RC Adria Internship Programme

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Final report on the ADRIA Internship implementation

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Contents

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1. Introduction

1.1 Hub CRF: a scalable model on the regional territory

CRF, a research body, operates in the knowledge chain, in order to extract the results of public research by orienting them towards mission projects, which can be translated into innovative product or service concepts, for the birth of new companies. The mission of CRF research organization is to encourage young people to stay in their native territory, creating opportunities for development and qualified work without having to move to Northern Italy or other European countries to exploit their skills. The progressive inclusion of young people in mission projects allows to support the development of technological skills and guarantees the inter-generational transfer of competences. The action of incubation and acceleration of new startups, also contributes to the development of the territory and favors the development of generative Welfare. The CRF research body intends to contribute to the creation of industrially organized knowledge chains, stimulating the culture of innovation and encouraging the birth of new businesses with a particular interest in circular economy. Thus, CRF is committed to the development of specific research activities that can allow the overcoming of the current state of the art in the waste processing sector, allowing a reconversion in a circular perspective. There is an international need for radical innovation in the field of waste treatment. In particular, the treatment cycle should be closed in an environmentally friendly manner ensuring neutrality in terms of CO_2 emissions. New technological concepts can allow the achievement of these objectives. In fact, it is necessary to evaluate the possibility of creating integrated bio-treatment platforms, made with adequate plant scales, with the possibility of converting biogas to biomethane, ensuring the overall neutrality of the supply chain in terms of CO_2 emissions. For this purpose, CRF is developing two lines of research. The first concerns the synthesis of a process scheme of a waste bio-refining platform that allows the closure of environmental cycles. These objectives can be achieved thanks to the use of already tested treatment units (biogas upgrading systems to biomethane, systems for the high treatment of wastewater), through the development of new systems for storing and converting CO_2 into methane and the improvement of pyrogasification system of biomass and subsequent treatments. The second line of research concerns the study of the potential applications of WOX (wet oxidation) processes for the treatment of organic fractions to conventional biological treatments and aimed at ensuring the in-situ treatment of liquid effluents. As regard the first line of research, during my Internship I worked to make a state of art concerning Bio-Refining of waste biomass for waste-to-chemical. Since my work was only a theoretical one, I didn’t use labs or any machinery. I only looked for papers, research, scientific article which concerned my study. However, I had the opportunity to visit the different labs which there are at CRF headquarter: FABlab, IOTlab, 3D manufacturing lab. The first is for mechanical testing, the second is a process lab, while the latter is equipped with 3D printers.

This report lacks the materials and methods section because as told before it isn’t an experimental study, but only a sort of review, a state of art which involved activity of research, looking for scientific article, recent publication and new perspectives about the topic we had selected.

2. Results and Discussion

2.1 Processing routes

There are several technologies which make it possible to obtain bio-fuels and in general products that can be exploited as intermediates for subsequent transformations which can replace those deriving from fossil fuels. In particular, a well-established and mature process is the hydrogenation of oils: Hydroprocessed Esters and Fatty Acids. It is a technology certified in 2011. A feedstock such us palm oil, used cooking oil and tallow is treated with hydrogen and then subjected to Hydrocracking/Isomerization. These drop-in biofuels are referred to as HEFAs. They are distinguished from FAME (fatty acid metyl ester) biodiesels, which are too oxygenated to be used as a drop-in fuel. Vegetable oils contain 10% by weight of oxygen and to remove it using this process you need 3% by weight of hydrogen. Other oxygenation processes that do not require hydrogen have lower yields. The problem with this technology is the fairly high costs of raw materials and also that it is necessary to use H_2, which is usually gray H_2.

Another technology that can be taken into account is the pyrogasification of biomass coupled with subsequent processing, which allows to obtain hydrocarbons with medium-high molecular weight starting from a syngas consisting essentially of CO and H_2. Using biomass as a feed the composition of the syngas can vary and enrich itself even a lot in methane, but the advantage of this technology is that you can use virtually any waste material to produce not only thermal energy, but also intermediates with many other applications. Thus, it can be used local biomass or the so-called Municipal Solid Waste (urban waste), which could lead to the production of fuels if properly treated. The most valuable cuts can be used as jet fuel, while the others can feed an urban system delivery, which can serve the city itself. As for light products, these can be burned to obtain energy for the plant or be used as intermediates for subsequent processing. In any case, the biomass pyrogasification plant is extensively investigated and also developed.

In general, once the syngas has been obtained from the gasification process, there are different routes for its subsequent processing. In particular, we can have:

- processes based on Fischer-Tropsch synthesis
- processes based on fermentation in biorefinery

Fisher Tropsch Synthesis

The Fischer Tropsch process allows the production of a wide range of hydrocarbon liquid products (olefins, paraffins, alcohol, aldehydes, ketones, etc.) from synthesis gas, by hydrogenation of CO. These products (raw products) are then subjected to a refining process (upgrading) that leads to the production of diesel, gasoline and more. Since the synthesis gas is previously purified, the liquid fuels that are obtained are free from sulphides and aromatic compounds. The distribution of the products, i.e. the greater selectivity towards a class of hydrocarbons, is influenced by the reaction temperature (200°C-350°C), the composition of the mixture (H_2/CO ratio = 1-2), the pressure (10-40 bar), the type (cobalt or iron) and the composition of catalyst, the size and type of reactor (recirculating fluid bed, fixed bed or slurry bed). FT synthesis is a process of polymerization and growth of carbon chains that occurs through the catalyzed reaction between CO and H_2 and that leads to the formation of a mixture of liquid products, according to the reaction:

$n\,CO + 2n\,H_2 \Longrightarrow [-CH_2-]_n + n\,H_2O$ $H_0=-165$ kJ/mol (1)

The main products can be formed depending on how the various groups $[-CH_2-]_n$ (basic monomers of the polymerization process) are combined and depending on when you want to stop the growth of the chain. Consequently, we can have the following main types of reaction:

$CO + 3\,H_2 \Longrightarrow CH_4 + H_2O$ methanation (2)
$n\,CO + (2n+1)\,H_2 \Longrightarrow C_nH_{2n+2} + nH_2O$ paraffins or Wax (upgrading to diesel) (3)
$n\,CO + 2n\,H_2 \Longrightarrow C_nH_{2n} + n\,H_2O$ olefins (upgrading to naphta) (4)
$n\,CO + (2n+1)H_2 \Longrightarrow C_nH_{2n+1}OH + nH_2O$ alcohol (e.g. methanol) (5)

The Fisher Tropsch process produces olefins and paraffins of different lengths, in fact the growth of the chain can continue through the adsorption of CO on the catalyst and the formation of another group $[-CH_2-]_n$ or end in olefin or paraffin. In the reactor the shift reaction and the reaction of Boudouard also

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take place. The latter produces deposits of coal on the active surface of the catalyst going to poison the same and to decrease its useful life. Mainly products from the FT process are classified, similarly to petroleum products, according to the length of the chain and the vapor pressure range:

- Gas (C1-C4)
- Naphtha (C5–C8)
- Diesel (C9–C22)
- Wax (C23+)

Reactions are kinetically controlled, and selectivity is determined by the ability of the catalyst to propagate or terminate the growth of hydrocarbon chains, the probability of propagation of which is independent of the length of the chain. Normally to obtain liquid products we have to try to minimize unreacting H_2 and CO and the production of gaseous compounds (C1-C4). The parameters are:

- temperature
- working pressure
- partial pressure of CO and H_2
- catalyst
- H_2/CO ratio (normally between 1.7 and 2.4)
- type of reactor.

The operating conditions are between 10 and 30 bar and between 250 ° C-350 ° C, higher temperatures lead to excessive formation of methane to the detriment of heavier products. It is therefore not possible to obtain selectivity for a single class of products, but the liquid fraction produced (crude oil) is a mixture of several components that therefore require a subsequent stage of both refining and separation.

The most common catalysts for the Fischer-Tropsch synthesis are group VII metals (Co, Ru, and Fe) with the following scale of activity: Ru > Co> Fe > Ni>Co > Rh > Pd > Pt. Ni generally leads to a high formation of methane, which is not desirable, while Ru shows high activity and selectivity, but has prohibitive costs to be used industrially. Iron-based catalysts are the most commonly used for their low cost compared to other metals. The first catalysts used in the process were prepared with precipitation techniques, currently the new catalysts are made by sintering and melting metal oxides with the desired promoters. Alkaline promoters for iron-based catalysts have been used industrially for many years. These catalysts also exhibit catalytic activity for the reaction of water gas shift and lead to a greater production of olefins. They are also used when producing a syngas with a high ratio of H_2/CO. Cobalt-based catalysts have a higher yield and a longer life and are more selective towards the production of linear alkanes (paraffinic products C10-C18 and C >20 also referred to as wax). The use of cobalt-based catalysts is more expensive. With regard to the operating conditions with cobalt-based catalysts, the required H_2/CO ratio is about 2.15 while the use of iron-based catalysts allows to operate with lower H_2/CO ratios, equal to about 1.7. With the use of the latter catalysts, however, a greater production of CO_2 is achieved. As mentioned, the choice of iron as a catalyst favors the shift reaction in the reactor, a competitive reaction to Fischer Trospch reactions. Recently a study has been developed that shows how high yields can be obtained using a Co-based catalyst supported on titania (TiO_2) in the crystallographic form anatase (which allows to have a greater surface area).[2] It has also been modified with metal ions. However, this is only a preliminary study, which requires further research and experimentation cycles so that this technology can be used at an industrial level. The development and improvement of catalysts is a crucial point to improve and make industrial processes more sustainable.

As for the block scheme of the process an FT plant can be divided into:

- the generation of syngas through the gasification process, aimed at producing a gaseous mixture consisting mainly of CO and H_2
- syngas purification in order to remove unwanted compounds for the subsequent section of conversion of gas into liquid fuels
- the Fischer-Trospsch synthesis section
- refining and separation of products (upgrading).

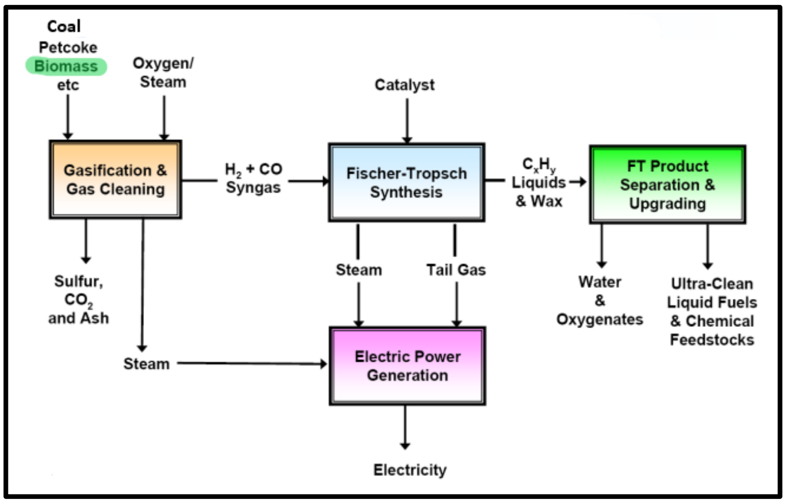

Figure 1.

There is also a study concerning the possibility of using hybrid catalysts to obtain a wax-free FT synthesis. It is a technology (Gas Conversion Catalysis, GCC^{TM}) that uses as a catalyst an active metal and a zeolite-based component, which allows to obtain a liquid hydrocarbon product under commercially viable conditions. Moreover, this liquid hydrocarbon product is a true "synthetic crude" with product specifications that allow for transparent blending into many existing crude oil streams without the need for downstream hydrocracking or hydroisomerization.[3]

With regard to the processes based on fermentation in biorefinery after the biomass gasification step and the bioconversion of syngas into alcohols and organic acids, the molecules produced could be used for the production of biofuels (e.g. bioethanol), pharmaceutical, nutraceutical and industrial chemicals, and biomaterials (e.g. bioplastics).

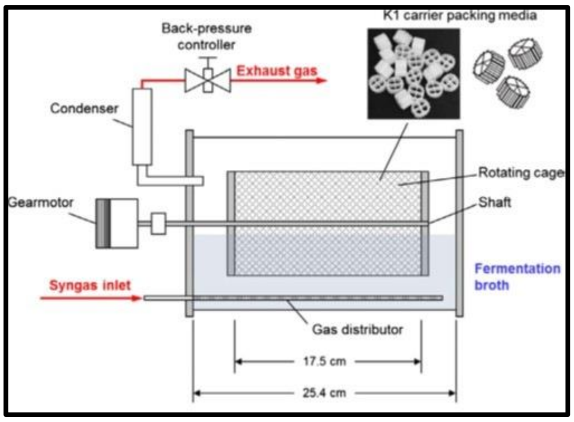

Figure 2.

The fermentation of syngas

The microorganisms most used in the fermentation processes of syngas, individually or in mixed cultures, are bacteria belonging mainly to the species Clostridium aceticum (for the production of acetic acid), Butyribacterium methylotrophicum, Clostridium drakei, Clostridium scatologenes (for the production of butanol), Clostridium carboxidivorans (for the production of butanol and traces of hexanol and hexanoic acid), Clostridium ragsdalei (for the production of ethanol and AOV). The most used bacteria in industrial-scale processes are acetogens, i.e. obligate anaerobic microorganisms capable of using CO and/or CO_2 together with H_2 to produce organic acids, alcohols and other chemicals of industrial importance. To date, more than 100 acetogenic species are known, belonging to 22 genera, which have been isolated from different habitats. Acetobacterium and Clostridium are the most representative of these genera. Despite the wide metabolic diversity of these microorganisms, the Wood – Ljungdahl metabolic pathway is commonly used for the fermentation of syngas.

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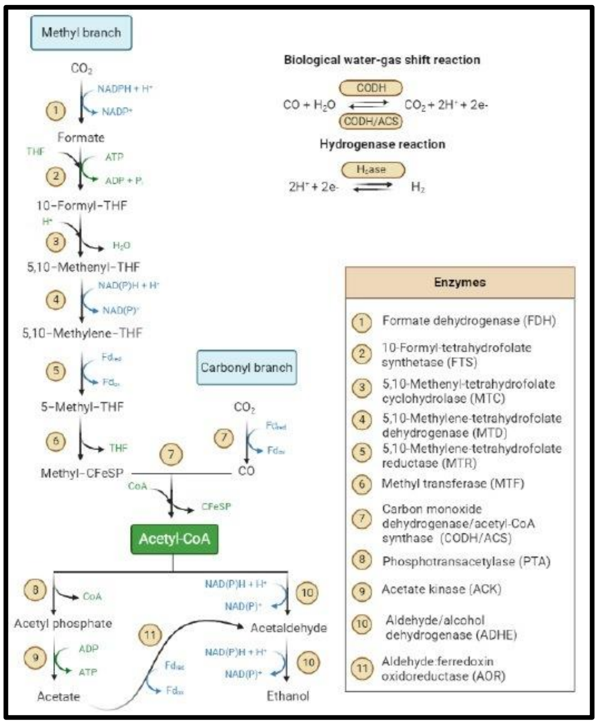

Figure 3.

Advantages of syngas-based biorefinery models

The advantages of this modern hybrid biorefinery scheme, based on thermal and biological conversion processes, consist of:

- as in any gasification, the type and chemical composition of the biomass used as feedstock is indifferent;
- a complete conversion of lignocellulosic biomass, including lignin, is achieved;
- comparing the chemical composition and the cost of glucose with those of CO_2 of syngas we obtain that the carbon of glucose has a cost of 0.875 euros / kg while the carbon of synthesis gas has a cost about five times lower equal to 0.185 euros / kg;
- microbial biocatalysts are highly selective for ethanol production while using chemical catalysts results in a wide spectrum of reaction products;
- many of the bacteria are tolerant to contaminants present in syngas (chlorine and sulfur-based compounds), which, even in traces, can easily poison metal catalysts;
- fermentation is conducted at environmental values of pressure and temperature, significantly reducing the costs of the conversion process;

Challenges of syngas fermentation

At the same time, however, there are still several scientific challenges and limitations that research is trying to solve in order to ensure full technological and economic sustainability of this modern biotechnological process. These limitations are represented by:

- Limitations in the mass transfer of gas in the fermentation liquid;
- Low ethanol productivity, usually related to low cell density caused by the production of toxic by-products of microbial metabolism;
- Sensitivity of microorganisms to environmental conditions (pH, oxygenation, redox potential).

Syngas fermentation is a promising technology for converting CO and CO_2-rich gases into a variety of valuable chemicals. Lignocellulosic biomass, municipal solid waste and polymer waste are suitable raw materials for gasification. However, the increase in process yields and the increase in the mass transfer of gas in the culture medium represent the two main challenges that this technology will have to face in the coming years.

2.2 Tecnology provider and Industries

2.2.1 Pyrogasifier ECO20

Feeding and pyrogasification

The feed material is sent to the machine after being taken from the hopper (placed inside the container). The pyrogasification of biomass and organic materials of plant or cellulosic origin, obtained by heating it (from 300 to 900 ° C), produces a mixture of gases (syngas) whose combustible part consists essentially of CO, H_2 and CH_4. Before being mixed with air to obtain the correct air/fuel ratio to be sent to the engine, the syngas must undergo a cooling, filtering and cleaning process. Only after the cleaning process, the air-fuel mixture is sent to the internal combustion engine in cogeneration trim.

From syngas to energy

The crankshaft, connected to a synchronous alternator, is capable of producing 20 kWel (peak value). The heat recovery system of the plant allows to obtain up to 40kWth of thermal power (peak value) by recovering the heat contained in the engine coolant and that released by the exhaust gases. The microcogenerator is also suitable for use in a trigenerational structure (production of electricity, heat and cooling), combining it with an absorption chiller.

Principle of operation

Gasification and the production of energy from wood waste are highly technological processes, which CMD (Costruzioni Motori Diesel) has made accessible to anyone with the ECO20x microcogenerator. The biomass, loaded into the loading hopper, is pushed through the auger driven by an electric motor inside the reactor. Thermochemical decomposition produces syngas that, before being used in the internal combustion engine, needs to be cooled and cleaned. For this reason, the syngas is passed through:

1. a reactor cyclone for the removal of ultrafine ash
2. a cooler to increase its density and to condense the tars in the syngas
3. a biological filter for the further removal of ultrafine ash and residual tar
4. a cyclone near the engine that allows mixing with the outside air and the final removal of condensate.

In case of particularly dusty biomass, additional filtration elements, cyclones, column filters can be added. As far as the heat recovery section is concerned, the system consists of two section to realize:

- a first recovery at low temperature: exploiting the cooling water of the engine by means of a plate exchanger;
- a further recovery at high temperature: exploiting the exhaust gases of the engine by means of a shell and tube exchanger.

The expansion vessel, placed at the head of the system, allows to compensate for the increase in volume produced by the heating of the water present in the gas cooling circuit in the cooler.

Possibility of H_2 green by coupling an eco20x and an electrolyzer

Fossil fuels (grey hydrogen) are still used to produce hydrogen today, but a collective aim is to produce decarbonized hydrogen:

- *green* hydrogen, deriving from the electrolysis process, which exploits electricity from renewable sources (solar, wind, biomass)
- *blue hydrogen,* made through the Carbon Capture & Storage process, following reforming, which allows the sequestration of emissions produced by the combustion of carbon compounds.

A valid green alternative is also represented by the steam reforming of biomethane in the production of hydrogen. In this context, the ECOH2O system, designed and built by CMD's Energy division, is a system capable of producing green hydrogen deriving from the electrolysis process, exploiting the electricity coming from the gasification of biomass / residual materials. The advantage of this system for the production of H_2 lies in the fact that it guarantees energy continuity, which is not possible using a photovoltaic or wind power plant.

2.2.2 ENEA Trisaia

Noteworthy is the fact that locally there is an experimental station for the thermochemical conversion of biomass: it is the one carried out by ENEA Trisaia. This is interesting in view of the development of a technology of this type at a local level, perhaps also exploiting a biomass typical of this area, such as that deriving from the cultivation of olive trees or almonds. In this sense it is important to develop a plant that is as versatile as possible and able to adapt to the different type of biomass that is available.
This experimental station includes prototype gasification and pyrolysis plants based on process reactors of different designs. The main purpose for the study and development of these technologies are the direct production of electricity for the use of the syngas produced, possibly coupled with the production of also thermal energy, and the conversion into advanced energy carriers, both liquid and gaseous, such as: Fischer-Tropsch biofuels, methanol, DME, SNG, H_2. To carry out basic research activities, a process development laboratory is set up equipped with bench scale infrastructures. All experimental activities are supported by analytical laboratories for the appropriate characterization of matrices and process and by pilot gasification plants based on different technologies and sizes:

- 30 kWe downdraft fixed bed gasification
- 150 kWt updraft fixed bed gasification
- 1000 kWt boiling fluidized bed gasification
- 150 kWe multistage gasification
- gasification in supercritical water
- ORC for energy recovery from low temperature thermal waste

These technologies are examined in detail below.

30 kWe down-draft fixed bed gasification plants

The gas produced due to the presence of nitrogen has a relatively low heating value (LHV 4-5 $MJ/Nm3_{dry}$) and it can power internal combustion engines. To clean the gas from contaminants (tar and particulate matter) harmful to the engine, the raw gas passes through a cleaning system consisting of two cyclones, a water scrubber, a dirt separator and a biological filter. In addition, an oxygen enrichment section of air allows to obtain a gas with a higher heating value. The plant is suitable for preliminary tests of energy valorization of biomass through gasification or for the analysis of internal combustion engines modified to use syngas.

150 kWt up-draft fixed bed gasification systems

The gasification plant has an updraft reactor. The biomass feed rate is 30-50 Kg/h; the type of biomass that can be fed is: almond shells, hazelnut, lignin and wood waste. The gasifying agent is air/oxygen/vapour or mixtures thereof. The thermal power of the system is 200 kWth. Syngas has a LHV ranging from 5-6 MJ/Nm^3 to 10-11 MJ/Nm^3 depending on the gasifying agent. The plant is equipped with a biodiesel scrubber for the abatement of the tar produced by the reaction. A series of filters allows the purification of syngas from tars up to the maximum concentration of 0.04 $g/Nm^{3.}$

1000 kWt recirculating boiling fluidized bed gasification system

The gasification plant is a boiling fluidized bed with two beds interconnected by means of a separator. The two beds are fluidized with different flow rates of oxygen-vapor gasifying mixture that induce a different density of the beds and an internal recirculation of the material. In the freeboard of the bed, a hot cleaning of the raw gas takes place by means of catalytic ceramic candles. The architecture of the gasification reactor has been patented by ENEA. The nominal capacity of the system is 220 kg/h. Syngas has an average heating value of 10-11 MJ/Nm^3.

150 kWe multi-stage gasification plant

In the multi-stage gasification plant, the gasification process takes place in three stages: pyrolysis in an Auger-type reactor, the combustion of pyrolysis gases for the overheating of the reagents (oxygen, air, steam or their mixtures) necessary for gasification, the gasification of pyrolysis carbon that takes place in the lower part of a downdraft reactor. In this way the tar content produced by the gasification reaction turns out to be very low. The biomass feed rate is 150 Kg/h. The plant allows the use of a residual biomass also in order to reduce the costs of the process. The electrical power of the system is 150 kWe. Syngas has a LHV ranging from 5-6 MJ/Nm^3 to 10-11 MJ/Nm^3 depending on the gasifying agent.

Pilot gasification plant in supercritical water

The gasification with supercritical water of wet feedstock such as virgin biomass, microalgae and sewage sludge, etc. allows to avoid the drying of the matrices. This process makes it possible to produce a synthesis gas (H2, CH4, CO, etc.) at high pressures that can be used well for energy recovery by expansion, but above all, it allows to obtain natural gas substitutes with pressures suitable for input into the national distribution network. In addition, the process could be suitable to produce a liquid fraction that contains a series of intermediates of commercial value, if properly separated and used as chemicals. The laboratory scale plant, built for the gasification of organic matrices in supercritical water, operates at 350 atm and 550 ° C and has a volume of 450 ml.

ORC system for energy recovery from low temperature thermal waste

The developed unit allows the energy enhancement of thermal waste in order to make both thermal and electrical energy production systems more efficient. Specifically, the activities concern the development of innovative ORC cycles using special organic fluids that, under certain operating conditions, allow to recover energy from thermal flows at very low temperature up to 90 ° C. In the laboratories of the Center, a small ORC (Organic Rankine Cycle) experimental station has been designed and built. It allows to test different operating conditions, operating layouts, organic fluids and different levels of heat exchange. There is also a heat transfer station with innovative carrier fluids.

2.2.3 Maire Tecnimont

Maire Tecnimont has also developed a technology from waste to produce methanol in this case. This waste-to-methanol technology has its roots in the chemical conversion of non-recyclable municipal waste, which would otherwise be disposed of in landfills or incinerated, into syngas used to produce methanol. Through the chemical conversion of non-recyclable municipal and industrial waste, mainly plastics and dry waste, the resulting hydrogen and carbon oxides can be used to produce more sustainable chemicals. Methanol derived from this process can be used as an intermediate for low-carbon additives in the mixing of gasoline and diesel, in order to replace the fossil-based component with that derived from recycling, as well as raw material for chemical, construction and plastic industries. Ultimately this guarantees a lower carbon footprint, demonstrating the sustainability of this technology. Methanol is an important intermediate used in many products that play an important role in daily life (just think of resins). It can be used as fuel in transport and, above all, it is a powerful factor for decarbonization.

2.2.4 Bio-Thermal-Energy Inc. of Cedar Rapids

Another process that uses waste to produce energy is the one developed and patented by Bio-Thermal-Energy Inc. of Cedar Rapids and which exploits landfill gases composed essentially of CO_2 and methane. This process aims to boost the economy and reduce the environmental impact of landfills. Studies suggest that this new process will reduce annual CO_2 emissions by 50%. The process combines landfill gas with steam in a reformer. The syngas produced, composed of CO and H_2, goes into a fermenter from which ethanol is obtained. Landfill gas, typically composed of 50% methane and 50% carbon dioxide with some impurities, is cleaned up before entering the catalytic reformer. After cleaning, the syngas is fermented to produce ethanol using an existing commercial process similar to the fermentation of corn ethanol. A carbon balance on the entire process from landfill gas to ethanol indicates that about 56.9% of the carbon is contained in the finished product: ethanol. This is 56.9% of the carbon from landfill gas not emitted into the atmosphere. In addition, leachate from the landfill can create additional gas for the production of more ethanol. Leachate is the liquid that forms in landfills when rainwater infiltrates and percolates through degrading waste. The recycling of leachate reduces the need to transport it to an ad hoc plant for the treatment and final disposal of solids in landfills. The landfill gas-ethanol process also provides funds for landfill maintenance as required by regulatory agencies even after landfill operations have closed. Gas is typically produced for more than 20 years after a landfill closes. The process can be schematized as below:

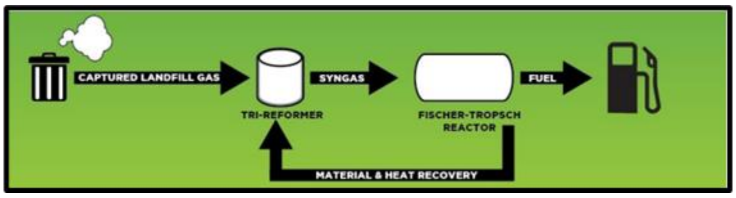

Figure 4.

in which in particular a tri-reforming is used to treat landfill gases. This is the simultaneous use of CO_2 as oxidant, steam and O_2. This process eliminates the problem of coal formation and the high energy consumption of CO_2 reforming by incorporating H_2O and O_2. The heat generated in situ can also be used to increase energy efficiency and achieve a neutral heat balance of reactions.

2.2.5 Sauber - Università di Parma

At the University of Parma, a first prototype version of a technology conceived by Sauber to enhance the waste from the agricultural, agri-food and forestry supply chain was born. The ultimate goal of this plant is in fact to produce clean energy from agricultural waste, such as fruit and vegetable residues or pruning and generate quality biochar, to be introduced into the soil, as a soil improver for crops. The new technology allows the material to be loaded automatically into the plant, feeding the gasification reactor. Here, through the high temperatures, the presence of air as a gasifying agent and the pressure, the thermochemical degradation of the biomass and the production of a syngas takes place. The latter is then used for the generation of thermal and electrical energy. The process is energy self-sufficient and does not require auxiliary fossil fuels. In addition, the poly-generative configuration aimed at the production of biochar makes the process carbon negative, therefore sustainable from an environmental point of view and ideal for the enhancement of waste biomass on a small scale.

2.2.6 Belleli Group

The Belleli Group deals with oil & gas chemistry, power generation (it also has biomass gasification plants), water treatments and construction of infrastructure related to the sector. With a view to green production, the company installed photovoltaic (PV) systems (in Italy in Viterbo and in South Africa in Upington, both with a capacity of 25MW) and started to develop the Prometheus Green Power project. Prometheus develop advanced Power-2-Gas technology, dedicated to energy conversion and storage using electrolysis fed with PV electricity. Large PV plants on site convert electricity into the electrolyser producing green hydrogen and then green methane. Power-2-Gas is a highly effective way of integrating PV energy, with a scalable technology and leverages the existing natural gas infrastructure. This results in a higher overall integrated system efficiency with CO_2 global capturing. Prometheus green power demonstrates on large commercial scale Power-2-Gas technology to address Europe's needs to integrate PV power, gas and energy storage. The overall objective of the project is to design, engineer, and construct a large commercial-scale power-to-gas facility and provide energy storage services to the European energy system. The core of the Envigreen Hydrogen project is Prometheus Green Power methanation system, which employs a unique advanced solution converting PV energy in methane. The system includes a large PV plant, an electrolyser, a commercial scale methanation module gas upgrading system and gas grid pumping station, all located in South Europe. The system draws renewable electricity during times of low demand and converts that electricity to renewable gas for direct injection into (and storage in) a nearby gas distribution grid. Biogas is being produced on-site via anaerobic digestion and delivers the carbon dioxide required for methanation. Heat and oxygen, which are generated as by-products in the Power-2-Gas process, are being captured and combined in the process plants operations. The system is flexible and responds rapidly to power availability, providing frequency regulation services to power grid while pumping biomethane into European gas grid.

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3. Conclusions

There are different processes and technologies that allow to produce energy or chemical intermediates using waste substances as feedstock, such as biomass deriving from crops, municipal solid waste, biogas. The main problem in carrying out these processes on a large scale is to make them commercially competitive, because it can happen that while the power supply is very cheap (or practically at no cost), the necessary equipment is not as cheap or that the yields are not high, so from an economic point of view it is still convenient to use fossil fuels. It may also happen that in the course of the process some intermediate is needed that is typically produced using fossil fuel, for example H_2 which in most cases is gray H_2. It would be necessary to integrate the different technologies in order to be able to outline a process that is somehow self-sufficient and continue to study how to optimize these different technologies. The interactions of a possible plant with the territory should also be studied, to exploit its potential as much as possible. It must be a resource, not a problem or damage for local environment.

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