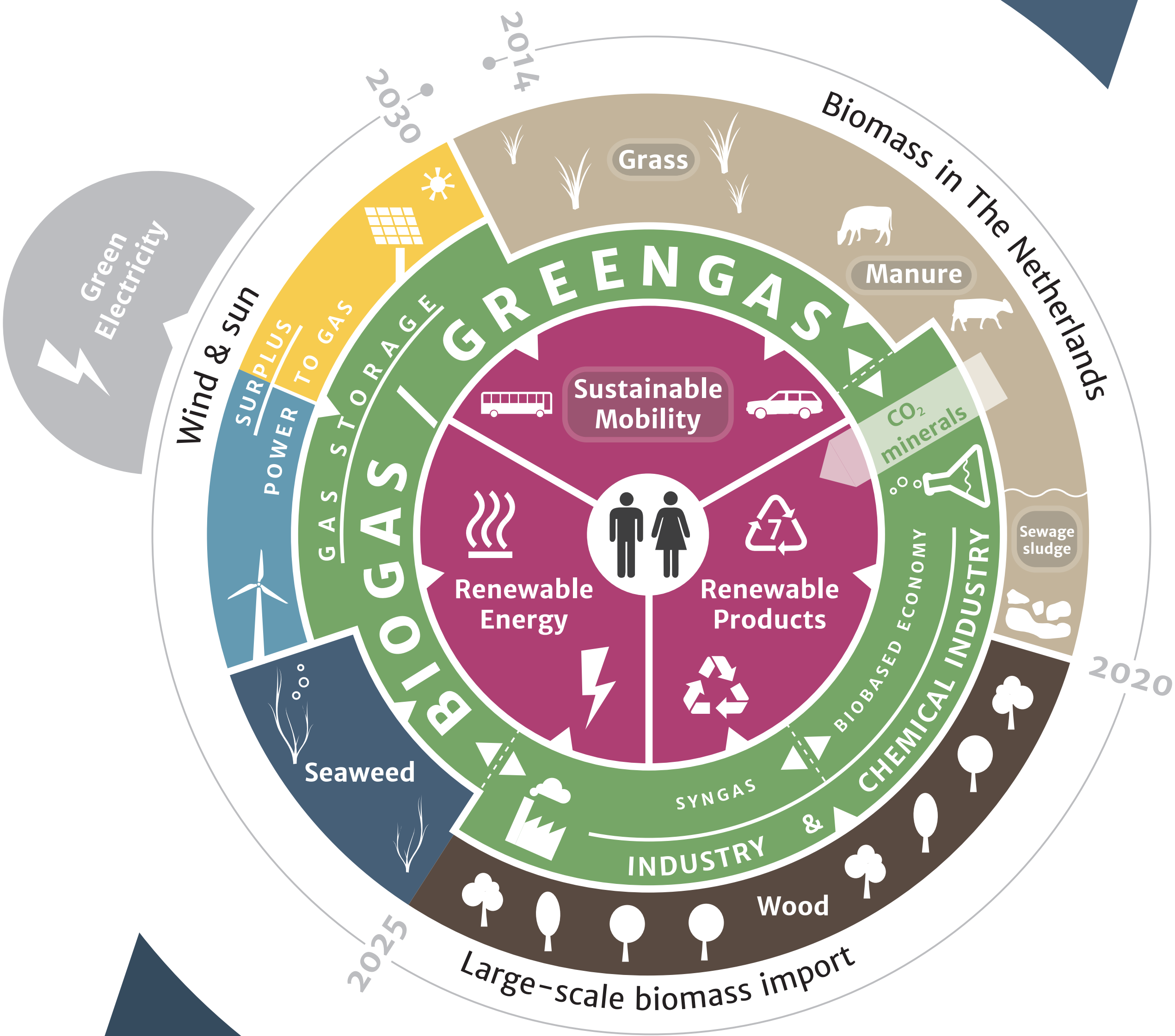
Green gas roadmap



Green Gas Forum
Green Gas Green Deal (deal 33)

July 2014

Green gas roadmap

This roadmap was prepared by De Gemeynt, ECN and Groen Gas Nederland, RVO.nl and was commissioned by the Green Gas Forum. A large number of parties in the renewable gas supply chain also provided useful information for the compilation of the roadmap.

Contributors:
De Gemeynt: Jan Paul van Soest (projectmanagement), Hans Wiltink, Heleen van Soest.
ECN: Eppe Luken, Marc Londo, Hamid Mozaffarian.
Groen Gas Nederland: Har van Himbergen, Ron van Dorp, Xander van Mechelen.
RVO.nl: Mathieu Dumont, René Wismeijer.

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Design: Jaap van der Voort, uxds.nl

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groengasnl Stichting Groen Gas Nederland
De Gemeynt
Rijksdienst voor Ondernemend Nederland

Contents

Foreword

The Green Gas Green Deal was signed on October 3, 2011, by the Dutch Ministry of Economic Affairs and 25 parties that together form the Green Gas Forum. The Green Gas Green Deal focuses on the development of the Dutch green gas market in the medium term. As such, it specifically applies to the scaling up of digestion plants, innovative technologies such as biomass gasification, and Research & Development. In their capacity as the Green Gas Forum, the signatories of the Deal have taken over responsibility for the organisation of the green gas supply chains.

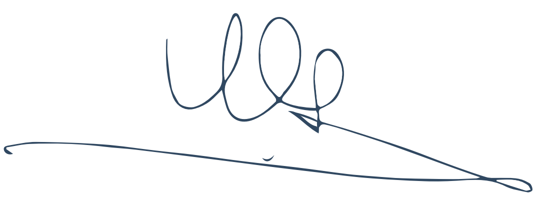
All agreements made by the Green Deal are made in partnership with organisations such as Groen Gas Nederland, TKI Gas - as part of the Top Sector Energy - and by market parties, whether or not the latter are represented in the Green Gas Forum.

This is how the required results were achieved. There are initiatives for the large-scale deployment of the mono-digestion of manure on a farm scale, and initiatives aimed at biomass sources such as grass. The grid feed-in conditions for green gas will also be set out in a ministerial decree.

In order to outline the potential for renewable gas in the periods 2014-2020 and 2020-2030, the Green Gas Forum has produced this *Green gas roadmap*, as was agreed in the Green Deal.

This Roadmap outlines the prospects for renewable gas from digestion and gasification, and also analyses which raw materials will or can be used for renewable gas, as well as discussing how the products can be used in the economy and the energy grid as a whole.

Ulco Vermeulen



Chairman, Green Gas Forum

Summary

1 Introduction

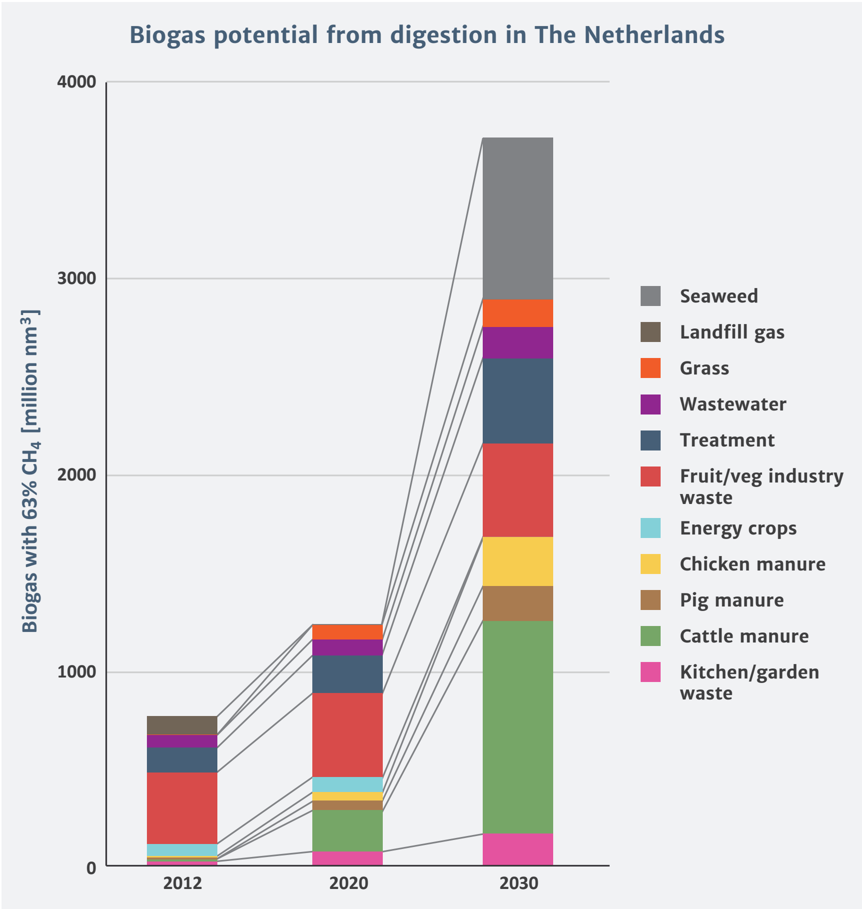
The *Green gas roadmap* outlines the potential for the production of biogas, green gas (natural gas quality) from biomass, via gasification and digestion, and what actions are needed in order to realise this potential effectively. In the longer term, 'new gas' (hydrogen and methane) produced using renewable electricity could also play a role. Hence we use the umbrella term 'green gas' for the entire range of gaseous energy carriers (including compressed and liquefied).

The main findings are listed below.

2 Supply, digestion

An increasing potential is seen for digestion, because the use of some digestible (wet) waste streams could grow significantly:

- Manure, particularly cattle manure, due to changing market conditions and relaxing regulations; and also pig and chicken manure.
- Sewage sludge.
- Grass.
- By 2030 we will also be able to cultivate an additional biomass stream, namely seaweed.



By 2020, digestion could potentially produce an estimated 1.2 billion m^3 of biogas, or 0.75 billion m^3 of natural gas equivalent (1 m^3 of biogas yields 0.63 m^3 of natural gas equivalent). By 2030 this figure could rise to an estimated 3.7 billion m^3 of biogas, or 2.2 billion m^3 of natural gas equivalent. If this digestion potential is fully realised it would account for three quarters of the stated ambition of the Green Gas Green Deal (3 billion m^3 of natural gas equivalent in 2030).

The total energy content of the biogas potential in 2020 is circa 25 PJ. Depending on the selected conversion routes this will contribute around 15-20 PJ towards the 14% renewable energy target (in gross final energy consumption) in 2020. Biogas could therefore make a contribution of between 5 and 7% to the renewable energy target by 2020, with that contribution set to increase rapidly between 2020 and 2030.

3 Sales, demand

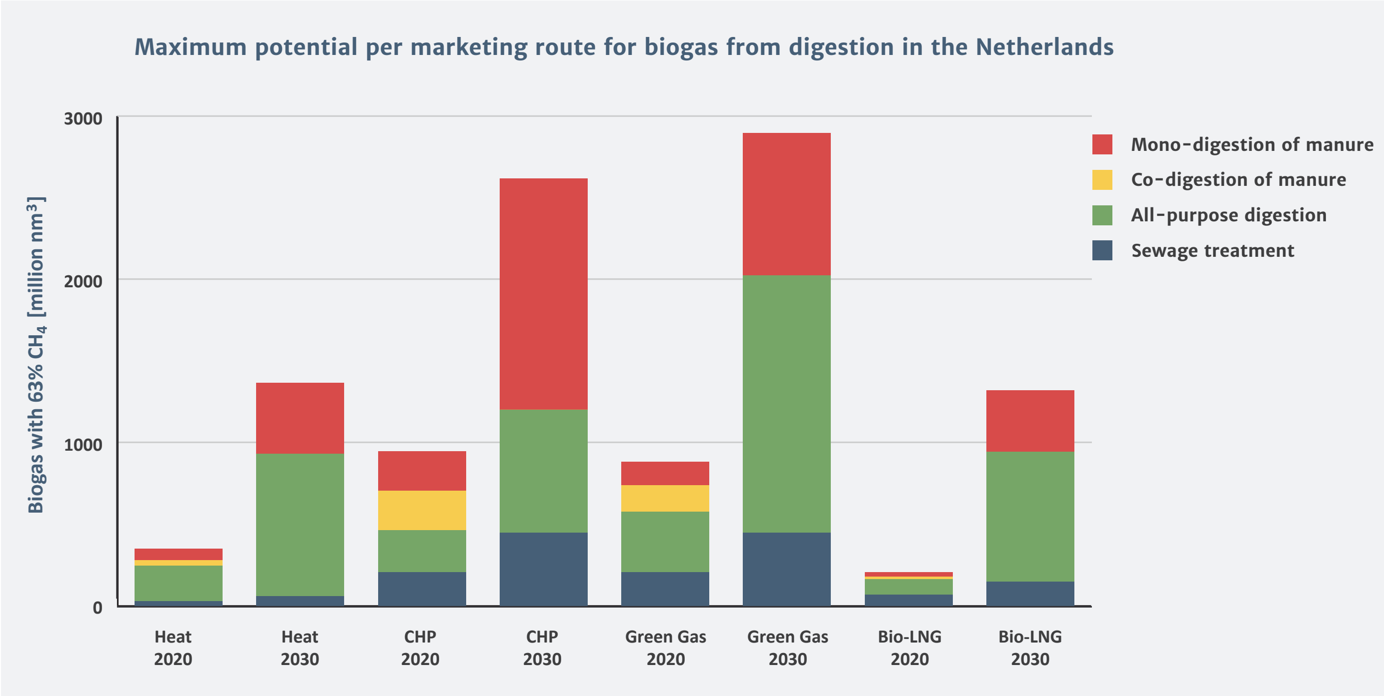
The production and use of biogas has social benefits (processing of waste residues, emissions reductions, energy independence), but from a strictly financial/economic point of view, green gas remains more expensive than fossil fuels. In order for green gas to be widely accepted, society must find a way to bridge that gap by (a mixture of) raising the costs of fossil fuels, incentives for non-fossil fuels, and/or regulation of the market segments (quotas, obligations).

Besides the presence and extent of government incentives, the specific circumstances at any particular location will determine the current use (route choice) of biogas, whether in the form of heat production, CHP, injection into the gas grid, or as bio-CNG or bio-LNG in transport:

- The direct supply of biogas to produce heat has the lowest financial gap. The disadvantage is a lack of flexibility: there is a limited number of places where a biogas producer can be linked to a stable, guaranteed heat demand.
- Injecting biogas into the natural gas grid offers more reliability.
- In transport, the alternatives to 'greening' are limited, and there are possibilities to cash in on the 'green value' of non-fossil methane in the form of bio-CNG and bio-LNG.

Overall, the transport sector seems the most interesting marketing route in the long term, and is one that can also grow with increasing biogas production. Use in the natural gas grid and for CHP, where locally possible, are good alternatives.

The graph on page 13 shows an estimate of the maximum potential of the different marketing routes for biogas digestion in 2020 and 2030. The graph takes into account the specific features (such as scale and location) of each type of digestion and marketing route.



4 Actions and measures

Digestion

The above potential will not necessarily be realised. Therefore certain actions and measures are necessary. The most important of these are:

- Action 1: Launch a joint government and industry programme to get the mono-digestion of manure off the ground.
- Action 2: Make the use of biogas in the Dutch Stimulation of Sustainable Energy Production subsidy (SDE+) more flexible, so that the sales route is able to change over the lifetime of a project.
- Action 3: Ensure that high-value utilisation of biomass is stimulated in (government) contracts for waste disposal and roadside verge management.
- Action 4: Organise and professionalise both market and sector. The sector is currently too fragmented. Make use of the knowledge and experience of other countries.
- Action 5: Work systematically to improve the (financial) value of the social benefits of biogas.
- Action 6: Develop a coherent plan for a green level playing field in the transport sector so that the social benefits of green gas in transport (based on well-to-wheel) become rewarding in a comparable way to other options.
- Action 7: Keep developing new raw materials and technology to increase the potential for green gas.

Gasification

Further technology developments are needed before a substantial amount of gas can be produced via gasification.

- Action 8: Develop gasification in a three-step strategy:
  - Now until 2020: Technology development: find evidence of the viability and relevance of various gasification options; find a role for TKI Gas.
  - 2020-2025: Market development: create niche markets; market and government cooperation.
  - 2025-2030: Commercial rollout: market parties to work with clear policy frameworks.

With the current state of the technology, it is not possible to give an accurate quantitative estimate of the potential contribution from gasification.

Given that further technology developments are needed, the choice of a route does not have to be made yet. But in formulating marketing routes for gas from gasification, advance consideration should not primarily focus on methanation/injection into natural gas grids, but on the substitution of natural gas, where this is relevant and possible (syngas, feedstock).

5 Long term

Gaseous energy carriers can play a long-term role in sustainable energy management:

- Renewable, green gases in the natural gas mix: based on this roadmap about 3.7 billion m^3 of biogas (2.2 billion m^3 of natural gas equivalent green gas) per year will be produced from digestion by 2030.
- System function, storage, flexibility: gas can be regulated quickly, and the storage and transport costs of gas per energy unit, or per energy unit per kilometre, are relatively low. Flexibility is increasingly needed to cope with the unpredictability and variability of solar and wind as renewable energy sources.
- With reference to the above: electricity from solar and wind power can, at times when supply exceeds demand, be converted into hydrogen. This hydrogen can be mixed into the gas grid, or used directly in transport or industrial applications. Another possibility with potential is Power-to-Gas: the conversion of hydrogen together with (non-fossil) CO_2 into methane.
- Pushing the envelope with developments in Green Gas for the biobased economy: the use of biogenic (non-fossil) carbon as a raw material. Ideally, non-fossil carbon, preferably high up in the energy value chain, will be used; after ‘cascading’ (down the usage ladder to lower levels), energetic use is still possible. Conversely, Green Gas can also be a (financial) tool to climb towards rungs higher up the ladder.

These possibilities lead to:

- Action 9: Develop a shared perspective on a logical role for gaseous energy carriers in energy management that aims at profound CO_2 emissions reductions; this is desirable in order to give current research, development and investment efforts lasting value.

Innovation

Green gas sits on the boundary between energy and the biobased economy. Continuous innovation that focuses both on the short term (manure digestion, upgrading) and medium term (supercritical gasification, seaweed, biorefineries) is crucial. The appropriate parties to provide this innovation are therefore TKI Gas and TKI Biobased Economy working in close cooperation. Besides stimulating technology developments, they also have an important function in improving cost effectiveness.

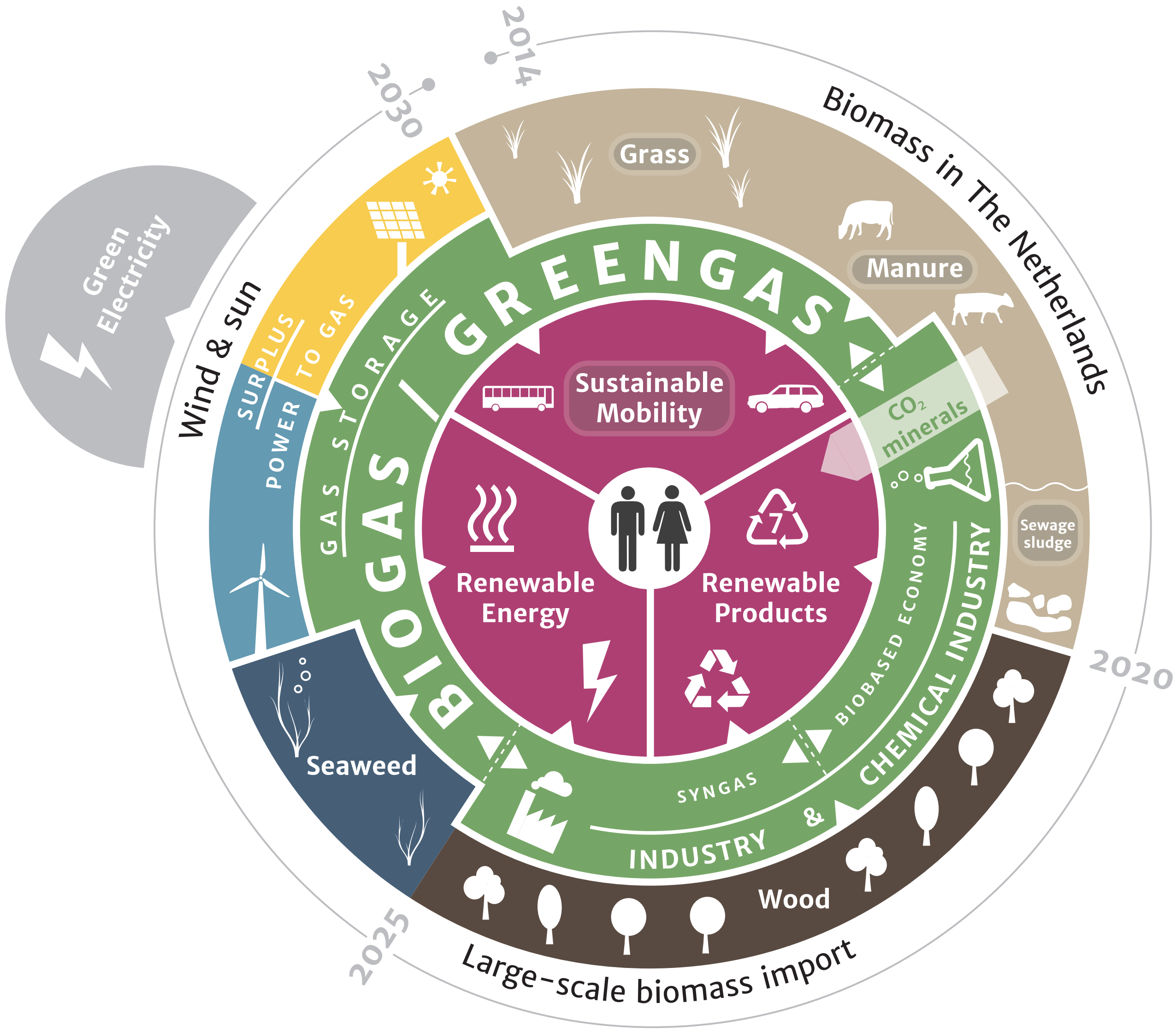
- Action 10: Based on the roadmap, establish a sound innovation agenda that can be followed systematically, and updated every few years based on the established facts.

6 Report structure

The *Green gas roadmap* consists of this summary and a compact main report that follows below. The original Dutch version also contains an in-depth background report, complete with appendices. To make this background report readable separately, each chapter includes introductory passages from the main report. The bibliography is the basis for both the main report and the background report.

Green gas

The link between low-grade materials and high-quality applications



Roadmap highlights

In 2020, biogas could cover around 5-7% of the renewable energy target (ca. 15-20 PJ gross final energy consumption)

The potential for biogas from digestion is:

- 2020: 1.2 billion m³ biogas
- 2030: 3.7 billion m³ biogas

Short-term actions

Focus on:

- Manure, grass, sewage sludge
- Level playing field for transport
- Innovation programmes, including (supercritical) gasification and Power-to-Gas

Strengthening of supply chain management:
combining the strengths of existing organisations and continuing the public-private partnership (PPP) approach

Perspective for 2030

Important role of green gas in Power-to-Gas and a biobased economy

With strong growth of the biobased economy, the potential for biogas will continue to increase

Green gas roadmap
Groen Gas Green Deal
Groen Gas Forum

1 Roadmap
Introduction

1.1 Mission and scope

This *Green gas roadmap* is part of the Green Gas Green Deal, a joint initiative of market parties and government that aims to stimulate the production of green gas in the Netherlands. The roadmap aims to provide a structure for activities within the framework of the Green Deal, and thus to provide a basis for decisions made by the partners in the Green Deal.

The roadmap was prepared by a project team from De Gemeynt (coordinator), ECN and Groen Gas Nederland, in cooperation with RVO.nl. It is based on a literature analysis, and input from and discussions with relevant stakeholders and experts, under the direction of De Gemeynt. The underpinning estimations and calculations were made by Groen Gas Nederland and ECN.

The roadmap covers all gaseous energy carriers from non-fossil origins. These can be obtained by digestion (wet biomass (waste) streams) and gasification (dry biomass). In the longer-term it will also cover the production of hydrogen and possibly methane (after the reaction of hydrogen with CO_2 from digestion) using renewable electricity: Power-to-Gas (P2G).

As an umbrella term we could use 'renewable gas'; but for convenience and because the emphasis in this roadmap is on gases containing biogenic (non-fossil) carbon, we mostly use the term Green Gas. Where we specifically mean biogas ('crude' gas obtained from digestion), syngas or fuel gas (obtained by gasification), or green gas (natural gas quality), this will be explicitly mentioned.

Renewable raw materials and the gases extracted from them can both play a role in the energy system as a whole and in the biobased economy. That makes route planning difficult, but many opportunities lie in the multi-applicability of (renewable) gases.

Terminology

- Biogas: unrefined gas mixture obtained from digestion, containing approx. 50–55% methane (CH_4), and mainly CO_2 and H_2O, and traces of other components such as H_2S.
- Syngas or product gas: unrefined gas mixture obtained from gasification, containing mainly hydrogen (H_2) and carbon monoxide (CO).
- Green gas (lower case): biogas or syngas upgraded to natural gas quality (Groningen gas).
- Power-to-Gas (P2G): gases obtained using electricity (power), namely:
  - Hydrogen gas (H_2) from the electrolysis of water.
  - Methane (CH_4), wherein H_2 is methanised using CO_2. (This can only be termed 'renewable' or 'climate neutral' if not only the electricity, but also the CO_2 for the methanation derives from renewable sources.)
- Renewable gas or Green Gas (capitalised): a general term for all non-fossil gases.

1.2 Green gas supply chains: main routes

The starting point in developing this roadmap is the common ambition to obtain 3 billion m^3 of green gas by 2030.

The main routes of digestion and gasification each require a separate approach.

The primary driver for the further development of digestion supply chains is that there are waste streams that can only be used once; in such cases the energetic use of biogas with the possible further conversion into green gas becomes a valuable route.

The primary driver for the development of gasification supply chains lies in a mix of:

- Industry/technology policy: developing a group of Dutch companies and knowledge institutions about gasification technology, and:
- Energy/sustainability policy: potentially making a sizeable contribution to renewable energy and raw materials management with an energy carrier (gas) that fits well with the Dutch energy infrastructure.

This leads to two different main routes, each of which is developed differently:

1. In 'wet biomass (waste) streams - conversion: digestion - infrastructure/transport - application' supply chains, this largely means rollout and further development so that fast-growing but hitherto not-yet-fully-utilised waste streams can be converted into biogas/green gas: manure (particularly cattle dung), grass and sewage sludge, and eventually seaweed. To make this possible, it is important to create the right market and policy conditions.
2. In the case of 'dry biomass - conversion: gasification - infrastructure/transport - application' supply chains, for the next 10 years or so this means technology development. Green gas from gasification (as syngas or after further processing into methane) will not start contributing to the objective until the second half of the 2020s.

A relatively new technology, *supercritical (water) gasification*, falls between these two main routes: high-efficiency gasification of wet biomass.

In supercritical gasification, under supercritical conditions (in water above 300 bar and 400 °C), very wet biomass (slurry, sewage sludge) will decompose into methane, minerals and various by-products. The potential increases in revenue from the successful introduction of supercritical gasification have, however, not been calculated in this roadmap, because the technology must first be proven (currently at the prototype stage).

2 Roadmap Digestion

2.1 International developments

Internationally, the Netherlands is in the vanguard in the field of Green Gas, and is active in various international projects. You can find more information about these by visiting the project website ***www.greengasgrids.eu***. International developments are reported by the International Energy Agency (Bioenergy Task 37: ***www.iea-biogas.net***).

Table 1. gives an overview by country of the number of projects, incentive schemes, whether they play a specific role in grid balancing, and the motives for action and relevant legislation.

Table 1. Overview of digestion measures in selected European countries

Country	No. of projects	Incentive	Role in grid balancing	Motives, legislation
Germany	> 100	Feed-in subsidy for final production of electricity via CHP.	Yes	General: Energiewende (energy transition). Production target 2020: 6 billion Nm^3. Law: Regulated gas grid access via GasNetzZugangsVerordnung.
Sweden	30-40	Financial measures	No	Application particularly in transport.
Austria	20-30	Feed-in subsidy	No	Most important application: transport.
Switzerland	20-30	Certificates trading	No	Most important application: transport.
Denmark	10	Feed-in subsidy	Yes	Climate policy: 50% manure in digestors in 2020 in order to limit CH_4 emission from manure storage; strong growth expected.
United Kingdom	10	Feed-in subsidy	No	Strong growth expected; drive for application in heavy transport.
France	3	Feed-in subsidy	No	Strong growth expected from the introduction of subsidies in 2013.
Italy	0	Feed-in subsidy	No	Strong growth expected from the introduction of subsidies in 2013.

2.2 Potential

Due to the nature of the process (organic: bacteria), it is possible to obtain energy from the digestion of (waste) streams that is not or is rarely usable for other, higher-value applications. Thus we will look here at the potential of the different streams: now, in 2020, and in 2030: what is the maximum available for digestion, how much biogas/green gas does that produce, and at what cost? The development of potential between now and 2020, and from 2020 to 2030, is estimated in Figure 1.

Manure, sewage sludge and grass will be the raw materials for digestion in the coming 15 years.

Most growth is expected to come from the use of manure, mainly cattle manure, and to a lesser extent pig and chicken manure. The proportion of cattle manure is expected to grow due to the removal of limits on milk production, and to changing agricultural and mineral laws. In addition, some growth in digestible streams is expected from sewage treatment and grass.

In 2020-2030 an additional waste stream will be added: seaweed. That will increase the potential in 2030, including seaweed, to 3.7 billion m³ of biogas, or 2.2 billion m³ of natural gas equivalent (approximately 0.63 m³ of natural gas quality can be obtained from 1 m³ of biogas). This equates to about 75 PJ.

Digestion can therefore potentially cover almost three-quarters of the ambitions of the Green Gas Green Deal (3 billion m³ of natural gas equivalent in 2030). Whether that potential will be used for energy purposes will depend on the economics of digestion, and also on competing applications. Therefore the opportunities to use substreams for the biobased economy (chemicals, materials) will have a higher added value. This use will initially mean a reduced potential use for digestion. However, after input into, and multiple use in, the biobased economy, it will often still be possible to exploit the waste streams energetically.

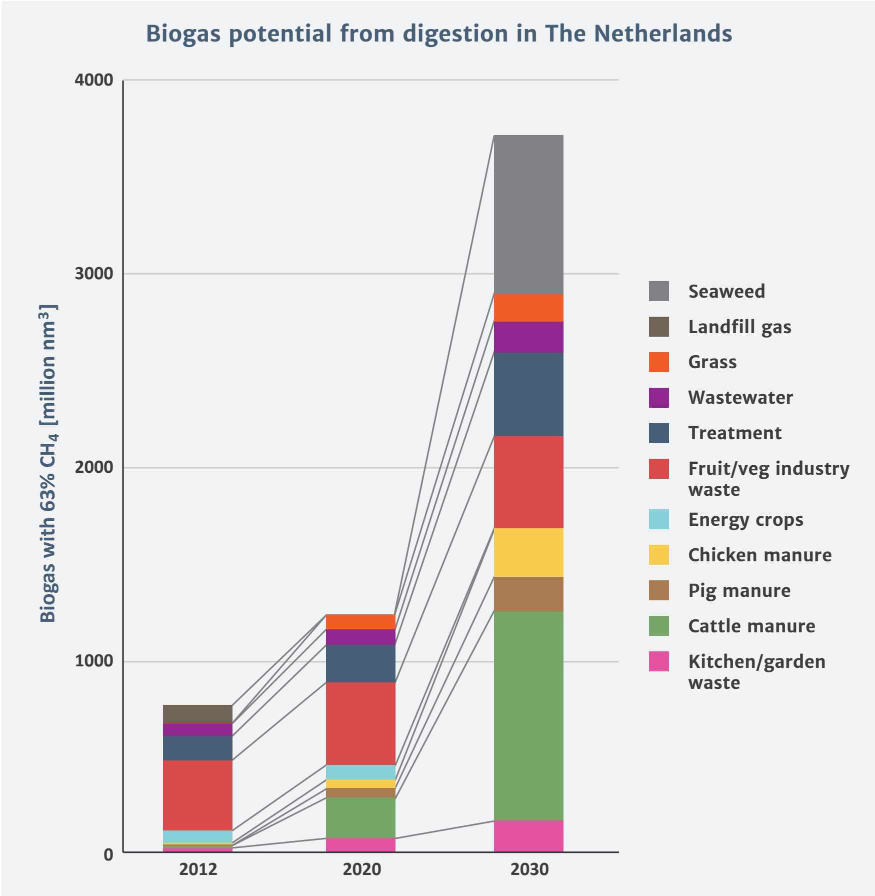


Figure 1. Development of potential for digestible raw materials

When, for either social or political reasons, restrictions are placed on the use of substreams, this of course also directly has an impact on the potential from that substream. This roadmap makes no comment on the social or political desirability of these constraints.

2.3 Costs

Without structural intervention in the market, the production of biogas is and will remain more expensive than the production of natural gas. The reasons to use biogas nonetheless stem from social ambitions regarding the climate and renewable energy. In order to realise the potential, the additional costs, i.e. the 'financial gap', of realising these ambitions must be evaluated from a social perspective. This can be done by legislating/regulating to enforce the use of biogas, or through financial regulations that give a value to CO_2 and CH reductions, manure processing and the use of minerals.

Through targeted efforts, the 'financial gap' in digestion can be greatly reduced

The cost structure of biogas production can vary greatly between the options and marketing routes. This is illustrated in Figure 2, which compares the indicative cost price structure of both the co-digestion and mono-digestion of manure.

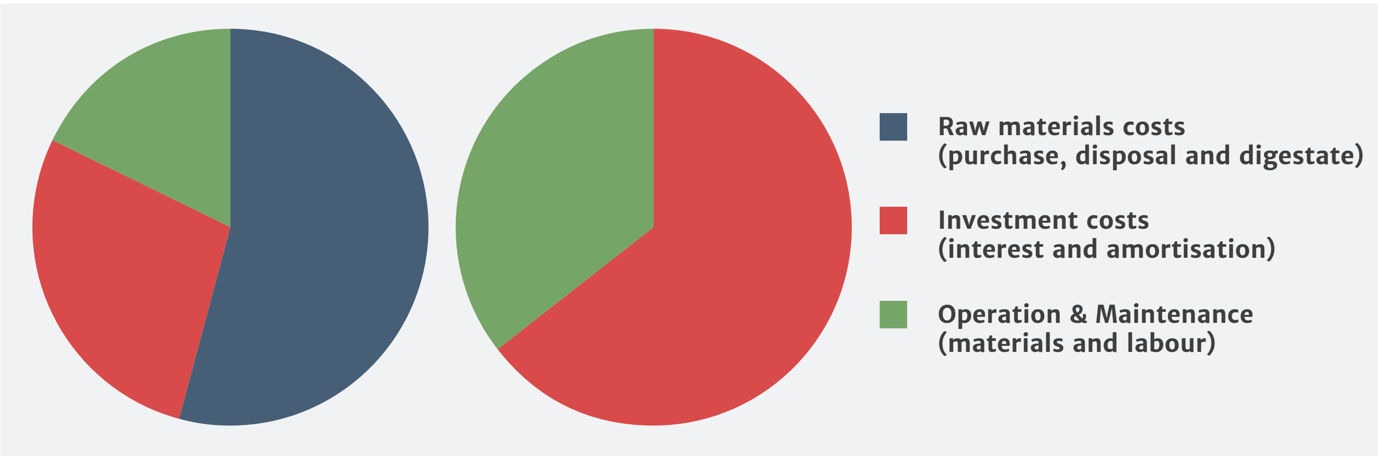


Figure 2. Relative shares of raw materials costs, investment costs and operation and maintenance costs in green gas production from the co-digestion (left) and mono-digestion (right) of manure. Based on figures from the SDE 2014 (Lensink 2013b)

Figure 2. shows that the biggest challenge in the co-digestion of manure lies in lowering the cost of the raw materials (including disposal of the digestate). Logical actions for this include searching for cheaper substrates (such as roadside verge and grass from nature conservation areas) and digestate valorisation. For mono-digestion of manure, cost reductions should mainly result from reductions in investment costs, and possibly digestate valorisation. A more detailed analysis of this cost structure complemented by an analysis of the potential earnings per technology could help to improve the business case for digestion projects and the effective use of R & D resources.

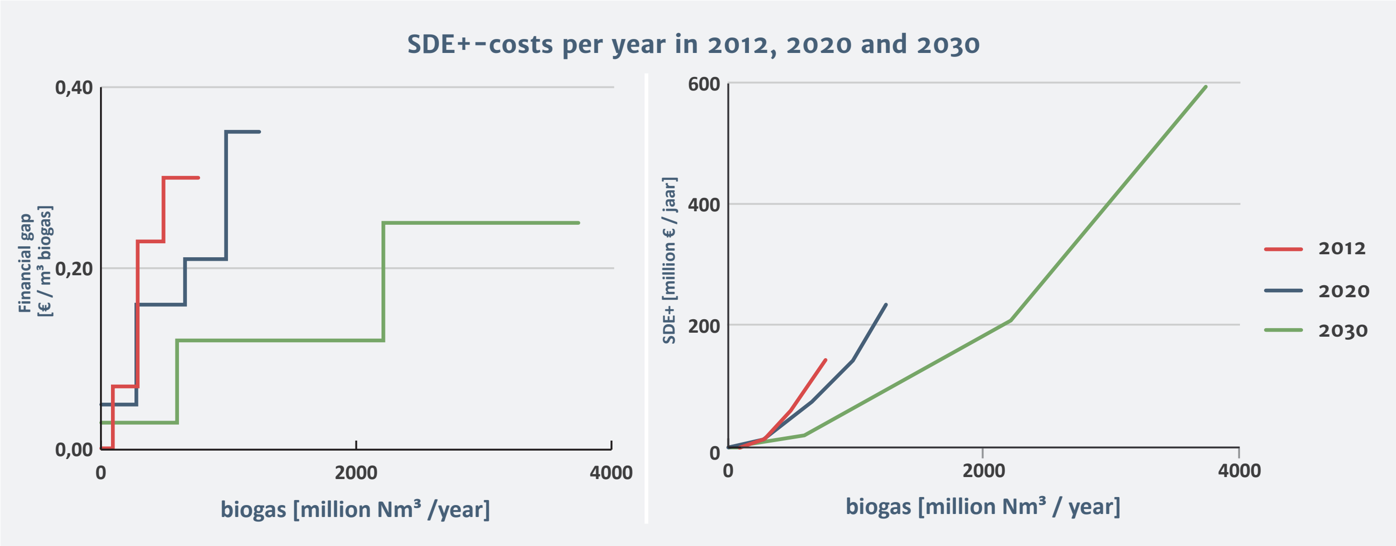


Figure 3. Financial gap in 2020 and 2030; marginal (left) and cumulative (right)

Figure 3. estimates the financial gap for 2020 and 2030. The bases for this are cost reductions realised through developments in technology, logistics and infrastructure, and increased yield and the financial valuation of (intermediate) products of 30% and 50% respectively. For each m^3 the marginal financial gap (the additional cost of using the most expensive digestion process: mono-digestion of manure) decreases by approximately € 0.35/m^3 in 2020 to approximately € 0.25 / m^3 in 2030.

Cumulatively, to realise the full potential of over 3.7 billion m^3 of biogas per year by 2030, some € 600 million/year is needed to bridge the financial gap. In 2020 this will be around € 230 million/year.

It is important to note that this is a technology that largely avoids the emission of methane from livestock manure into the atmosphere. This avoidance of adding to the greenhouse effect scores well from a social perspective. Digestion is and remains a way to process animal manure, in which biogas forms as a useful by-product. Financing the financial gap is therefore seen as a contribution to solving the growing problem of processing manure.

2.4 Applications

Biogas obtained via digestion, primarily methane (CH_4) and CO_2, can become *useful* via various routes:

- Direct combustion for heat production.
- Combustion in a CHP (cogeneration) plant to produce electricity and heat.
- Upgrading (such as through the removal of CO_2) to natural gas quality, then:
  - Injecting into the gas grid, to be used as regular natural gas.
  - Compression, then use in transport (driving with green gas).
  - Liquefaction (turning into a liquid) by cooling into LBG, then using in heavy transport (road, shipping).

The optimal energetic and financial-economic route is to a large extent determined by local conditions and can only be outlined in terms of general considerations (see **Box: General considerations in biogas project development**).

Use as green gas (methane) in the gas grid and CHP are effective marketing routes for biogas. After 2020, use in transport as bio-LNG could also take off. The 'green value' of biogas in the transport sector is high.

Box: General considerations in biogas project development

- Is local heat use possible?
  If yes:
    - Is there also sufficient electricity demand?
      If yes: CHP (cogeneration).
      If no: direct combustion: boiler.
  If no:
- Are the volumes sufficient for conversion into methane and is there a gas grid injection point in the neighbourhood?
  If yes: convert and inject into gas grid.
  If no:
- Are there any nearby biogas producers?
  If yes: consider the development of a biogas hub.
- Are there any possibilities for physical supply to the transport sector?
  Choice:
    - Compression: CNG.
    - Liquefaction: LBG (bio-LNG).
  Then:
    - Book-and-claim via natural gas grid.
- Are there any additional possibilities?
    - Sale of CO_2.
    - Fertilisation value of digestate.
    - Refinement of minerals/raw materials.
    - Income from grid balancing (bio-CHP or Power-to-Gas).

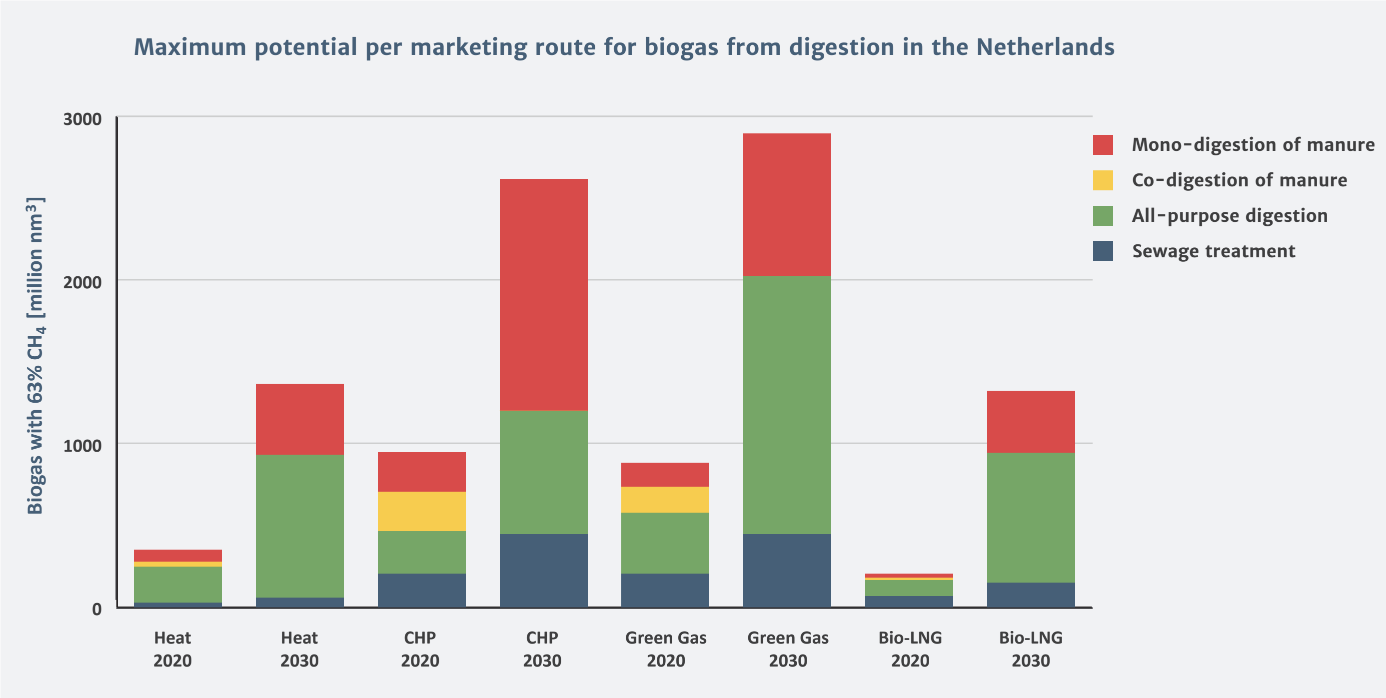


Figure 4. Maximum potential per marketing route for biogas from digestion

By considering the typical conditions of the type of digestion and the marketing route for biogas, an estimate can be made of the maximum potential per marketing route for 2020 and 2030, as shown in Figure 4. Use as bio-LNG in transport could potentially take off between 2020 and 2030, once the first steps are in place (in particular development of the infrastructure needed for LNG).

N.B: The routes are not counted together, but compete with each other.

3 Roadmap
Actions for digestion

3.1 General

In the short term, the business case for digestion is determined by the local situation (see **Box: General considerations in biogas project development**) and the current market situation and policy regulations: SDE+, Guarantees of Origin and biotickets, along with the generic emissions trading instruments (EU-ETS) and generic fiscal regulations. In terms of the roadmap, it is not expected that these arrangements will (or can) change substantially in the period between now and 2020. The green values that stem from these regulations and schemes (the additional price paid for green energy in various market segments) can change due to fluctuations in supply and demand.

A range of actions is needed in the coming years in order to fully realise the potential for biogas from digestion; some will have an immediate impact, while some will only become effective in the longer term.

This conclusion has implications for the timing of the actions that will be needed to realise the potential:

1. In the relatively *short term* (now until 2020) actions should focus on accelerating and improving existing frameworks, which are not in themselves changeable in the foreseeable future. For this a limited number of key actions have been selected from the multitude of available options.
2. In the *medium term* (2020-2030) we also need to make preparations for and create a stable and attractive investment and development climate for the greening of the gas supply.

The actions should be taken by:

- The sector/market parties.
- The knowledge world (educational institutes and advisors).
- Governments and regional authorities.

Social groups (NGOs, nature and environmental organisations) can also play a role. However, no specific actions are listed for these.

3.2 Short-term actions: now until 2020

In the short term (now until 2020), a limited number of key actions have been identified. They are summarised below:

Action 1: Launch a joint government and industry programme to get the mono-digestion of manure off the ground.

Create an innovation programme for the development and rollout of small-scale manure digesters including a manure-refining step. This programme will be supplemented with a plan to support larger-scale manure digestion by assisting with finding locations and funding. Moreover, the regulatory framework (including licences, environmental, digestate input) should also facilitate this plan optimally.

Action 2: Make the use of biogas more flexible.

The Dutch Stimulation of Sustainable Energy Production subsidy (SDE+) currently stipulates that the use of biogas (as heat, biogas, CHP) is determined for the entire duration of a project. This restricts the optimal use of the biogas and the creation of biogas hubs.

Action 3: Ensure that high-value applications of biomass, such as the possibility for gas production, are included in (government) procurement.

The energetic utilisation of organic waste streams such as biogas should be standard in all public procurement. To this end, Groen Gas Nederland and RVO.nl could develop a procurement model.

Action 4: Organise and professionalise both market and sector.

The level of organisation within a sector normally grows with the maturity of the market. In the case of green gas we recommend improving organisation and professionalism in order to speed up market development. The sector is currently fragmented. There are organisations, task forces and platforms for different parts of the supply chain and market segments. Combining forces into one single organisation and contact point is required. In particular, the production and sale of green gas, especially in the transport sector, should cooperate more intensively. Cooperating industry players and knowledge institutions can then, with a combined (virtual) knowledge base, support market parties in their professional development. Use can be made of the lessons and experiences from neighboring countries.

3.3 Medium-term actions: 2020–2030

In the medium term (2020–2030) there will be more freedom for essential changes to take effect. The preparations for this should already be underway. The general line is:

- Capitalising financially on the social benefits of biogas supply chains.
- Creating a level, stable and green playing field whereon competing options can be assessed pro rata on the basis of their social costs and benefits.

This leads to a number of key actions in the medium that must have an effect in the period after 2020:

Action 5: Work systematically to improve the (financial) value of the social benefits of biogas.

The additional value of converting biomass into biogas can make the entire biogas supply chain more interesting economically. To achieve this, the social values of the avoided emissions (CO_2, methane, etc.), the eventual application of CO_2, the fertiliser value of the digestate, and the contribution to the mineral balance, must all be estimated financially. The sector should also take the initiative to establish a programme, together with the government, regional authorities and research institutions.

Action 6: Develop a coherent plan for a green level playing field in the transport sector.

Green gas could be an interesting alternative in transport applications, particularly for heavier transportation. This requires a well-to-wheel approach in which the environmental benefits of green gas are accorded the same status as other transport options. This requires changes to the regulatory framework, which in turn require an intensive public-private partnership.

Action 7: Keep developing new raw materials and technology to increase the potential for green gas.

In the medium term, new sources of biomass can be developed, such as algae. Also, new conversion technologies can be given a chance at a better cost-benefit ratio, such as supercritical gasification and biorefining. This requires a coordinated research and development programme within the context of TKI Gas and TKI Biobased Economy.

4 Roadmap Gasification

4.1 Possible main routes

Compared to digestion, gasification technology remains immature: further technology developments are needed before good choices for a rollout strategy can be made. An important influencing factor is: which intermediate and end products are being aimed at? In other words, which conventional intermediate and end products will be the competitors? The pricing of competing products will ultimately determine the marketing route, and place demands on the cost of the conversion technologies in the supply chain.

There are three possible main routes for gasification, but for now it is too early to choose just one.

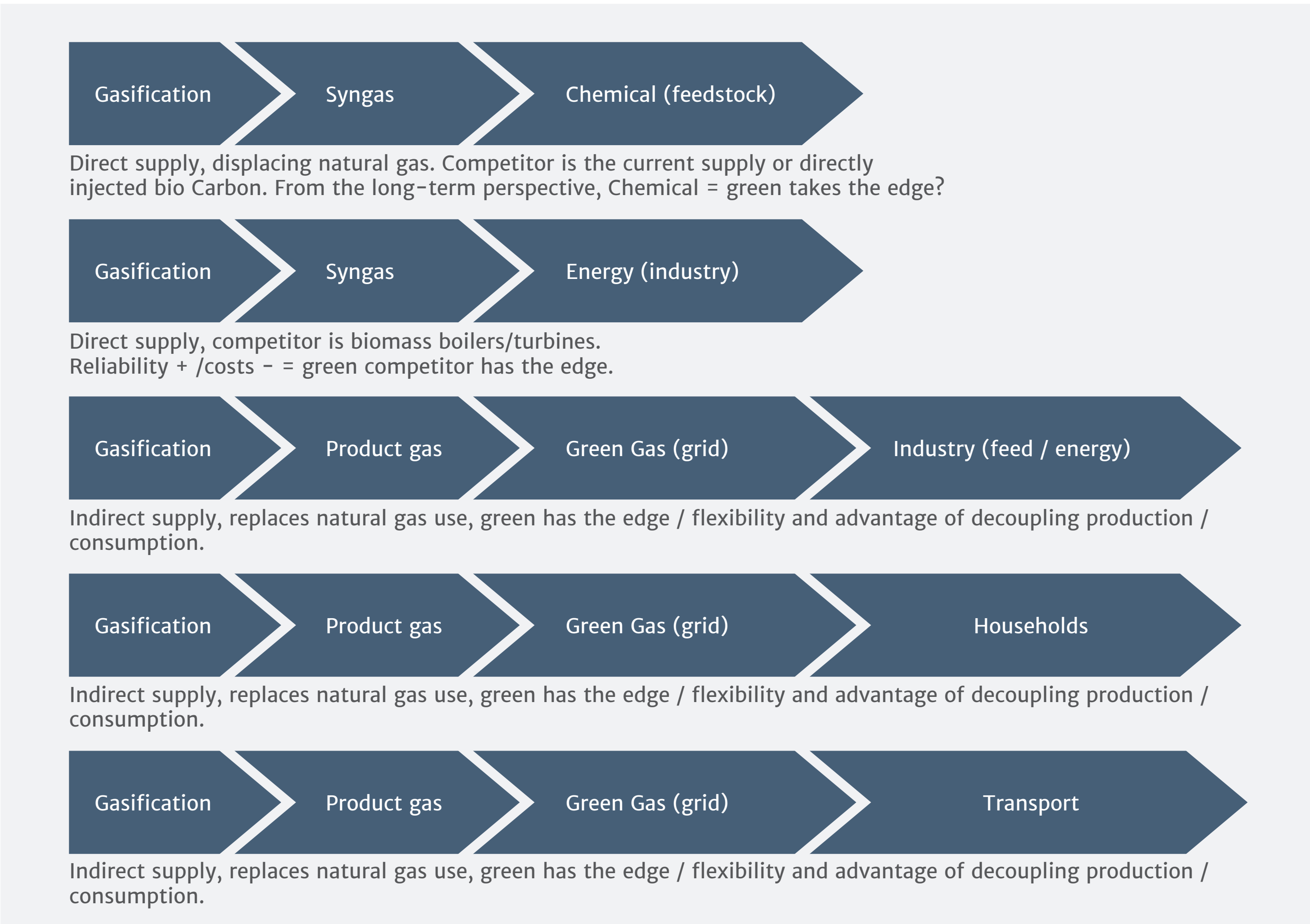


Figure 5. Main routes for gasification

The three main routes now emerging from ongoing technology developments are:

a) Biomass -> product gas/syngas

This product gas (a mixture of mainly H_2 and CO) is used directly in industry as a feedstock. Gasification will be incorporated, in an industrial port area, for the delivery of biomass and utilisation in industrial plants. The rationale for this route is that gasification can be part of a strategy for the greening of industry, and the biobased economy.

b) Biomass -> energy

In this route, the resulting product gas/syngas is used for direct energy generation (electricity, heat). It is competing with the direct use of biomass for energy production. Gasification is only the preferred option ahead of direct energy from biomass if there are efficiency benefits across the entire (regional) syngas supply chain in both transport and consumption.

c) Biomass -> green gas

In this route, the syngas is methanised into methane. The rationale here is to have to a new, green source that can make use of existing gas infrastructure, with all its advantages of cheap energy transport, cheap energy storage, and flexibility in a sustainable energy economy.

The aim is not to use gasification in preference to green gas (methane), but in areas where fossil natural gas can be replaced with syngas (components) from gasification.

The choice of route is, given the current state of the technology, not yet clear. In order to compare the routes with each other, the roadmap advocates assuming the possibility, where it is most logical, of replacing fossil natural gas, rather than moving straight towards a natural gas equivalent based on syngas. This offers the possibility of choosing the technology based on what ultimately turns out to be needed: syngas, hydrogen, Power-to-Gas or green gas.

4.2 Actions

Action 8: Develop gasification in a three-step strategy.

Given the current state of the technology and the choices that will have to be made later, the roadmap has come up with a three-step strategy:

1. Now until 2020: Technology development

   The aim is to show the different gasification options in parallel in order to compare economy, reliability, and relevance to the future of energy supplies. Technological development and gaining a better understanding of the options are central to this. The roadmap recommends using the tendering of technology in a PPP framework as a basis for this, in order to limit market risks. TKI Gas seems the most appropriate party.

2. 2020-2025: Market development

   This phase is characterised by a focus on the creation of market conditions that support the commercial rollout of gasification technology. Given the current state of the technology, choices can be made about the markets for which the options will be relevant. In this phase, the development of PPP financing is essential. Market parties and governments will have to work together to accelerate international development, both for the technology and for green gas.

3 2025–2030: Commercial rollout
This phase is characterised by large-scale investment in production and commercial rollout. Market players here have to move within prescribed government policy frameworks. As with digestion, we estimate that there will still be a financial gap, even after 2030, which will have to be compensated for based on the social value of green gas. Investigating the possibility of spreading both development and operating costs internationally is recommended.

4.3 Power-to-Gas

Power-to-Gas (P2G) deserves special mention here in view of the current interest in this topic. Due to the increasing use of non-controllable decentralised renewable energy production such as wind and solar, the need arises for the balancing of supply and demand, on various time scales: on an hourly basis, and also on a day/night and seasonal basis. The idea is that not only can the gas grid fulfil an effective and efficient balancing role, through buffering, you can also make gas from renewable electricity. This route would run from the production of hydrogen (H_2) by electrolysis, optionally followed by methanation with CO_2. The gas thus obtained can then be used in the existing gas grid. Hydrogen is currently, both technically and in terms of regulation, limited to mixing; methane is naturally more widely applicable.

At this time, the value of these functions is being studied and discussed. Although the last word has not yet been said on the matter, the impression from the first analyses that ECN and others are currently carrying out, is that the main advantages of using the abovementioned P2G option via the gas grid only occur with very substantial emission reduction percentages.

It is not the current expectation that those percentages will be required or achieved within the lifespan of the roadmap (2030). At this time, the Power-to-Gas option is therefore mainly being considered from the perspective of the need to develop the innovation via pilot schemes and demonstration projects, in order to have it available at a later date if required.

5 Roadmap
Green gas beyond 2030

5.1 The role of gaseous energy carriers

The development of biogas and green gas will be easier if the relevant parties also recognise there is a clear role for gaseous energy carriers in the overall energy system in the long term, beyond 2030. Then the research, development and investment efforts will have long-term value.

In future planning, the main focus is currently on renewable electricity, because the electricity grid is relatively easier to make greener than the heat supply and transport sectors. A sustainable energy supply (more efficient, renewable sources, low CO_2) also provides opportunities for gaseous energy carriers.

In the longer term, gaseous energy carriers can make an important contribution to sustainable energy management: greener natural gas, options for transport, and flexibility and storage in the energy supply.

Gases can fulfil various roles in sustainable energy management:

- Green gases in the natural gas mix: based on this roadmap, by 2030 some 3.7 billion m^3 of biogas, or 2.2 billion m^3 of natural gas equivalent green gas per year will be produced by digestion. In addition to this, there will also be an as-yet-undetermined amount of green syngas from gasification, depending on technology development; the (dry, woody) feedstocks for this will need to be imported.
- System function, storage, flexibility: gas can be regulated quickly and the storage and transport costs of gas per energy unit or per unit of energy per kilometre are relatively low. Flexibility is increasingly needed to cope with fluctuations in the supply of renewable solar and wind power.
- With reference to the above: electricity from wind and solar power can, at times when supply exceeds demand, be converted into hydrogen gas, which can be mixed into the gas system or used directly in transport or in industrial applications. It is also possible to convert the hydrogen into synthetic methane (Power-to-Gas), with the help of CO_2. In order to be carbon-neutral, this must be non-fossil CO_2 (for example, from digestion).

Action 9: Develop a shared perspective on a logical role for gaseous energy carriers in energy management that aims at profound CO_2 emissions reductions; this is desirable in order to give current research, development and investment efforts lasting value.

5.2 Application areas for gases

We can indicate qualitatively in which application areas the green and flexibility values of gases are expected to be highest. This provides guidance for the direction that business cases will have to take in the long term:

- Electricity is relatively easier to make sustainable than other sectors. By using renewable sources with zero marginal costs, the market price for electricity will fall, and hence the value of green electricity from biogas.
- Heat is more difficult to produce sustainably, and the extent to which this is so varies by market segment:
  - For new buildings in the built environment, various heat options can be considered, such as the inclusion of biogas/green gas use in the EPC (Energy Performance Coefficient) or EMG (energy performance standard for measures at regional level).
  - Existing buildings are harder to make more sustainable, with an assumed higher green value for Green Gas in that segment as a result.
  - Heat (often high-temperature) for industrial use is very difficult to make greener; that in principle makes the green value in that segment relatively high. But as there is a great deal of international competition in industry, there is relatively little willingness to pay in that segment. On balance therefore, the green value in industry will vary widely.
- Of all market segments, transport offers the fewest options for greening. The green value in transport is therefore expected be the highest.

On top of this, green value in market segments can also come from a flexibility value or bonus, in those cases prepared by industry and by policy makers. With the further introduction of intermittent renewable energy sources, the value of flexibility grows, and this can be provided by renewable gases.

5.3 Innovation agenda

Developing various roles for renewable gaseous energy carriers in sustainable energy management requires coordinated research and innovation efforts. It is essential that use is made of international experiences. Green gas sits on the boundary between the *energy system* and the *biobased economy*, and can play a vital role in connecting the two domains.

That role deserves a systematic approach, with the following important ingredients:

- Further analysis and development of the roles of gaseous energy carriers in the wider energy system, and the role that grid operators can play in this.
- Developing mono-digestion of manure in the short term.
- The development of new digestion feedstocks, particularly seaweed, in the medium term.

- Developing innovative and efficient conversion technologies such as supercritical gasification.
- Further development of gasification technology and Power-to-Gas.
- Systematic approach to the usability (biorefining concepts) and ‘added value’ of substreams such as minerals, CO_2 and proteins.
- Further development of marketing opportunities, in particular in transport (including bio-LNG).
- Development of policy instruments (regulations, incentives) that promote the use of biomass according the principles of cascading.

TKI Gas and TKI Biobased Economy are the appropriate parties to work out and address this agenda.

Action 10: Based on the roadmap, establish a sound innovation agenda that can be followed systematically, and updated every few years based on the lessons learned.

Green Gas Forum
Green Gas Green Deal (deal 33)

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