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BiGUV – Agricultural waste valorisation process compliant with the circular economy principles

Executive summary

As Fossil resources are becoming a less desirable feedstock for the realization of many products, an alternative bioeconomy transforming renewable resources in valuable products could provide viable solutions to the global challenges posed by environmental, economic and societal sustainability. Globally, about 998 million tonnes of agricultural waste are produced yearly. Moreover, the composition of agricultural waste is more or less constant during time. Thus, it is a good building block to produce fuel that can be exploited by the farmer himself. Today, agricultural waste is either disposed or converted into biogas, a mixture of 60% methane and 40% carbon dioxide, which is combusted to produce electricity and heat. Disposing the waste is an expense, while burning the biogas allows to recover only 60% of the energy potential of the waste, since only methane undergoes the combustion reaction.

The following project describes BiGUV (Biogas Upgrading and CO2 Valorisation), which is a solution that aims at following the principles of circular economy by enhancing biomethane production on farm, providing farmers with bio-fuels and exploiting the potential value of CO2 as a building block for further chemical transformations. BiGUV is the union of three already existing processes into one industrial process with the aim of maximizing the recovery of the energetic value of agricultural waste. The processes are biogas production, CO2 separation and CO2 conversion, achieved respectively with a biodigester, ionic liquids and other micro-organisms. Italy is already in the European top Five for production of biogas on farm and therefore possesses the foundations to begin a transition towards an economy of auto traction based on methane. This is the vision shared by the BE-SEI Team and industries like Sapio [7], Air Liquide [5] and CNH Industrial [6], who is soon releasing new methane tractors in the European market.

BiGUV is intended to be more than just a novel process plant configuration. It proposes a future of communication and tight collaboration between farmers that begins with the solar system model proposed for the biogas upgrading unit operation. As in cosmic solar systems, sun farms surrounded by planet farms are distinguished. A sun farm is meant to sustain the investment costs to upgrade its already existing biodigester into a BiGUV plant and manages the final products: methane (used as fuel or production of electricity), digestate (used as fertilizer) and added value products from CO2 (more clean fuels or building blocks for the chemical industries). The planet farms around their sun send their waste to it and receive a monetary compensation or part of the products back. The presence of a network of farmers and industries, CIB (Consorzio Italiano Biogas), that already pushes towards production of biogas on farm and the transition to methane as a fuel for auto traction makes Italy the perfect ground to develop the BiGUV plants and vision.

The realization of BiGUV requires working in multiple directions at the same time. The solar system model needs a network of farmers first, which will be achieved thanks to a digital platform. The platform will initially contain information on the existing biodigesters of Italian farms and it will allow the farmers to know their neighbouring farms and what they are doing innovation-wise. That will be the first asset of the SEI-BE Team and the main difference with respect to the vision and plans of the big industrial players mentioned earlier. The relationship of the Team with the companies acting in this field will be crucial to bring the new paradigm of BiGUV on the whole Italian peninsula. Moreover, established companies already possess the know-how to build new plants or upgrade existing ones, making them extremely valuable potential partners of the BiGUV project. SNAM is another key player that needs to be on board for the realization of BiGUV. They manage the Italian national methane network and only their push towards the development of such network and innovative solutions to store methane will allow to exploit on farm the full potential of the clean fuels produced by BiGUV plants.

From the technical point of view, BiGUV proposes the upgrading of biogas with Ionic Liquids, which could allow efficient and sustainable removal of CO2 from biogas streams. These novel compounds are being extensively studied by the industrial partner of the BE-SEI Team, the Italian Institute of Technology, but they are not commercially employed for CO2 separation today. Further studies on these compounds are needed to assess the economic and environmental feasibility of the separation unit operation, to be compared with the technologies already used in the industrial field, namely pressure swing adsorption, separation with amines, separation with water and cryogenic separation. Moreover, the step of CO2 valorisation also requires more data to determine the most fruitful final product. On the one hand, conversion of carbon dioxide to methane would allow to fully exploit the energy potential of agricultural waste and close a sustainable loop. On the other hand, isobutanol can be used as a better additive in gasoline instead of ethanol, and this pathway might be a great compromise during the transition to the methane-based economy.

Finally, Italian and international laws are pushing more and more towards a sustainable future and the BiGUV project, both the technical and societal sides, are perfectly in agreement with the requirements for less emission, circular economy development and lesser carbon footprint in the agricultural field.
In conclusion, the BiGUV scheme is representative of how circular economy principles, process industry and research frontiers can be integrated to design an innovative approach to convert waste into valuable products and move the dominating paradigm towards sustainability and closed loop economy.

Keywords: agricultural waste, technological innovation, circular economy, collaborative economy.

Project description written by the Principal Academic Tutor

The project from the BE-SEI Team describes BiGUV (Biogas Upgrading and CO2 Valorisation), a solution that aims at following the principles of circular economy by enhancing biomethane production on farm, providing farmers with bio-fuels and exploiting the potential value of CO2 as a building block for further chemical transformations. BiGUV is the union of three already existing processes into one industrial process with the aim of maximizing the recovery of the energetic value of agricultural waste. The processes are biogas production, CO2 separation and CO2 conversion, achieved respectively with a biodigester, ionic liquids and other micro-organisms.

BiGUV is intended to be more than just a novel process plant configuration. It proposes a future of communication and tight collaboration between farmers that begins with the solar system model proposed for the biogas upgrading unit operation. A central farm is meant to sustain the investment costs to upgrade its already existing biodigester into a BiGUV plant and manages the final products: methane (used as fuel or production of electricity), digestate (used as fertilizer) and added value products from CO2 (more clean fuels or building blocks for the chemical industries). Surrounding farms send their waste to it and receive a monetary compensation or part of the final products back. The presence of a network of farmers and industries, CIB (Consorzio Italiano Biogas), that already pushes towards production of biogas on farm and the transition to methane as a fuel for transportation, and the presence of many biogas production plants on Italian farms make Italy the perfect ground to develop the BiGUV plants and vision.

The project develops multiple directions at the same time. The socio-economic impacts of the solution are discussed. Today's Italian and European contexts are analysed. Laws, incentives, and the vision of different key industrial players are presented. Finally, the relationship between BiGUV and various stakeholders such as Consorzio Italiano Biogas and SNAM are presented. The current limitations for the implementation of the BiGUV project are also discussed.

The technical side is also developed. BiGUV proposes the upgrading of biogas with Ionic Liquids, novel compounds that are being extensively studied by the industrial partner of the BE-SEI Team, the Italian Institute of Technology. The technology was compared with other existing techniques already employed in the industrial context. Moreover, the step of CO2 valorisation to the most fruitful final product is presented. On the one hand, conversion of carbon dioxide to methane would allow to fully exploit the energy potential of agricultural waste and close a sustainable loop. On the other hand, isobutanol can be used as a better additive in gasoline instead of ethanol, and this pathway might be a great compromise during the transition to the methane-based economy.

The project also deals with the methodology of work of the Team, that followed an agile framework and employed the scrum methodology.

In conclusion, the BiGUV scheme is representative of how circular economy principles, process industry and research frontiers can be integrated to design an innovative approach to convert waste into valuable products and move the dominating paradigm towards sustainability and a closed loop economy.

Team description by skill

We are the Bio Engineering Team from the School of Entrepreneurship and Innovation and the Alta Scuola Politecnica Programme. Our Passion is largely focused on Sustainable Development and we truly want to make a difference to people's lives. We have solid technical backgrounds and an ample knowledge of Green Chemistry and its latest developments. After years of theoretical studies we look forward to making practical our competences, believes and hopes for a more sustainable future.

Andrea is a chemical engineering student and he is the most enthusiast and enterprising team member. His dynamism was the driving force behind the project. He listens to everybody's opinion and puts into effect many ideas.

Giorgio is a chemical engineering student and he is an inexhaustible source of ideas. His is proactive in every sector and has an entrepreneurial mindset. He accepts every challenge and that makes him a reliable team member.

Michele is a chemical engineering student and he is the most methodical and logic-driven of us all. His ability to analyse and dissect the complex problems we faced is invaluable. Not even the smallest detail will escape his gaze.

Valeria is a physics student and distinguished herself for her adaptability. Despite her different background, she turned out to be a great asset for the team, showing flexibility and dedication without being scared of new challenges.

Johnny is a materials engineering student and he is the wisest of us all. He has shown empathy with everybody and his maturity has always driven the project towards the right direction, with a constant focus on the main goals.

Simona is a chemical engineering student and her diplomacy has always maintained the balance of the group. She is reliable, organised and positive. These skills are essential in teamwork and have made her an irreplaceable team member.

Goal

As Fossil resources are becoming a less desirable feedstock for the realization of many product, an alternative bio-economy transforming renewable resources in valuable products can provide viable solutions to the global challenges posed by environmental, economic and societal sustainability. Synthetic compounds (e.g. carbon dioxide, methane) originating from human industrial activities are negatively affecting the natural greenhouse. However, they could potentially be up-cycled in a wide variety of industrial applications displacing fossil fuels as a raw material. Nature displays an enormous diversity of microorganisms which fix and transform a carbon feedstock into potentially useful platform chemicals (e.g. biopolymers, biosurfactants, and bio-flavours, biofuels). Chemical engineering, (bio-)chemistry, microbiology and metabolic engineering collectively nowadays enable the rational engineering of efficient bio-processes.

On the other hand, extraction and purification of obtained products from microorganisms often requires high efforts that could compromise the economic revenue and the environmental benefits of the proposed biotechnological process. The use of ionic liquids (defined as salt fused below 100°C) could help to overcome these issues providing a selective solvent not toxic for the microorganism and for the environment. Moreover, the low volatility and high thermal stability allows to recover the target product simply by distillation with low energetic cost.

The topic proposed by IIT was inspired by one of the contemporary most pressing topics, namely the exploitation of CO2 to develop new solutions and applications of value. The focus is to develop an innovative value chain whose novel elements depend on photobioreactor design affording direct bacterial conversion of CO2 into a chemical widely expendable in the food and cosmetics industries, on the product extraction and purification by ionic liquids. The partner tech product challenge will go in the direction of transformation of CO2 to develop new solutions and applications of value.

Understanding the problem

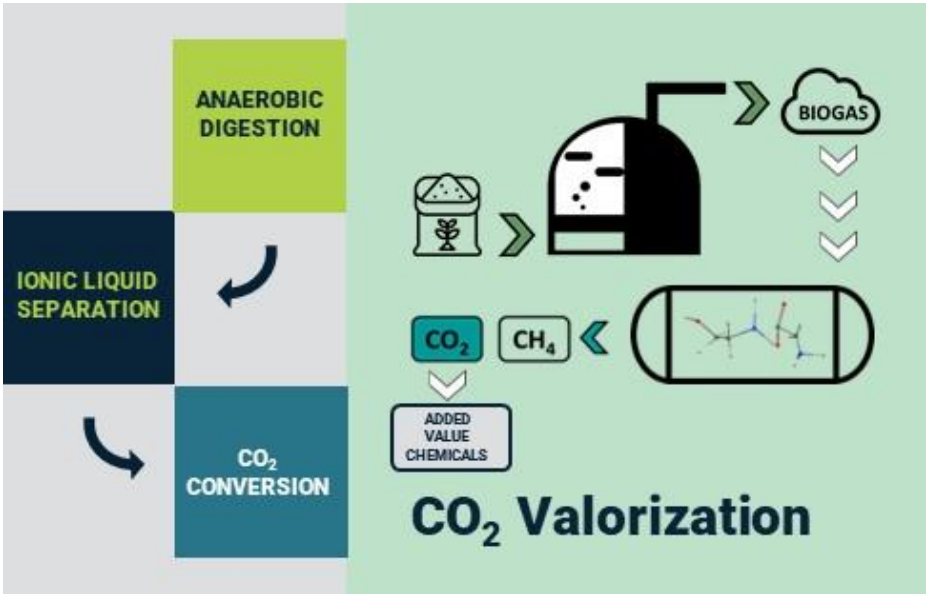
The topic proposed by IIT was inspired by one of the contemporary most pressing topics, namely the exploitation of CO2 to develop new solutions and applications of value.

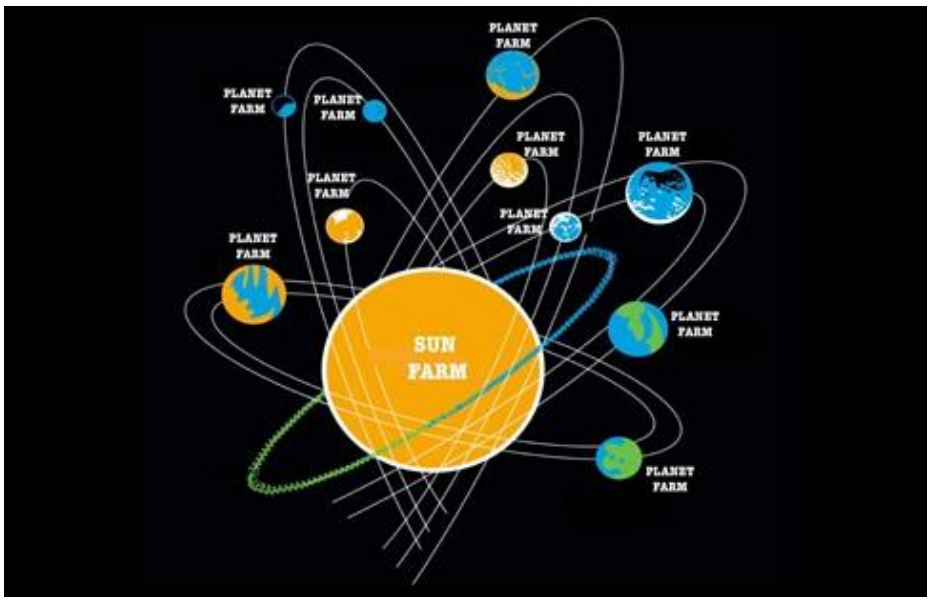
Environmental requirements led the BE-SEI Team to focus the attention on the waste management in the agricultural world, where the amount and the type of wastes make it promising for a further exploitation. Indeed, the life cycle and management of the waste produced in this field is still based on a linear paradigm of economy; the waste produced by Italian and European farmers is still mainly disposed, becoming a cost. An alternative to waste disposal, which is becoming more and more popular, is the convertion of agricultural waste into biogas.

Nowadays, the main exploitment of the produced biogas is production of electricity and heat by combustion. However, burning the biogas allows to recover only 60% of the energy potential of the waste, since only methane undergoes the combustion reaction. Following this strategy, almost half of the energy potential of the initial waste is not exploited in the process. Moreover, not any farm is big enough to possess a biodigerstor, hence, for these stakeholders, the only possibility is disposing their waste, losing all its energetic value, sustaining a relevant cost and not applying the principles of circular economy.

It is known that synthetic compounds (e.g. carbon dioxide, methane) originating from human industrial activities negatively affect the natural greenhouse. It is estimated that, globally, about 998 million tonnes of agricultural waste are produced yearly. Organic wastes can amount up to 80 percent of the total solid wastes generated in any farm of which manure production can amount up to 5.27 kg/day/1000 kg live weight, on a wet weight basis [1].

In a world society that is becoming increasingly aware of environmental issues, it is clear that a transition towards green-process is necessary and urged to provide and ensure a safer future, and we can not wait any longer.





Exploring the opportunities

Biogas and biomethane both have enormous potential to contribute to clean energy transitions and help achieve energy-related Sustainable Development Goals.

Regarding biogas production, the number of European Biogas plants is drastically increasing over the past decade, indicating a robust nature of the sector. By the beginning of 2018, there were 17,783 biogas plants and 540 biomethane plants in operation Europe-wide. Within the years 2012-2018, in Europe we have observed an increase of +43% in the number of biogas plants and of +188% in the number of biomethane plants [3]. In such scenario, Italy is a key player, being the second European country for the number of installed biogas plants, with more than 1600 plants installed [8].

Despite these promising numbers, the worldwide availability of sustainable feedstocks for biogas and biomethane displays that the technical potential to produce biogas and biomethane is still largely unexploited: it is predicted that biogas and biomethane are to play a more prominent role in the future energy mix [10].

For these reasons, governments and other stakeholders seek to facilitate biogas and biomethane market development, with the employment of several policy measures. Italian and international laws are pushing more and more towards a sustainable future and the BiGUV project, both the technical and societal sides, are perfectly in agreement with the requirements for less emission, circular economy development and lesser carbon footprint in the agricultural field.

Generating a solution

The solution generation process started from the identification of the System Requirement Specifications (SRS) that helped the team to propose a solution considering its purpose, its contest, the specific requisites and a general market prospect. After some months of problem framing and state of the art evaluation, the team took part to a challenge launched by CNH and New Holland Agriculture, having the opportunity to meet experts of the sector. This debate with competent people was what convinced the team that a change of paradigm is in act in the agricultural world and that it is the time to boost this shift towards completely sustainable activities with the introduction of new infrastructures and networks between the farms, and it is what the team mean with BiGUV.

BiGUV (Biogas Upgrading and CO2 Valorisation) is the union of three already existing processes into one industrial process with the aim of maximizing the energetic value of agricultural waste. The processes are biogas production, CO2 separation (Biogas upgrading) and CO2 conversion. To separate the CO2 from the biogas, ionic liquids are exploited as a strong candidate. Ionic Liquids (ILs) are salts that can be found in the liquid state before they decompose or vaporize [2] [11]. The separated CO2 can undergo various pathway reactions to produce alcohols such isobutanol (gasoline additive) [9] or methane [12] to add value to the overall process. Users are of two different types, depending on their dimension and on the possibility to process waste. The smallest farms are only in charge of delivering processable waste while the biggest ones process the agricultural waste in order to convert into biofuels. In order to strengthen the networks between the farms, the team proposed also the introduction of a digital platform that connects the users.

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