg/CO₂/MWh.
**MODELLING THE LIFECYCLE GHG EMISSIONS OF BIOMETHANE**

**RED LIFECYCLE MODEL IN PRACTICE**

The RED GHG methodology has been developed to calculate the carbon intensity and GHG emissions savings of solid biomass and biogas used for electricity and heat generation. The methodology incorporates recommendations set out by the EC. This facilitates increased understanding of the breakdown of GHG emissions between the different supply chain steps in biomethane production and increases knowledge on how further cost-effective GHG reductions might be implemented.

**BENEFITS OF USING RED LIFECYCLE METHODOLOGY**

The RED methodology for LCA was developed for calculating the GHG emissions from solid biomass and biogas used to generate heat and electricity, and covers every step from feedstock production through to energy generation. This enables bioenergy generators and other stakeholders to analyse the life cycle emissions from bioenergy using different feedstocks, production processes and transport methods. Member states that adopt this methodology will:

- Help bioenergy generators to report emissions consistently and fairly
- Fully compatible with the RED for calculating GHG emissions
- Takes account of recommendations set out by the EC
- Fully assess the performance of crops feedstocks for AD in terms of targets for improving life cycle emissions.

As illustrated in Figure (4) the use of the RED methodology allows the lifecycle GHG emissions to be calculated for each stage of biomethane production. Figure (4) uses typical default values for a variety of feedstocks.

![Figure 4: Percentage Lifecycle Emissions by Feedstock](image)

- Silage Grass
- Whole Crop Maize
- Organic Whole Crop Maize
- Whole Crop Wheat
- Sugar Beet
- Wet Manure
- Dry Manure

Cultivation & Harvesting
Transport & Distribution
Production of Biogas
Biomethane Upgrade
Biomethane Injection
The GHG emissions are quantified as a percentage of the total emissions related to each stage of biomethane production. As shown, all energy crops indicate that the highest proportion of GHG emissions are sourced from cultivation and harvesting, representing a minimum of 40% of total GHG emissions. Whereas, using manure as the feedstock shows biomethane upgrade as the highest contributor of GHG emissions, however a greater quantity of manures and slurries will have to be processed to make the equivalent amount of biogas produced by a small amount of crop. In both cases biomethane upgrade is also highlighted as a large GHG source, being the second highest “emitter” for crop based feedstocks.

The UK Carbon Calculator developed from the RED methodology assumes the default value for methane slip of 0.01MJCH4/MJ of biogas produced. This value can however vary depending on the level of best practice adopted. This will be explored further later in the document.

Figure 5 shows the total GHG emissions in terms of carbon intensity (g CO2eq/MJ biomethane) for each stage of the LCA as well as the total GHG emissions produced for each feedstock. Whole crop wheat feedstock is seen to produce the highest levels of GHG emissions, in contrast to using dry manure, which produces the lowest levels of GHG emissions. This is likely to be due to the use of fertilisers in crop based feedstocks contributing a significant proportion of emissions in the harvesting and cultivation stage in comparison to manures which are considered to have “zero emissions”.

![Graph showing lifecycle greenhouse gas emissions by feedstock](image-url)
Predictions suggest that the global biogas market is projected to reach US$8.9 billion by the year 2017 according to a report by Global Industry Analysts. Europe is still considered the dominant player in the market, yet India is poised to emerge as the fastest growing regional market. While this growth is welcome, it has prompted an influx of questions regarding sustainability in the AD industry. For this growth to be managed safely best practice methods will need to be implemented in order to promote and allow sustainable biomethane production to continue.

REDUCING EMISSIONS THROUGH BEST PRACTICE

Greenhouse gas emissions from biomethane can be calculated based on scenarios of ‘best’ and ‘worst’ practice – having reviewed industry practices these have been inputted into the model.

GHG emissions from biomethane production can be affected by a number of factors. In order to generate the best and worst cases were considered for the following parameters:

- Yield
- Moisture content
- Quantity of digestate used
- Quantity of artificial fertilisers used
- Transportation distance of feedstock
- Efficiency of the biogas digester
- Methane emissions associated with biogas production
- Methane emissions associated with biogas upgrade
- Electricity use for biomethane injection into the grid

Operators are able to use member state default values to calculate carbon intensity based on the values set out in the EC Report. The EC’s default values for GHG savings for the various biomass feedstocks can be used in combination with the actual conversion efficiency of the plant, thereby allowing users to input their own information. When using the default values the user must ensure that they use the correct default value for their feedstock.

The second option is to calculate the carbon intensity based on ‘actual values’ obtained from industry and operator experience. If the actual value method is used, a more accurate calculation can be made of the carbon intensity of the biomass fuel being used. This approach also helps give a greater understanding of the lifecycle emissions.

Table 1 indicates the potential difference in GHG emissions as a result of best and worst practice biomethane production with the use of maize as a feedstock. Adjusting the figures for best and worst practice has a substantial effect on the level of GHG emissions produced in the biomethane production process. Notable changes occur to the emissions level in the cultivation and harvesting stage of production. Similarly the second largest source of emissions, biomethane upgrade, has a highly varied total emissions produced depending on the scenario, reflecting the importance of monitoring areas of methane slip.

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The difference between best and worst practice total emissions is over 37 g CO$_2$eq/MJ biomethane, which highlights the potential boost that best practice methods can provide. These results are also presented in Figure 6 and Table 1 alongside the best and worst case GHG emissions scenarios for both silage grass and sugar beet. In all cases the worst practice scenarios all produced higher levels of GHG emissions.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Default gCO$_2$eq/MJ biomethane</th>
<th>Best Practice gCO$_2$eq/MJ biomethane</th>
<th>Worst Practice gCO$_2$eq/MJ biomethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivation and Harvesting</td>
<td>16</td>
<td>6.7</td>
<td>27</td>
</tr>
<tr>
<td>Transport and Distribution</td>
<td>2.1</td>
<td>0.22</td>
<td>2.1</td>
</tr>
<tr>
<td>Production of Biogas</td>
<td>4.3</td>
<td>0.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Biomethane Upgrade</td>
<td>8.5</td>
<td>3.9</td>
<td>13.1</td>
</tr>
<tr>
<td>Biomethane Injection</td>
<td>1.7</td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Total Emissions</strong></td>
<td>30.6</td>
<td>11.6</td>
<td>48.5</td>
</tr>
</tbody>
</table>

Table 1: GHG Emissions Lifecycle Assessment for Maize: Best and Worst Practice

![Graph showing carbon intensity for different feedstocks (silage grass, maize, sugar beet) for default, worst practice, and best practice.]

Figure 6: Best and Worst Practice GHG Emissions Lifecycle Assessment

<table>
<thead>
<tr>
<th>Total GHG Emissions (g/MJ)</th>
<th>Silage Grass</th>
<th>Maize</th>
<th>Sugar Beet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Default</td>
<td>67.31</td>
<td>30.65</td>
<td>27.53</td>
</tr>
<tr>
<td>Best Practice</td>
<td>41.6</td>
<td>11.6</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Table 2: Best Practice GHG Emissions
CULTIVATION & HARVESTING

USING DIGESTATE

Cultivation and harvesting is one of the largest sources of GHG emissions over the LCA of biomethane. Best practice methods to minimise emissions can be implemented in a number of key areas. Research evidence is accumulating that biomethane production via anaerobic digestion provides further environmental benefits if the AD digestate is used as an alternative fertiliser for crops and pasture. The value of AD digestate as an agricultural fertiliser is measured both as the cost of replaced fertiliser and its several environmental benefits. The nutrient profile and fertiliser value of digestate is dependent on the feedstock composition. Energy crops generally have greater DM (dry matter) content and more favourable nutrient composition than manure slurries, resulting in a more concentrated and valuable digestate.6

Digestate is an easy product to handle and apply making it a successful substitute for mineral fertilisers. The quantities of nutrients that are supplied to a digester via the feedstock are nearly equal to those in the digestate. Adoption of best practice management has the potential to give direct environmental benefits from the use of digestate as a fertiliser. Such practices will result in lower gaseous emissions into the atmosphere as well as less diffuse pollution from surface run off and leaching through the use of artificial fertilisers.

RECOMMENDATIONS

- Use digestate as a substitute for artificial fertiliser, digestate has a significantly reduced odour in comparison to animal manures and organic wastes, which contain volatile organic compounds, which produce unpleasant odours.
- Avoid spraying liquid digestate to minimise ammonia emissions. Direct injection techniques should be recommended whereby the digestate is concentrated over a smaller area of soil without disrupting the soil structure.

NITROGEN INHIBITORS

Nitrogen is regarded as the most yield-limiting element in crop production in most soils, but is also the most easily lost nutrient from the soil. The amount of nitrogen oxide emitted is increasing, emissions from agriculture currently account for approximately 68% of this, mainly stemming from the decomposition of nitrogen compounds in the soil. The nitrogen within fertiliser is crucial to ensuring agricultural productivity, however, when excess nitrogen remains in the soil, in certain conditions it is converted to N2O and is released into the atmosphere as a harmful GHG.7 Nitrification is the process that converts ammonium nitrogen to nitrate nitrogen in the soil. Nitrogen inhibitors retard the process, thereby increasing the proportion of ammonium nitrogen stored in the soil.

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7 Committee on Climate Change. Agriculture, Emissions from Agriculture, November 2012.
- Applying nitrogen transformation inhibitors is promising in reducing nitrous oxide (N\textsubscript{2}O) in both arable and pastoral soils, with some reports indicating a 10-29%\(^8\) reduction in emissions through reducing nitrate production by slowing the nitrification process.

**TRANSPORT & DISTRIBUTION**

Purpose Grown Crops are an important feedstock for anaerobic digestion (AD) plants, both mixed with farm and other organic waste and on their own. As well as offering a high level of energy generation, they can make a significant contribution to the economic and environmental sustainability of farming. The role of purpose grown crops in increasing the sustainability of agriculture in conjunction with use as a feedstock can be a delicate balance.

Best practice measures focus on using locally sourced crop based feedstocks which do not impede upon food production by fitting into the normal crop rotation and working as a “break crop” providing additional financial benefits for farmers as well as promoting biodiversity and boosting soil conditions on marginal lands previously unsuitable for food production. In addition to this, biogas systems are very flexible; feedstocks often include plants that are not used directly for human consumption including grass.

**RECOMMENDATIONS**

- Transportation distance should be minimised as much as possible. Digestate removal and application should also be accounted for.

**BIOGAS PRODUCTION**

**METHANE SLIP**

Methane is an essential component of biogas, however it is an area of potentially significant emissions. Emissions of methane may result in worsening the positive climate balance of biogas production and use. Methane emissions from biogas plants occur if unburned biogas escapes into atmosphere (diffusion through foils, leaks, high-pressure cut-off valves, engines failures etc.) and if fermentation residue which has not completely decomposed leaves the closed system of the biogas plant (fermentation residue tank not gas-tight covered). Greater requirements have been put in place for biogas plants so that methane can no longer escape into the atmosphere. This is achieved with additional technical measures, such as double membrane roofs on the fermentation tanks, gas measurement and analysis devices, a covered end tank for fermentation residue and fermentation residue distribution on fields using drag hoses, as well as the frequent checking and measuring of the methane slip.

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\(^8\) Vistoso et al. 2012. Effect of nitrogen inhibitors on nitrous oxide emissions and pasture growth following an autumn application in a volcanic soil. Chilean Journal of Agricultural Research, 72(1).
RECOMMENDATIONS

- Methane slip detection system should be implemented during the operational life of the plant. This requires a methane ‘detection camera’ to assess possible leaks from the fermenter, piping, joints and valves.
- Methane slip detection should be carried out on an annual basis to ensure any plant deterioration does not increase methane emissions from the plant.

DIGESTATE STORAGE

Digestate is produced throughout the year and must therefore be stored until the growing season, which is the only appropriate time for its application as a fertiliser. Similarly, to manure, if liquid digestate is stored in open tanks, ammonia and methane gases (residual biogas) are given off and therefore make it a potential site of GHG emissions. Best practice measures focus on the use of a protective layer over the liquid digestate to reduce emissions. Some European countries with a developed biogas sector (e.g. Germany, Denmark and Austria) now have financial incentives to establish covered digestate stores, with the main objective of reducing emissions.

RECOMMENDATIONS

- Covered storage of liquid digestate. This is now mandatory in the UK in order to meet the National End-of Waste criteria (PAS110). This will reduce any potential methane slip from the digestate process. In some cases nearly 10% of the total biogas production is generated in the digestate store.

HEAT USAGE

Currently, whilst there is some use for the heat that is created in the AD process, where biogas is used for electricity it is the norm that a large proportion of the heat is dumped as a result of there generally being constrained demand in the immediate vicinity of the plant. Biomethane production counters this problem in some respect through the upgrading of biomethane to injectable standards. This allows gas to be input into the network and a consummate amount of gas to be taken out at another location to be burned in a CHP where there is a use for the heat. However, in addition to producing biomethane for grid injection, many biogas plants use it on site to produce heat or electricity. Farm- based biogas plants for instance use the produced biomethane to cover their own energy needs but may also sell surplus electricity to the grid or suppliers.

Best practice methods promote the use of all available heat, whether it is used for local heating or remote heating (via district heating networks). The excess heat can be distributed to more distant premises, either directly through gas pipes or indirectly through district heating networks. Alternatively excess heat may be used for the production of additional electricity, although this is comparatively new. This takes place in ORC (Organic Rankine Cycle) plants. They allow an increase in the overall electrical efficiency of conversion into electricity by a significant amount. Owing to the still high additional investment costs this option is notably suitable for larger biogas plants.
Biogas upgrading and the production of biomethane is a state-of-the-art process of gas separation. A number of different technologies to fulfil the task of producing a biomethane stream of sufficient quality to act as a vehicle fuel or to be injected into the natural gas grid are already commercially available and have proven to be technically and economically feasible. Nevertheless, a small percentage of methane is lost during the upgrade stage.

Intensive research is still in progress to optimize and further develop technologies to minimise methane slip. A range of different technologies currently exist each with their own specific advantages and disadvantages and this review shows, that no technology is the optimal solution to each and every biogas-upgrading situation. The right choice of the economically optimal technology is strongly depending on the quality and quantity of the raw biogas to be upgraded, the desired biomethane quality and the final utilisation of this gas.

**RECOMMENDATIONS**

- Methane slip from biomethane upgrade plants can be up to 1-2% of the total methane production – selecting a type of upgrade technology that generates the lowest amount of methane slip is crucial.
  - Biogaspartner\(^9\) report on Biogas Grid Injection in Germany and Europe provides an overview of methane loss from different upgrade technologies.
- Post-treatment techniques can be implemented to deal with methane slip, these include:
  - Regenerative thermal oxidizer
  - Recuperative thermal oxidizer
  - Biological de-methanation.

\(^9\) Biogaspartner – a joint initiative. Biogas Grid Injection in Germany and Europe – Market, Technology and Players.
FUTURE FEEDSTOCKS

Ideally biogas production would benefit from a consistent mix of feedstock materials, chopped and blended to ensure optimum methane yield. A base feedstock from break crops, or energy crops grown as part of a farm rotation, is an ideal solution for farmers and helps provide an alternative income stream alongside standard combinable and commodity crops. There are several low risk crops e.g. grass and wholecrop cereals, which are well suited to biogas production, however their yields/ha do not match those of common feedstocks such as maize or beet. The biogas industry is also working on new crops to substitute standard feedstocks for AD. These crops offer a number of benefits including; enhanced biodiversity, lower farming inputs and high biogas yields.

WILDFLOWER MIXES

Wildflowers are being assessed in terms of their ecological and environmental benefits. They can be used on borders and may act to enhance biodiversity when mixed with maize.

PERENNIAL CROPS

Silphium Perfoliatum (Cup Plant) is an example of a perennial crop, which can be grown on poor or marginal land. Crop trials have shown significant biodiversity benefits for insects and other wildlife as well as providing a rich mixture of vegetation.

PERENNIAL GRASS

Perennial grass can also provide a biogas output with minimal land disturbance. They have a low cost of supply and the biodiversity benefits make this an attractive future feedstock.

LUCERNE

Lucerene is a flowering species offering a high biogas yield and significant environmental benefits post harvest. The plant has a high drought resistance, whilst also being very efficient at taking in liquid digestate as fertiliser.

SZARVASI GRASS

Szarvasi grass is a perennial energy crop that is able to produce biogas yields comparable to feedstocks such as maize.

In order to meet future sustainability criteria for biomethane systems, it will be crucial to demonstrate systems do not negatively affect current food production. This is of special relevance regarding future biogas production from energy crops cultivated on arable land and in the potential implementation of assessments of indirect land use change (iLUC).
The utilisation of biogas as vehicle fuel has been successfully implemented in several European countries for years. In Sweden, biogas vehicle fuel has been developed in regions such as Stockholm and West Region (Göteborg), whilst simultaneously methods of best practice have been promoted to counter the large potential source of methane emissions in biomethane upgrading and biogas production.

- 2007 - Voluntary Agreement, “Frivilligt atagande” - in order to establish a systematic approach to quantify and minimise methane emissions.

**VOLUNTARY AGREEMENT DETAILS**

The Voluntary Agreement system encompasses all parts of the biogas production: from storage of substrate, pre-treatment processes, mixing, digestion, post-digestion and storage of digestate at the plant. Emissions during transport, storage on farms or spreading of digestate are not included. The source of emissions monitored include:

- Ventilation, Mixing tanks, Digester, Digestate storage

The Agreement also encompasses the biogas upgrade process. The Agreement starts when gas enters the building containing the upgrading equipment and ends when the gas is cleaned, dried and odorized. Emissions during transport of the upgraded biogas, compressed, propane addition, gas storage or emissions at filling stations are not included. Source of emissions include:

- Off Gas, Ventilation, Instrument for gas analysis

The Voluntary Agreement consists of three main parts:

- Quantification every three years – measurement and calculations
- Systematic emissions source – classification plans
- Leak detection – recommended monthly

The Agreement is based upon operating staff attending an emissions course provided by the Swedish Waste Association, further to this, a classification plan is mandatory for all Biogas Plants describing where systematic emissions may be expected as well as carrying out leak detection.

**RESULTS**

The IEA\textsuperscript{10} Bioenergy Report assessed 18 biogas plants and 20 upgrading plants, the results showed considerable differences in methane emissions from the plants. It has been reported\textsuperscript{11} reported that methane emissions fell for both biogas production and biogas upgrading.

<table>
<thead>
<tr>
<th>Biogas Production Methane Slip</th>
<th>2007</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss 7.5%</td>
<td>Loss &lt;0.1%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biomethane Upgrade Methane Slip</th>
<th>2008</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss 12%</td>
<td>Loss 7%</td>
<td>Loss 2%</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{10} IEA, Biogas Sustainability, The Swedish Voluntary System for control of methane emissions, May 2012.

\textsuperscript{11} SP Technical Research Institute of Sweden, Nordic Biogas Conference 2012
European energy and environmental legislation has developed markedly over the last five years. The RED Directive 2009/28/EC focuses on the promotion of the use of energy from renewable sources. The key mandatory targets for 2020 remain:

- 20% of energy to be sourced from renewables
- 10% of EU transport fuels to be sourced from renewables

The Fuel Quality Directive (FQD) 98/70/EC requires fuel suppliers to reduce by 31 December 2020 the life cycle GHG emissions per unit of energy from fuel and energy supplied based on a 2010 baseline by 6%. For biofuels to count towards the 6% reduction target, they must also comply with the previous sustainability criteria.

Both directives include criteria on greenhouse gas saving thresholds, however emissions associated with indirect land use change (iLUC) were not previously subject to reporting under previous legislation, however, both Directives did include an obligation to review the impact of indirect land use change on greenhouse has emissions associated with biofuels.

AMENDMENTS TO THE FUEL QUALITY DIRECTIVE 98/70/EC

The Commission has recently released further legislation to minimise the climate impacts of biofuel production. The Commission are proposing that the greenhouse gas emissions saving threshold from the use of biofuels taken into account for the new installations shall be at least 60% for biofuels production processes starting operation after 1st July 2014.

The Commission is keen to implement this increase in CO₂ reduction target as it believes it would an effective way in reducing indirect land-use change (iLUC) as it would lead to the replacement of those biofuels with estimated high ILUC emissions (such as vegetable oils) by those with estimated low emissions (such as cereals, sugars and advanced biofuels).

It is proposed that members will now also be obliged to include indirect land-use change (ILUC) factors in reporting by fuel suppliers. The Commission has set typical values for ILUC emissions which producers should include when accounting the lifecycle GHG emissions. The values are shown in the table below.

<table>
<thead>
<tr>
<th>Feedstock group</th>
<th>Estimated indirect land-use change emissions (gCO₂eq/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals and other starch rich crops</td>
<td>12</td>
</tr>
<tr>
<td>Sugars</td>
<td>13</td>
</tr>
<tr>
<td>Oil crops</td>
<td>55</td>
</tr>
</tbody>
</table>

Fuel suppliers shall by 31 March each year report to the authority designated by the Member State, the biofuel production pathways, volumes and the life cycle greenhouse gas emissions per unit of energy, including indirect land use change emissions set out in Annex V Member States shall reported these data to the Commission.
For compliance with target referred to in first paragraph, the maximum joint contribution from biofuels and bioliquids produced from cereal and other starch crops, sugars and oil crops shall be no more than 5%, the estimated share at the end of 2011, of the final consumption of energy in transport in 2020, the remaining to come from advanced biofuels (waste/agricultural residues such as straw).

Under the amended RED:

- Biofuels produced from feedstocks listed in Part A of Annex IX (e.g. algae, mixed MSW, but not separated household waste) shall be considered to be four times their energy content.
- Biofuels produced from feedstocks listed in Part B of Annex IX (e.g. used cooking oil, animal fats, non-food cellulosic material) shall be considered to be twice their energy content.
- Renewable liquid and gaseous fuels of non-biological origin shall be considered to be four times their energy content.

To provide market incentives for biofuels with no or low ILUC emissions, and in particular the 2nd and 3rd generation biofuels produced from feedstock that do no create an additional demand of land, including algae, straw and wastes, as they contribute more towards the 10% renewable energy in transport target of the RED.

These new measures are to promote biofuels that help achieve substantial emission cuts, do not directly compete with food and are more sustainable at the same time. The Commission considers that in the period after 2020 biofuels should only receive financial support if they lead to substantial greenhouse gas savings and are not produced from crops used for food and feed.