BIOMASS GASIFICATION FOR PRODUCTION OF "GREEN ENERGY" (COMBINED HEAT AND POWER, GREEN METHANE...)

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1. INTRODUCTION

The development of renewable energy is a major topic all over the world, in response to various environmental (reducing greenhouse gases emissions), geopolitical (limiting dependency on fossil fuels) and economic (developing new green industries) issues.

The European Union aims to use 20% of renewable energy in the energetic consumption in 2020, reduce by 20% its greenhouse gases emissions and increase of 20 % its energy efficiency. Among the renewable sources, biomass is the resource with the greatest potential in Europe, estimated around 212 Mtoe. Its use today represents 78-80 Mtoe, which is already the first renewable energy before hydro-electricity for example. Today, biomass can be burnt (for heat and/or power production) or used to produce first generation bio-fuels but its potential is still under-exploited. For this reason, developing biomass use is strategic and essential to meet the energetic goals fixed by the European Union. Among these goals, biomass for energy resources diversification, for fossil fuel consumption limitation and for CO\textsubscript{2} reduction should be underlined.

France is one of the European countries with the largest biomass potential. It may be considered that the potential for energy is today 15 Mtoe, mainly composed of woody biomass (forestry, forest residue). In addition, France still needs to promote renewable production to catch up and to satisfy its own obligations (23% of renewable energy in the energetic consumption by 2020). Biomass can also be seen as a new economic opportunity of development for land and countries, as it will create new activities for resource management and pre-treatment, and develop local employment especially in rural areas.

Gasification is a very promising way for biomass conversion, as it opens the way to a wide range of valorisations, especially to produce storable and transportable energy vectors. This document aims to present the main issues of biomass gasification and to explain how biomass can be used to produce a green substitute of Natural Gas, which could tomorrow be injected into the natural gas grids and used like natural gas.

2. BIOMASS GASIFICATION: A PROMISING WAY TO PRODUCE GREEN METHANE

2.1. Gasification and methanisation: two different ways for biomass valorisation, comparison and interests

Gasification and methanisation are two different ways of using biomass, with one major difference: while gasification is mainly dedicated to dry biomass (water content between 20 and 40% is recommended) mainly composed of ligno-cellulosic material, methanisation is operated with wet biomass (water content above 50%), based on fermentable compounds. In addition, gasification requires processes at elevated temperatures (higher than 700°C), which distinguishes it from biological processes operated at room temperatures to produce biogas.

- Process description:

**Methanisation** is a biological process that occurs in anaerobic conditions: it is the degradation of organic matter. It produces a biogas, which can be cleaned and upgraded to separate bio-methane, used to produce heat, electricity, or used as bio-NGV in vehicles.

**Gasification** is a thermo-chemical partial oxidation of organic matter due to high temperatures. It generates a fuel syngas, which can be either used to produce electricity, or transformed and upgraded into SNG (Substitute Natural Gas) or into BTL (Biomass-to-Liquids). It can also be converted in hydrogen.
2.2. **Gasification: principle and ways of valorisations of bio-energies**

- **Gasification: definition – principle**

Gasification **is an incomplete thermo-chemical oxidation** at elevated temperature (higher than 700°C, the temperature can reach 1400°C), which allows producing low calorific fuel-gas thanks to a gasification agent, air or steam. This gas, assimilated to a syngas, is mainly composed of CO, H₂, CH₄. It also contains contaminants that need to be removed, like tars and inorganic compounds.

It is important on biomass gasification to consider two critical issues:

- The calorific value of the syngas may differ consequently from one to another process depending on the gasification agent use: in case of air, the LHV of the syngas is low (1 - 2 kWh/Nm³) and the syngas valorisation is difficult into engines. Use of oxygen or steam avoid this decrease of LHV, which can reach 4 - 5 kWh/Nm³, making easier the valorisation into engines or turbines,

- Tars content is a critical point for gasification: all gasification processes produce more or less tars and the specific treatment requested to clean the syngas is a critic topic in regard of costs and profitability of the projects. It is why a process design made to reduce production of residual tars has to be privileged.
Principle of gasification processes

- **What are the interests of biomass gasification?**

  Biomass gasification can be considered as one of the best ways of reasonable valorisation of biomass potential. Several arguments justify and sustain biomass gasification developments:

  - Biomass gasification, compared to direct biomass combustion, leads to the production of a transportable energy that can be stored and used far away from the resource.

  - Biomass gasification is a common first step, which opens a wide range of valorisation: biomass can be transformed either into heat and power, either into bio-fuels. Those fuels can be liquid fuels (BTL) or gaseous fuels (SNG for example).

  The syngas issued from the gasification process can be used to produce:

  - **Power through engines:** syngas can be directly burned in engines, for combined heat and power production (CHP). The interest is that the electric efficiency is higher than with classic combustion: Gasification can lead to electrical efficiencies up to 30-32 % (against 17-25% for combustion) and achieve global yield of 80-85 %.
  
    o Energy efficiency “biomass to electricity”: 30 %.

  - **Green methane through Methanation:** it consists of a catalytic chemical conversion of the syngas into methane (CH₄), also called SNG (Substitute Natural Gas), after different steps of treatments. This “green methane” may be injected into the grid and used as a gaseous bio-fuel for vehicles (bio-NGV) or as a bio-substitute of natural gas. Its characteristics (LHV, Wobbe index) are very similar the natural gas’s ones.

    o Energy efficiency “biomass to SNG”: 55-65 %,

  - **Liquid Bio-fuels through Fischer-Tropsch synthesis:** this reaction leads to Liquid bio-fuels (BTL) production, which is among the 4 ways, the one with the lowest efficiency.

    o Energy efficiency “biomass to BTL”: 25-35%.

  - **Pure hydrogen or hythane (blend of hydrogen and methane) through Shift:** The syngas can be turned into hydrogen, after a complete water gas shift reaction.
The next figure shows the different ways of valorisation for the syngas issued of the gasification step.

Figure 2: Four different ways of biomass valorisation

- **CHP and bio-SNG**: two different ways for decentralized energy production

  As the synthesis of liquid bio-fuels requires a great number of complex single operations, it is then necessary to invest in huge plants (100 MWth) of BTL to achieve a cost-effective process. CHP units allow profitability at small to medium scale and SNG is expected to do the same. Those two valorisations can be considered as **decentralized biomass units**, which present many advantages:

  - Reduce biomass transportation: distances should be below 100km to limit environmental impact,
  - Limit heat production, which makes valorisation to a local customer easier,

  Moreover, SNG compared to BTL has a higher energetic yield of process, and this difference is then increased with the combined effect of the relative easiness of heat valorisation (compared to BTL).

The decentralized way for gasification seems to be the one of the best opportunities to better valorise biomass to preserve local landscape and to optimize energy conversion. Both CHP and SNG can lead to decentralized units.

The four different ways of syngas valorisation are not in the same scale of time: while CHP is a short-term issue, SNG and BTL are medium term valorisation. Today, CHP project are beginning to be enough profitable to be launched and will help developing gasification. SNG is a promising green pathway, for a local use or transportation through the natural gas grid.
2.3. **History of biomethane production**

The methanation processes aim to produce a synthetic gas with a very high level of methane and a LCV similar to the natural gas’s one, from liquid, solid or gaseous fuels. The first enhanced developments on methanation processes have started in the early 70s, mainly in the States, due to an important lack of natural gas. Several processes have been developed to produce SNG:

- From liquid fuels in the early 70s, but those developments were stopped after the very high increase of the fuel prices in 1973-1974,
- From coal: many studies have been led between 1974-1975 and 1980, in particular by Gaz de France, in order to study the development of SNG production plants from coal. Most of the research programmes dedicated to those technologies were stopped in the 80s after the decrease of the fuel prices.

Today, linked to the necessary development of renewable, which increases the interest of the biomethanation way, new research programmes emerge on the feasibility of producing a green SNG from biomass gasification and catalytic methanation.

2.4. **The whole chain of biomethane production**

Even if many works have been done in the past years, the adaptation of the methanation process to biomass presents several technical and economical gaps to be removed before reaching commercial development. However, this way appears from today as a very promising way.

Today, the most “classical” biomethane way contains four main steps :

- Gasification,
- Syngas purification,
- Methanation,
- Bio-SNG final upgrading before injection into the natural gas grid.

Other processes are under study, with a unique step combining gasification and methanation, but their development is still less advanced. They present the advantage to avoid the purification step, often complex and expensive.

- **Gasification**

The principle of gasification has been previously detailed. The next criteria will influence the choice of the gasification process before methanation :

- High level of methane in the syngas,
- Ratio [CO]/[H2] nearest as possible of 3,
- No dilution of the syngas with air (indirect gasification).

Those criteria are quite different of those requested for liquid biofuels production, for which even a small amount of methane implies a decrease of global efficiency.
• **Syngas purification:**
That step is the most critical and the main issue of the whole bioSNG production chain. The catalytic process of methanation is very sensitive to some pollutants, which presence, by poisoning the catalysts and reducing drastically their lifetime, increase operational costs and decrease the plant availability. Sulphur, chlorur and tars are the most critical components and should be removed at a very low level (< ppm). Nevertheless, the purification processes have to be chosen not to crack or absorb the methane present in the syngas.

Several processes, at low or high temperature can be used, but they still need optimisation to improve their efficiency.

That step can also include a water gas shift step to convert CO into H2 and increase the Hydrogen concentration, according to the next reaction:

$$\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$$

• **Methanation**
Methanation is a catalytic process, which principally consists in transforming CO (and CO2) and H2 into methane. Two reactions mainly occurs:

\[\begin{align*}
\text{CO} + 3 \text{H}_2 & \leftrightarrow \text{CH}_4 + \text{H}_2\text{O} & -206 \text{ kJ/g.mol}^{-1} \ (298k) \ (1) \\
\text{CO}_2 + 4 \text{H}_2 & \leftrightarrow \text{CH}_4 + 2 \text{H}_2\text{O} & -167 \text{ kJ/g.mol}^{-1} \ (2)
\end{align*}\]

Even if a ratio \([\text{CO}]/[\text{H}_2]\) of 3 is requested for methanation, some processes admit lighter ratio: the water gas shift reaction is carried out in the methanation reactor.

Methanation is a very exothermic reaction, but, for technical reasons (optimisation of the conversion ratio, preservation of the catalyst in the reactor…), the temperature has to be kept at a relatively low level. This is why the optimisation of heat flows generated during that step is capital to:
- Keep the reactor temperature under 450°C,
- Optimise the catalytic reaction into the methanation reactor.

Two different technological ways exist for methanation:
- **Fixed beds** can work under pressure, are easier to operate and have the more important return on fossil fuels.
- **Fluidized beds:** they have not yet been commercially developed but they allow a better valorisation of the heat flows and are less sensible to pollutants.

None of those technologies has yet been tested at an industrial scale with a syngas produced from biomass.

• **BioSNG upgrading before injection**
The last step consists in conditioning the bioSNG produced, and especially, cleaning the bioSNG from water and \text{CO}_2. Depending on the injection point, several additional treatments can be applied, such as compression, odorisation…
• Conclusion: a very promising way, or how renewable can support the natural gas business

The global efficiency of the whole production chain is very high (global efficiency from biomass to bioSNG is today evaluated around 55% and could reach in the future 65%), especially compared to the efficiency of the BTL production (around 25-35%). That efficiency can be improved by the valorisation of the heat from the methanation step. Smaller plants are advantaged, as they can find more easily a local customer for the heat.

BioSNG can be used for decentralized production of energy (size under 100 MWth). The benefits of a decentralized choice are:

- Avoiding transportation of biomass on long distances (supply radius < 100km)
- Possibility of local valorisation of the heat co-produced: for small and medium plants, which produce reduced amounts of heat, it is easier to find a local customer.

BioSNG is a very promising way to support the natural gas business. Biomethane, with similar characteristics as natural gas can be easily transported via the natural gas grid with very low emissions and energy losses, nor without any need to build new infrastructures.

BioSNG can be used in the same way as natural gas, for any industrial or residential applications, without anymore risk than natural gas. BioSNG can also be use as a green gaseous biofuel for vehicles, which is a major issue, as the transport sector is one of the most significant producers of greenhouse gases emissions.

That second generation technology is environmentally friendly, as it can use the entire part of the plant. The biomass potential around the world is very important and the competition with food very limited.

In conclusion, Biomass Gasification is highly efficient, close to resource, close to customer, and in long term will transport bioenergy to end-user through gaseous vector. A significant part of the methane sold could be, in the next 20 years, biomethane produced through biomass gasification.

2.5. Research is still required to reach industrialisation

Even if those technologies (gasification and methanation) are not totally new, as they have been developed since the 70-80s, their adaptation to biomass (and to a large range of biomass) requires solving technical issues. Biomass gasification projects are still too new to have a good return on investment without subsidies and methanation processes working with biosyngas are yet under development. The industrial development could be reached in 2015, if efficient research programmes are led.

The global pathway requires optimization of both investment and operating costs, which means improving:

- Reliability,
- Efficiency,
- Flexibility to different kinds of biomasses, and particularly to industrial wastes or by-product.
• **Economic issues:**
Economics is a key issue for the development of those technologies, which are still less mature and more expensive than classical ways of biomass valorisation. Two main subjects require hardworking:

- **Decrease of investment costs:** it is one of the most sensible parameter to the internal profitability rate of projects.
- **Decrease of operating costs.**

• **Environmental issues:**
The biomethane production way has two main environmental stakes:

- the biomass required for the process must not enter in competition with food,
- the objective is to confirm through dedicated studies the environmental benefits of the process, and the sustainability of the pathway: analysis of emissions (CO$_2$,…) to build strong arguments for such processes, compared with other ways such as 1$^{st}$ generation bio-fuel.

• **Technical issues:**
It is necessary to overcome the environmental and economical obstacles, but it is also necessary to solve the technical key points in order to sustain biomethane production. Main objectives are to be able to measure, analyse and understand physical phenomena in biomass gasification and methanation to control them. This step will lead then to industrialise an optimised process.

**Regarding biomass and its link with the process:**
If biomass is the most available renewable energy source, there is still a need to qualify quantities, qualities, availability, and sustainability. Then, for biomasses of interest, the key is to understand their way of thermochemical decomposition and the results on gas composition through gasification conditions.
Moreover, costs of biomass account for a major part of operating costs. A reduction of theses costs will be possible by using low-cost biomass in the process. So it is necessary to make the process accept biomass at lower cost, which are not suitable for existing gasification technologies.

**Specific topics for biomass are:**
- Conditioning of biomass (drying, grinding, compacting biomass),
- Comprehension of the mechanisms of biomass decomposition,
- Comprehension of the influence of physical and chemical properties of biomass (origin, size, composition…) on kinetics and thermodynamics in the reactor,
- Comprehension of catalytic mechanisms (catalytic effect of biomass and ashes).

**Regarding gasification processes, the main issues are:**
Gasification processes are not yet optimized to various kinds of biomasses, moistures, pellets sizes…There is a need to enlarge the panel of biomasses to be treated with gasification processes, which is today reduced to wood.
It is also a major issue to technically optimise the global system, in order to reduce costs, allow flexibility and improve availability and to increase syngas quality: by reducing tar production and improving gas purification efficiency, a key step in the gasification process.
Specific topics for process are:
- Controlling of pyrolysis/gasification’s staging reactor (adapting reactors to a type of biomass, optimization of conditions of reactions, understanding of catalytic mechanisms),
- Managing the effluents (syngas cleaning, water managing),
- Materials resistance,
- Optimization of regulation of the process.

Regarding methanation, the main issues are:

BioSNG: There are today four main technical issues before industrializing SNG from biomass:
- Purification of the syngas: it is a major technical issue as methanation catalysts are very sensitive to some components present in the syngas. Moreover, the controlling and optimization of the purification will lead to manage the costs of the global operation.
- Validation of the stability of the composition of bio-methane in long duration tests and of its compatibility with grid requirements. There is a real need to validate that SNG specifications are compatible with the grid,
- Energetic integration of the whole production chain.

For all these reasons, there is still an important need of research. Gasification for CHP arrives at industrial step, but gasification for methanation requires demonstration plants to reach industrialisation.

2.6. GAYA R&D project: an ambitious biomass project based on a collaborative research platform with demonstration plants dedicated to gasification and methanation

Renewable energy is a strategic issue for GDF SUEZ. The group is involved on green energy production and especially on biomass.
A project called GAYA has been launched by the Research and Innovative Division to investigate the field of biomass gasification, identify the stakes and sustain the development of this technology.
The aim of the project, by 2015, is to develop a reliable, profitable and energy-efficient method for producing bioSNG, which will be marketed as a biofuel or gaseous fuel and transported via the natural gas network.
The project must also guarantee that these new activities are approached from a perspective of sustainable biomass development, under the best social and environmental conditions, particularly with regard to other biomass user industries.
The project aims to:
- Demonstrate the technical and economic validity of a portfolio of innovative gasification and methanation technologies;
- Demonstrate the industry’s environmental and societal strengths: co-product recovery and effluent limitation, optimisation of energy integration and environmental aspects, avoidance of resource competition;
- Use industrialisation tools (simulation tools, etc.);
- Guarantee a sustainable and profitable supply industry by structuring the sector, knowing the supply areas, and integrating the chain as part of the biorefinery concept).

The success of these objectives presupposes that technical, economic and structural obstacles will be overcome at a pre-industrial level, to guarantee that results are representative. The short-term operational objectives are to:

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1 Biorefinery: sustainable, integrated industrial concept associated with biomass refining processes and a multi-sectorial recovery of co-products.
1 – **Create a technological platform** for the complete biomethane production line (biomass supply chain, gasification, pre-methanation gas processing and methanation, according to the specifications for the bioSNG produced).

This platform will be used to develop and test equipment, and support the industrialisation of new products. It will bring all French and other European participants together, act as a catalyst for developing skills, and facilitate knowledge dissemination. The feasibility study has already been conducted;

![Figure 3: R&D platform on biomass gasification](image)

2 - **Develop a 7-year R&D programme**, to include all issues relating to the industry: the effects of biomass and its pre-processing; the development, optimisation and modelling of gasification and methanation processes; biogas recovery and the development of biorefineries. From an "industry" perspective, the project will cover all other related aspects, including co-product recovery and effluent limitation, the optimisation of energy integration, and environmental and societal factors; a global Research program has been built, which involves 11 partners.

This platform is foreseen to be operating in 2011; its construction is now linked to getting financial supports. The project has been submitted to a French call for projects in the field of Energy and Environment. It would be an innovative technological platform at a pre-industrial scale in Europe on the whole chain of bioSNG production.

Moreover, in the field of CHP, the “Energy Services” Branch of GDF SUEZ will construct the first French **CHP plant** from biomass gasification at industrial size. The plant will produce 5,7 MW of electricity, 6,7 MW of steam for the industrial customer and 1,4 MW of hot water injected into the grid. The Research platform will be built close to the industrial site in order to create industrial synergies between them.
3. REFERENCES

[2] Fercher, Hofbauer, Fleck, Rauch, Veronik, “Two years experience with the FICFB-gasification process”

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