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Dossier

This paper is a part of the hereunder thematic dossier published in OGST Journal, Vol. 68, No. 5, pp. 789-946 and available online here

Cet article fait partie du dossier thématique ci-dessous publié dans la revue OGST, Vol. 68, n°5, pp. 789-946 et téléchargeable ici

DOSSIER Edited by/Sous la direction de : **A. Daudin et A. Quignard**

PART 2

Second and Third Generation Biofuels: Towards Sustainability and Competitiveness

Deuxième et troisième génération de biocarburants : développement durable et compétitivité

Oil & Gas Science and Technology – Rev. IFP Energies nouvelles, Vol. 68 (2013), No. 5, pp. 789-946

Oil & Gas Science and Technology – Rev. IFP Energies nouvelles, Vol. 68 (2013), No. 5, pp. 925-934

Dossier

Second and Third Generation Biofuels: Towards Sustainability and Competitiveness
Seconde et troisième génération de biocarburants : développement durable et compétitivité

Second Generation Gazeous Biofuels: from Biomass to Gas Grid

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Résumé — Biocarburants gazeux de 2e génération : du gisement de biomasse au réseau de gaz — La production de biocarburants gazeux et plus particulièrement de biométhane par voie thermochimique possède de nombreux atouts qui, d'ores et déjà, laissent supposer qu'elle doit être considérée comme une composante incontournable du futur panorama énergétique Français et Européen à l'horizon 2020. Cette filière innovante est basée sur l'utilisation d'un procédé de gazéification de la biomasse, grâce auquel un très large éventail de biomasses est accessible, garantissant un potentiel de développement significatif de la filière. En raison des avantages intrinsèques de la réaction de méthanation, les procédés de méthanation possèdent des rendements énergétiques globaux très élevés, dès aujourd'hui comparables à ceux des autres technologies de valorisation énergétique de la biomasse. De surcroit, ceux-ci peuvent être encore accrus par une valorisation de la chaleur fatale. L'existence de technologies adaptées à des installations de taille moyenne (20-80 MW biométhane) favorise une forte intégration au tissu local et s'inscrit de façon exemplaire dans le cadre du développement durable. Si la plupart des étapes du procédé de production de biométhane à partir de biomasse sont actuellement disponibles d'un point de vue commercial, la faisabilité technique de l'ensemble de la chaîne de production de biométhane à partir de biomasse n'a pas encore été démontrée à l'échelle industrielle.

Abstract — Second Generation Gazeous Biofuels: from Biomass to Gas Grid — *Gaseous biofuels and biomethane production by thermochemical pathway has many assets and, already, it should be seen as an essential component of future French and European energy panorama by 2020. As a biomass gasification process is used, a very wide range of biomass is accessible, guaranteeing a significant development potential of the sector. Because of the inherent advantages of the methanation reaction, methanation processes have very high overall energy efficiency, today comparable to other technologies for energy recovery from biomass. Moreover, these can be further enhanced by a waste heat valorization. The existence of technology adapted to installations of medium size (20-80 MW biomethane) promotes strong integration in the local area and is exemplary in a framework of sustainable development. Most of the steps of the process of biomethane production from biomass are at present commercially available. However, the technical feasibility of the whole production line of biomethane was not demonstrated to an industrial scale yet.*

INTRODUCTION

Amongst the various pathways for advanced conversion of biomass into biofuels, bioSNG (SNG: Synthetic Natural Gas) currently represents one of the most promising (Biollaz and Stucki, 2004), both for its ability to access virtually the entire lignocellulosic biomass source, due to its flexibility, and for its high overall energy efficiencies, the only ones amongst the 2nd generation processes to exceed 50%.

Due to the advantages intrinsic to methanation synthesis reactions:
- no synthesis of energy-greedy carbon chains (no hydroisomerisation step),
- high selectivity for methane synthesis: on average, over 95% of carbon monoxide conversion achievable (COMFLUX^{TM}/PSI fluidised bed process) (Gassner and Maréchal, 2009), methanation processes currently exhibit very high overall energy efficiencies, with an average of 55% to 60% (biomass to biomethane).

For the production of biomethane, methanation, through the use of gasification type thermochemical processes, allows access to a greater choice of biomass substrates and to a potential almost 10 times larger than biological methanisation (a potential of 24 MToe of lignocellulose *vs* 2.4 Mtoe of waste biomass (AFGNV/IFPEN/ADEME/GDF SUEZ study data, 2009)). Highly complementary processes (*Fig. 1*), biological methanisation and gasification/methanation target quite different types of biomass although each plays a role in the production of a single energy vector: biomethane (or bioSNG), whose physico-chemical and thermal properties are identical to those of natural gas.

1 POTENTIAL ESTIMATED AT MORE THAN 100 TWH IN FRANCE IN 2020

On the basis of data from biomass studies and databases available in France for energy (ADEME – Solagro, 2009; FAOSTAT (http://faostat.fao.org/) and Agreste (http://agreste.agriculture.gouv.fr/) databases, technical studies of the REGIX (http://www.biomasse-info-energie.fr/) and CARTOFA (http://www.fondation-tuck.fr/resultats/projets/2009/pop-up-2009-P01.html) projects, etc.), the maximum potential available for the 2nd generation biomethane pathway has been estimated at nearly 100 TWh available in France in 2020 and nearly 170 TWh in 2050 (*Gaz Réseau Distribution de France*[1], 2012).

This estimation is based on a combination of different technological scenarios in order to propose an industrial deployment of the pathway under realistic economic and environmental conditions. This estimation is based on diversified procurement scenarios (wood, straw, by-products of agribusiness industries, energy crops, etc.) which rely on currently available knowledge and feedback from pilot (Kitzler and Hofbauer, 2009) and industrial (Pröll *et al*., 2007) tests as well as feasibility studies (Mozaffarian *et al*., 2004). These studies also take into account the current uses of biomass for heating (individual, collective, industrial) and cogeneration applications without disturbing them. Lastly, this potential has been calculated assuming sustainable exploitation of these biomasses without disturbing the ecosystems and the traditional production systems.

This study confirmed in particular the advantage of a decentralised model of average power (between 20 and 80 MW_{SNG}) in the sustainable exploitation of mainly local biomasses and in order to obtain the best environmental balances.

This potential of 130 TWh must be compared with the 550 TWh (French Sustainable Development Ministry, 2011) of natural gas consumed in France on 2010. This estimation represents about 23.6% of French gas requirements, which could be covered by the 2nd generation biomethane pathway. This potential must be combined with the biogas pathway from methanisation which targets other resources (wet organic waste) and will continue to develop in parallel, driven by high environmental considerations, without competing with the 2nd generation.

2 PROCESS CHAIN AND EFFICIENCIES

Before production of 2nd generation biomethane can start, the biomass must be first selected and obtained. Conventional production of BioSNG is based on a method with 4 key individual steps (*Fig. 2*) composed of a high temperature thermochemical step: gasification (1) followed by a syngas treatment system (2) (syngas is rich in CO, H_2 and CH_4) to eliminate tars and inorganic compounds and essential for correct operation of the methanation catalytic step (3). A final methanation gas conditioning step (4) is required to ensure that this BioSNG complies with the standard specifications for mains natural gas (NCV, Wobbe index, composition, etc.).

The biomass to biomethane thermochemical conversion process can achieve an overall energy efficiency of about 55% to 60% with the technologies currently available on the market (Gassner and Maréchal, 2006) and a

[1] GrDF: French gas distribution network operator.

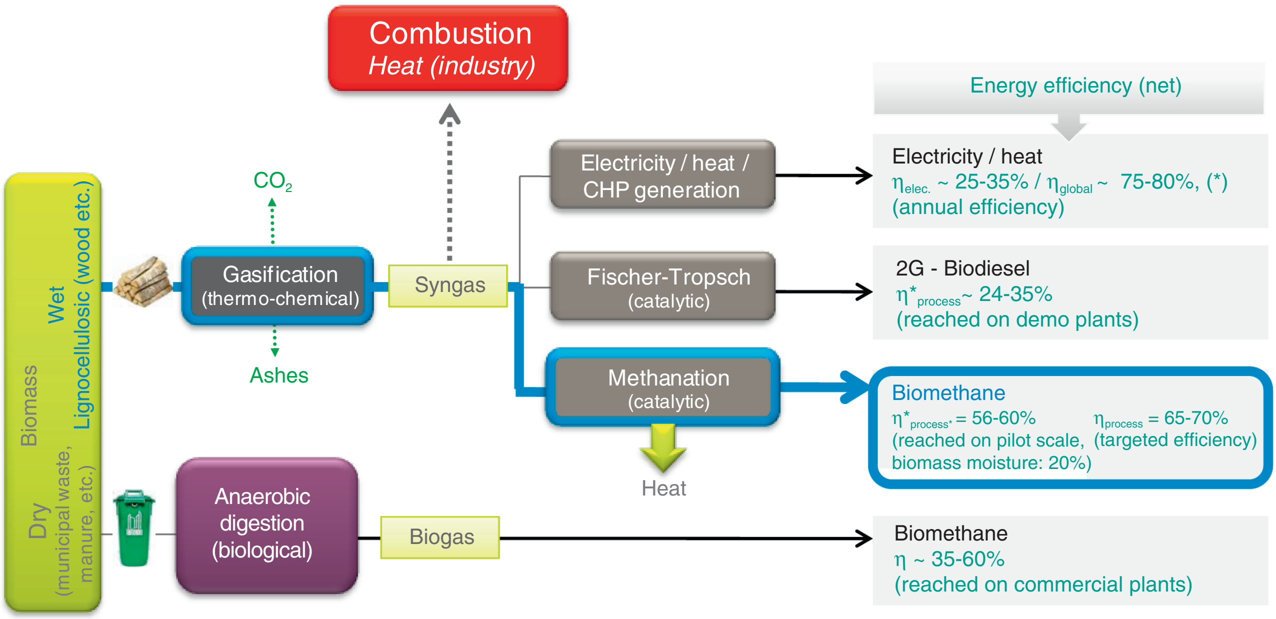

Figure 1

Production pathway of second generation biomethane.

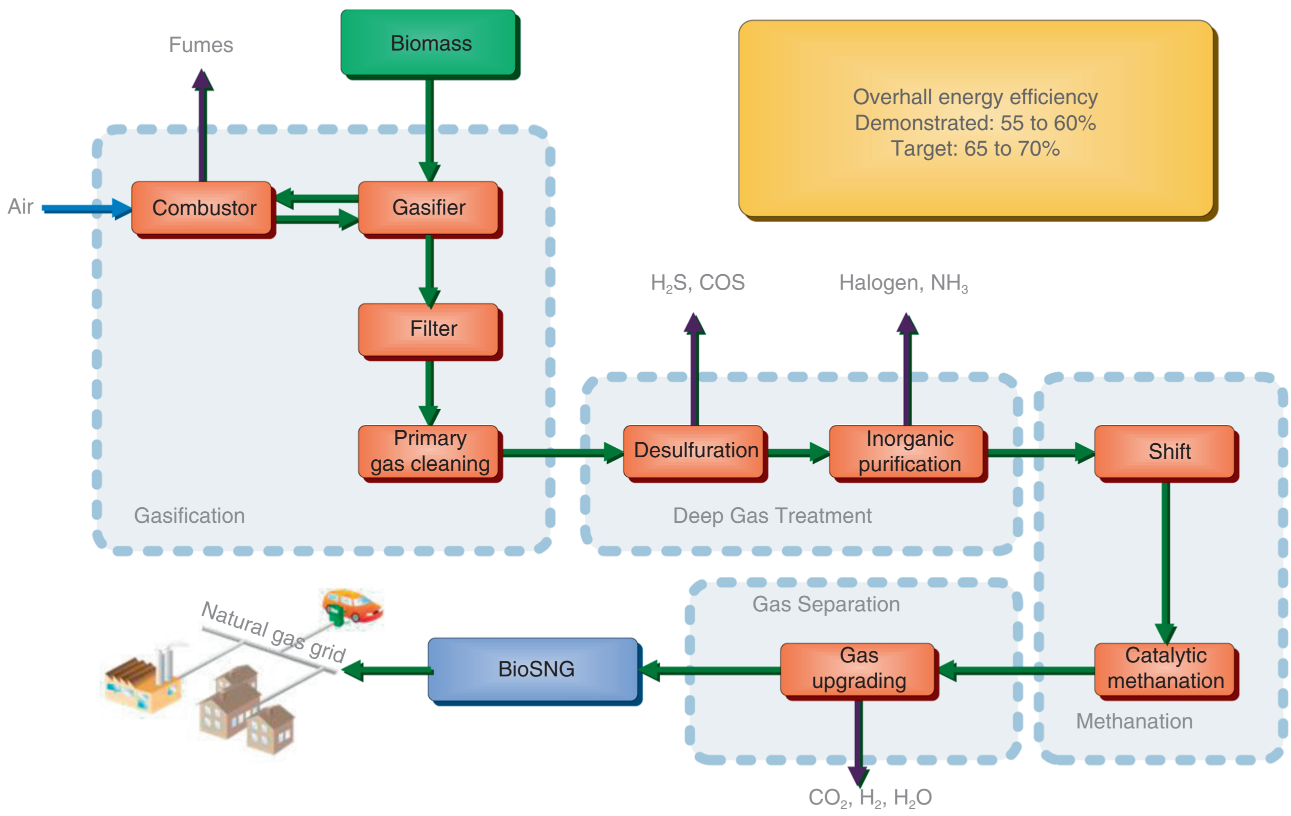

Figure 2

Biomass to 2G biomethane thermochemical conversion process.

carbon conversion efficiency of about 22% (ANR VEGAZ project).

For some process lines such as indirect fluidised bed gasification, the excess heat produced can be used on the installation and a “green” heat/SNG cogeneration process proposed without modifying the process chain. “Green” trigeneration (SNG/heat/electricity) is also possible by optimising the architecture of the methanation and syngas treatment process.

The R&D studies undertaken in various R&D programmes such as the GAYA project expect to reach maximum net energy efficiencies of about 65% to 70% (Zwart and Boerrigter, 2005; Boerrigter *et al.*, 2006; Mozaffarian *et al.*, 2006). These figures have also been confirmed by the Gas Technology Institute in the United States (Bush, 2008) which estimates the energy efficiency of this pathway at a maximum of 68% (biomass to biomethane) from an FICFB fluidised bed gasifier[2] and a standard fixed bed process (Haldor-Topsoe).

The following technical barriers are currently observed:

– acceptability of a wide range of biomass in the gasification reactors. Fluidised bed technologies are more flexible than entrained bed reactors (Hofbauer, 2008);
– improvement of the gasification step efficiencies with, in particular, better heat recycling and in-depth integration of the process within the plant;
– improvement of the efficiency and cost of purifying the syngas of organic and inorganic pollutants produced during biomass gasification;
– development of biomass syngas methanation catalysts offering longer lifetime;
– gas separation systems which are more efficient and which consume less primary energy.

3 A PATHWAY AT THE BRINK OF INDUSTRIALISATION

Two process chains based on the same technical principles but involving relatively different processes are currently available at commercial scale:

– the configuration resulting from the coal pathway (manufacturers Haldor-Topsoe, ECN, etc.) created in the 1980s to produce high-power optimised units (100 to 500 MW_{SNG}) on coal base with a pressurised entrained bed type gasification process and a pressurised fixed bed methanation reactor of conventional design (Woodcock and Hill, 1987). Although currently the most technically mature, this pathway still requires further improvements to the syngas purification step to take into account the differences in biomass composition compared with coal. However, these high-power installations require very large volumes of biomass, generally available through massive imports which are incompatible with the development of integrated local pathways;
– the configuration based on a fluidised bed type indirect gasifier and on a fluidised bed methanation reactor. This configuration operates at a pressure close to atmospheric for the gasifier and at a pressure of less than 10 bar for the methanation reactor. It seems suitable for small and medium powers (10-80 MW_{SNG}). The feasibility of these technologies has been demonstrated at pilot scale (1 MW_{SNG}) on the Güssing site in Austria by the consortium CTU-PSI-REPOTEC (*Fig. 3*). The advantage offered by this configuration, intended for installations of average size, is that the biomass can be used not only to produce SNG but also for other applications such as heat and electricity, depending on local requirements and potential synergies (proximity of companies, heat networks, etc.). It opens the door to cogeneration and even trigeneration (bioSNG/heat/electricity). The average size of these

Figure 3

Methanation pilote plant of Güssing.

[2] FICFB gasifier: Fast Internal Circulation Fluidized Bed.

installations allows for significant integration with local biomass procurement pathways in order to privilege short logistics circuits and sustainable development.

While most of these steps are currently available at commercial scale, the technical feasibility of the overall biomass to biomethane production chain has not yet been demonstrated at industrial scale.

4 PLAYERS IN THE 2G BIOMETHANE PATHWAY

4.1 MW_{SNG} Methanation Pilot Plant at Güssing (Austria)

The biomass to SNG production pilot plant results from the 6th European PCRD "BIO-SNG" whose aim is to implement and demonstrate the production of biomethane from solid lignocellulosic biomass.

The project started in 2006 for a period of 36 months, with the installation of a 10 kWth methanation pilot operating first on reference gas, then on real gas, to study the kinetic and catalytic aspects of fluidised bed methanation.

The main partners and technological backers were REPOTEC (Austria), PSI (Paul Scherrer Institute, Switzerland), the University of Vienna (Austria), *Güssing Biomasse Kraftwerk* (the company operating the biomass gasification cogeneration plant at Güssing, Austria) and *CTU-Conzepte Technik Umwelt* (Switzerland).

The 1 MW_{th} (*i.e.* about 100 Nm^3/h of SNG) pilot plant was coupled to the 8 MW_{th} gasification cogeneration commercial demonstration plant (REPOTEC process) in indirect fluidised bed Güssing (Austria) in bypass with respect to the line taking the syngas to the motor producing the electricity sold on the grid. The REPOTEC process is currently one of the rare biomass gasification processes to have demonstrated its industrial robustness with a service duration of 7 000 h/year (operational availability > 80%) since 2005, *i.e.* over 6 consecutive years, burning syngas in a cogeneration engine, the excess heat from gasification being used in the Güssing urban network (BioSNG European project (BioSNG: Project No. TREN/05/FP6EN/S07.56632/019895, www.bio-sng.com) and *GDF SUEZ* internal document). The town of Ulm in Germany (Stadt Werke Ulm) selected the REPOTEC process to build its new 13 MW_{th} and 4.9 MW_e biomass cogeneration plant, commissioned in 2012.

The Güssing methanation pilot has been operational for a limited period of about 6 months. Some of the syngas produced by the gasifier was sent to the pilot then returned to the gas engine as biomethane, with no impact on cogeneration operation. All the long-term test phases were carried out in 2009 and 2010 with a total of more than 1 000 hours testing on the entire downstream system.

4.2 PSI: Paul Scherrer Institute (Scale 10 kW_{SNG})

Since 2005, PSI has conducted an experimental programme to develop a fluidised bed methanation process around a 10 kW_{SNG} laboratory/pilot installation. The studies focused mainly on the catalytic aspects of methanation and more especially on the problem of sulphide poisoning (Biollaz and Stucki, 2004).

4.3 ECN (National Energy Center of the Netherlands) Pilot Project at Petten (the Netherlands)

Since 2003, ECN has developed a programme aimed at developing technologies to convert biomass into energy. One of these sub-programmes deals with the conversion of lignocellulosic biomass into biomethane. ECN's vision is to develop very large scale units (> 100 MW_{SNG}), similar to those built for coal in the 1980s.

They are currently equipped with a 1 MW_{th} pilot gasifier built in 2008 on the ECN site at Petten and coupled with a 1 MW_{th} OLGA gas washer. Their objective is to couple this installation to an electricity generation demonstration plant (engines) in partnership with the Dutch company *HVC* (specialised in waste incineration). ECN also operates a 30 kW_{SNG} SMR type fixed bed methanation laboratory unit used since 2003 to test the effect of syngas quality (*via* a laboratory OLGA unit) on the performance of the methanation catalyst (Zwart and Boerrigter, 2005; Boerrigter *et al.*, 2006).

ECN also has in-depth knowledge of methanation processes and technical data concerning the various process steps. In Europe, it is one of the best organisations working on the field of biomethane (Mozaffarian and Zwart, 2002; Mozaffarian *et al.*, 2004, 2006; Ecn-Biomass, 2005).

Their objectives are:

- demonstration in 2012 of a 10 MW_{th} cogeneration installation in partnership with HVC (waste retreatment and incineration company in the Netherlands) based on the MILENA and OLGA processes;
- demonstration in 2015 of a 50 MW_{SNG} installation with HVC based on the MILENA, OLGA and SACHA processes and in partnership with an external methanation process supplier;
- vision for the development of the SNG pathway:

– pilot phase 2009 to 2013-14 (size 1 MW_{SNG}): in progress, but focusing only on gasification,
– demonstration phase: 2015 to 2016-18 (size 10 MW_{SNG}),
– commercial phase: from 2018 (size 100-1 000 MW_{SNG}).

4.4 GAYA Project: Towards Industrialisation of the Pathway

The purpose of the GAYA project is to create, by 2017, a reliable, profitable and highly energy-efficient pathway for the production of "2G biomethane", that can be commercialised as fuel or second generation gas biofuel and transported *via* the natural gas network. Eleven industrial and university partners, coordinated by *GDF SUEZ*, participate in the project which was launched in June 2010. It is cofinanced by the *Agence Française pour le Développement et la Maîtrise de l'Énergie* (ADEME: www.ademe.fr/) through the Investments for the Future programme.

The project aims to guarantee that these new activities are in line with a perspective of sustainable biomass conversion, under the best possible social and environmental conditions, especially with respect to the other pathways using biomass. The objective of the GAYA project is therefore to industrialise a decentralised vision of the 2G biomethane pathway with very high efficiency biomethane/heat cogeneration installations of average power fuelled with local biomass.

The project consists of a 7-year R&D programme designed to remove the technological and environmental barriers, which include: the influence of biomass and its pretreatment, optimisation and modeling of gasification and methanation processes, use of the biomethane produced by injection into the network, evolutions towards the concept of biorefineries. The project also deals with all related aspects: use of by-products and limitation of effluents, optimisation of energy integration, environmental and societal aspects.

The R&D program is based in particular on an open platform of demonstrators, federating French and European players, which will be inaugurated in 2013.

5 ENVIRONMENTAL BALANCE

A Life Cycle Analysis (LCA) of the pathway was conducted during the ANR VEGAZ[3] project. Consisting of four stages, the LCA provided a global vision of the environmental impacts of a pathway, identified possible pollution displacements, evaluated which type of environmental impact prevails during a product life cycle and which steps or special elements of the product contribute most in terms of environmental impacts.

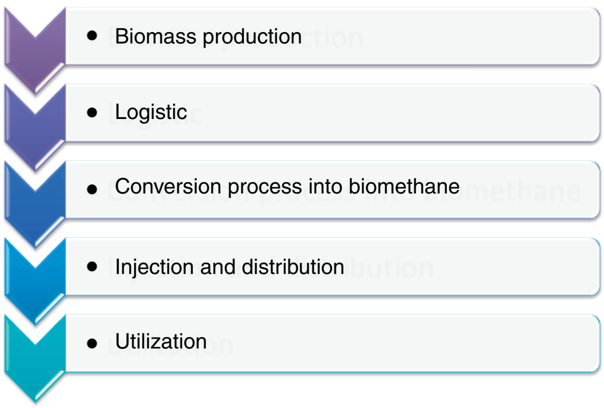

Figure 4

Life cycle stages considered in the study.

The objective of this LCA was therefore to evaluate, in greater detail than the highly simplified generic studies currently available in the literature (Müller-Langer *et al.*, 2009), the environmental impact of the entire 2G biomethane production pathway through the use of the following four indicators: climate change, terrestrial acidification, aquatic eutrophication and consumption of non-renewable energies.

This first study, based on a unit of average power 20 MW_{SNG}, *i.e.* about 37 MW_{th}, located as close as possible to the biomass source (about 84 000 t of forest biomass per year), concerned all stages in the life cycle to provide a global vision of the pathway.

The assessment was made in a French context representative of the conditions and technologies available in 2010.

The system studied was broken down into six major sections, including two main process blocks (*Fig. 4*).

5.1 Contributions of the Life Cycle Stages to Environmental Impacts

The contribution of the life cycle stages to the environmental impacts is illustrated in Figure 5.

[3] Deliverable 2.2, non public but available upon request from the *Agence Nationale de la Recherche* (ANR).

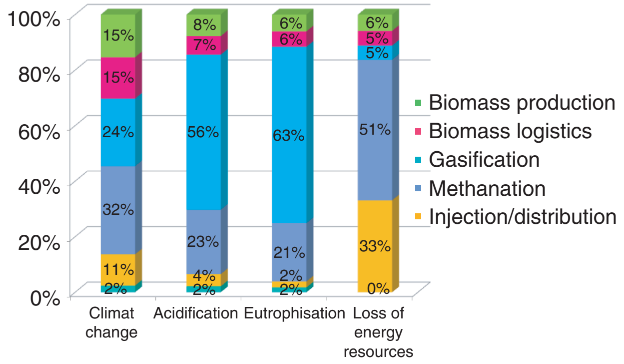

Figure 5

Contribution of the various life cycle stages to environmental impacts.

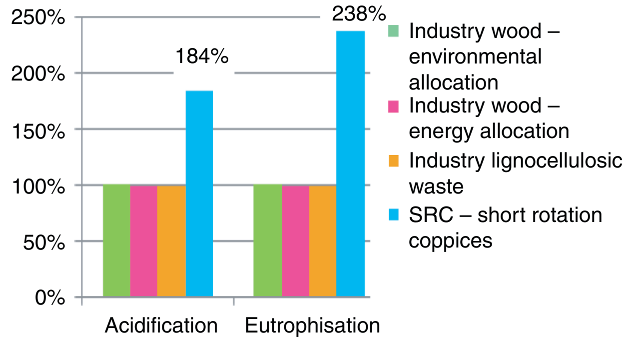

Figure 6

Effect of biomass type on acidification and eutrophisation.

With a contribution of more than 55% on all impacts, biomass conversion (gasification and methanation) represents the stage with the highest impact on the life cycle of the pathway.

These results can be explained by:

– direct emissions from gasification (NO_x et SO_x) responsible for 38% of acidification and 35% eutrophication;
– lastly, the electricity consumption, electricity being the main energy resource used in processes, especially for compressors (81% of process electricity consumptions), which represents 37% of non-renewable energy consumptions.

5.2 Impact of the Biomass Type

Figure 6 shows the results of the terrestrial acidification and aquatic eutrophisation assessments for the various types of biomass studied.

Use of Short Rotation Coppice (SRC) increases the total impacts by more than 104% for climate change and more than 151% for aquatic eutrophication. This sharp increase is mainly due to the additional inputs of this pathway such as the need for N, P, and K fertilizers to optimise biomass growth. This study nevertheless demonstrates that the SRC should remain an additional solution for the procurement of biomass units in order to meet the sustainability criteria imposed by the European Commission for biofuel production units.

These results must be considered with caution however, since the data on SRC obtained from the European RENEW project, which are the most complete in terms of impacts identified, are maximum values.

Concerning the humidity rate of the chips fed into the gasifier, since the heat input requirements are provided by the heat produced by the processes, there is very little variation in the impacts ($\leq$6%).

5.3 Recovery of Heat Excess

The comparison of a scenario with and without external recovery of the surplus heat (Gassner and Maréchal, 2006, 2009) demonstrates that external recovery of the surplus heat can significantly reduce all impacts with up to −26% for climate change. Consequently, when local conditions allow (proximity with industries consuming heat, heat networks, etc.), recovery of the surplus heat should be given priority. This first study will continue within the framework of the GAYA programme, which aims to develop in-depth integration of the conversion process by taking into account flexibility for external recovery of the available heat (Jurašcík *et al.*, 2009; Valle-Marcos, 2009). Note that if there are no local outlets for the heat, it can be used to generate electricity (*via* a generator operating on the principle of the Rankine cycle, for example).

5.4 Energy Efficiency

The net energy efficiency levels of 2G biomethane must be compared with those of the other technological pathways for biomass to energy conversion. They currently represent about 70-80% (ADEME) for the production of heat alone and 50-80% for electricity-heat cogeneration from biomass (depending on the variation in heat

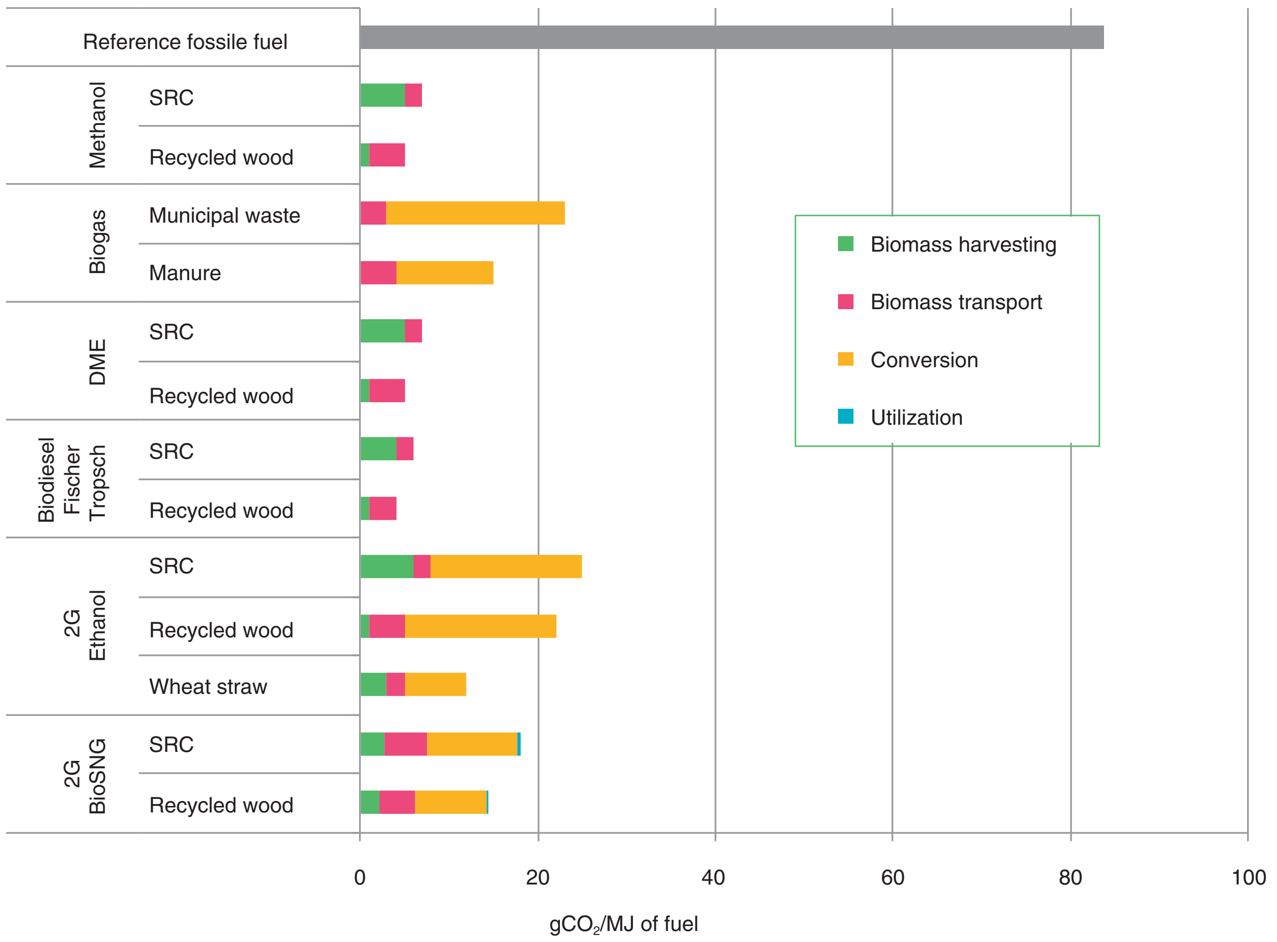

Figure 7

GHG balance of second generation biofuels.

requirement). We observe that the energy efficiency currently achievable with biomethane already compares with that of existing technologies. In addition, it will provide the flexibility of the gas energy vector, since there are numerous applications for natural gas: heat, electricity, transport.

5.5 Supply Distance

One of the major advantages of the 2G biomethane pathway is the fact that production sites can be set up near the biomass sources. The current grid of natural gas transport and distribution networks is such that biomethane can be easily injected, irrespective of the site location, with a minimum radius of 10 to 25 km. Sites of moderate size, which are therefore easy to supply with local biomass, are the easiest to set up. The advantage of this proximity is demonstrated by the fact that, when the chip transport distance increases from 50 km to 200 km, the impact of the reference scenario increases by 35% for climate change and by 12% for the consumption of non-renewable energies.

5.6 Greenhouse Gas Emissions

The environmental performance of biomethane in terms of greenhouse gas emission has been compared with the data contained in Directive 2009/28/CE for the other second-generation liquid fuels (*Fig. 7*). This directive sets as sustainability criterion for second-generation biofuels the following objectives: –35% and –60% greenhouse gas emissions compared with the reference fossil fuels for installations in which production will start on 1 January 2013 and 2018 respectively.

Based on the results obtained in this study, the biomethane pathway complies with the requirements of the directive with gains of −78% and −83% observed for scenarios with and without external recovery of surplus heat. This pathway ranks favourably with respect to the other second-generation biofuels and its balance is comparable with those obtained by the other second-generation pathways such as BtL which do not include conversion and use in their balances. Future studies could also take into account electricity self-sufficient biomethane units (presence of electricity generation units running on syngas or heat available directly from the process).

CONCLUSION

The thermochemical biomass to biomethane production pathway offers numerous advantages:

– demonstrated a minimal overall energy efficiency of 55%, which in the future could reach 80% in an integrated and optimised design (very high efficiency biomethane and heat cogeneration);
– sustainability (CO_2 avoided) due to the energy efficiency and modest size of the installations (10-100 MW biomethane) reducing the impact of biomass transport;
– development potential of 100 TWh of biomethane by 2020 and more than 185 TWh by 2050, *i.e.* more than 2.6 times the energy biomass development objective in France for 2020 (6 Mtoe, Grenelle 2, 2010), the ability to make almost a quarter of French natural gas consumption "green" in 2011;
– flexibility guaranteeing access to virtually the entire biomass source, especially lignocellulosic;
– highly positive environmental balance with a current reduction of nearly 83% in greenhouse gas emissions for the most favourable case;
– existence of technologies adapted to installations of reasonable size favouring high integration in the local fabric (biomass supply pathways privileging short logistic circuits, waste heat recovery) guarantees of optimised energy efficiency and ideally suited to a sustainable development approach;
– use of the existing gas transport and distribution infrastructure which perpetuates an investment already financed by the public community and without any adaptations of end user appliances.

While the feasibility of the entire production chain has not yet been demonstrated at industrial scale, the thermochemical biomethane production pathway can already be considered as an essential part of the future energy landscape.

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Manuscript accepted in July 2013
Published online in October 2013