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CONVERSION OF AN OLD BIOGAS PLANT INTO A BIOMETHANE ONE

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ABSTRACT

Biomethane plants serve as a major advancement for renewable energy because they create sustainable methods to generate power. The biological molecule shows promise to become a vital component for Italy's future energy systems. Biomethane farms are at the heart of the agro-ecological transition thanks to the opportunities of the National Recovery and Resilience Plan (PNRR) linked to the development of biomethane and agriculture measures 4.0, which will help to consolidate the role of agriculture as a major player against the energy and climate crisis. The research investigates Italy's entry into biomethane operations and delivers instructions for building facilities that fulfill all required administrative requirements. A biomethane plant design requires a complete system which unites engineering knowledge with environmental aspects and follows all relevant regulations. The first step of the technical process requires identification of available feedstock resources. The selection determines how much biogas will be produced and what level of impurities (H_2S, NH_3, siloxanes) will be present and the required anaerobic digester size. The upgrading stage transforms raw biogas into high purity biomethane represents the technological core of the plant. The implementation of auxiliary systems which include pretreatment units, gas cleaning, compression, drying, storage and odorization enables operators to meet all quality requirements for grid injections. The bureaucratic pathway stands as the most crucial element because organizations must execute various intricate procedures which vary between different settings. The Italian plant authorization process includes multiple stages which start with environmental impact assessment through VIA or screening procedure followed by AU or simplified communication procedures based on capacity, compliance with atmospheric emission rules, waste, digestate permits and safety standards for fire prevention and ATEX compliance. The process of grid connection needs operators from the gas network to check that biomethane meets all required specifications for injection (Wobbe index, calorific value, dew point, odorization). The implementation of incentive schemes through tariffs and certificates requires complete documentation which shows feedstock origin and proves greenhouse gas reduction in line with RED II standards and uses precise metering system data. A project requires both engineering design excellence and administrative management to succeed because it guarantees technical solutions meet all legal requirements.

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Chapter 1: Introduction and Relevance of Biomethane as a Renewable Energy Source

1.1 Introduction to Biomethane as a key of circular bioeconomy

The most intricate battle for humankind in the twenty-first century is the necessity to dismantle the correlation between economic growth and environmental degradation about energy production and consumptive infrastructure. The global energy system is also undergoing critical change as society must fight climate change while ensuring energy security. Biomethane is considered as a major renewable energy solution due to its high versatility in the changing energy landscape. Biomethane generation consists of anaerobic digestion of organic feedstock under specific conditions where we obtain clean biogas having the same quality and composition as conventional natural fossil gas. Biomethane attains its special quality because it is possible to adapt the quality of this renewable fuel to that of conventional fossil natural gas, which makes the integration into existing gas infrastructure systems possible. The next chapter discusses the various applications of biomethane, how it is vital for mitigating climate change and national energy security and how it sustains waste management along with sustainability practices in circular economy.

1.1.1 The Energy and Climate Crisis: Global Context and Transition imperative

Global warming and climate changes are caused by increasing (greenhouse gas) GHG through fossil fuel burning for power generation during human activities. The massive side effects of climate change such as sea level rise, ocean acidification, loss of biodiversity and stronger extremes are more than one reason to see a drastic change in energy production as an unavoidable necessity for planetary safety. The Intergovernmental Panel on Climate Change (IPCC) released new findings indicating that global GHG emissions must peak by 2025 at the latest and decline by 43% by 2030 to limit global average temperatures to 1.5°C above pre-industrial levels4. [1]

For this to occur, all energy-consuming sectors would have to be rapidly and fully transformed. People now know that fossil fuels are finite, and their delivery systems are geopolitically risky as well as volatile in price. The 2022 European energy crisis demonstrated that one should not depend on a single domestic source of secure energy, especially when geopolitical issues destabilized the situation. The extremely urgent renewable energy construction and application becomes a top priority of national and international strategy on both environmental crises and energy security. The Paris Climate Agreements calls for rapid development and deployment of renewable energy systems. The IEA Net Zero Emissions for 2050 calls on a radical rollout of renewable energy technology and the total banishment of fossil fuels by the swift introduction period of sustainable biomethane and other clean advanced bioenergy solutions. [2]

The move away from fossil fuels requires a mix of energy solutions to include intermittent sources, such as wind and solar, and dispatchable renewable systems. Biomethane represents an essential frequency stabilizing factor in the full energy transition approach as it is based on existing infrastructure, offers controllable power production and meets reasonable waste handling requirements particularly for industries that cannot convert to direct electrification.

1.1.2 Definition and features of Biomethane

The processing of raw biogas to serve as renewable gaseous fuel in the production of biomethane calls for effective treatment. Anaerobic digestion is a multi-stage complex biological decomposition of organic matter by diverse microbial communities under oxygen-free conditions, which makes biogas. The resulting biogas are mostly methane (CH_4 at 50-75% v/v) and carbon dioxide (CO_2 at 15-60% v/v). The gas is colored with a little amount of H_2S (100 to 10,000ppm), NH_3, saturated water vapor, N_2 and VOCs including siloxanes. [3]

The corrosive character of H_2S destroys the features of siloxanes in the biogas and so this molecule must be scrubbed off to maintain equipment safety and quality demands for end use applications. The raw biogas needs to be processed (cleaned) before it is suitable for use or further treatment. Several types of quality requirement specifications for biomethane grid injections are applied in different countries or at specific gas network operators within a country. The Wobbe Index and methane content and dew point as well as impurity concentrations of H_2S, O_2, and siloxanes must comply with stringent requirements for pipeline safety and operational integrity according to the European network code ENTSOG. [4]

The rigor of the purification processes makes biomethane a product with at least characteristics equal to those of standard fossil natural gas so that it is only in terms of functioning that they differ. Biomethane is known as a “drop-in fuel” meaning it can enter into natural gas systems already in place without requiring new infrastructure or costly overhauls. Deploying in parallel and reducing the need for significant new infrastructure-in this case through the circularity of biomethane as it makes sense to use existing infrastructure where possible-give us a more efficient energy transition.

1.1.3 The Strategic Role of Biomethane in the Global Energy Transition

BioCH4 shows a distinctive difference compared to other renewable energy sources, since it offers special features that complement the operation of an energy system based on renewables. It is a dispatchable and programmable energy source because it operates outside of solar photovoltaic (or wind) electricity which requires favorable weather conditions and daylight to be available. It is possible to produce biomethane and feed it back into the gas grid and then supply it on demand, as a flexibility option to stabilize the grid at times with low amount of wind or solar generation. As biomethane is a renewable gas and already interconnected to the natural gas network, there is no need for new distribution network investments making the energy transition faster and more cost effective. The 'drop-in' nature of biomethane means that it is a key option to enable the decarbonization of energy use in transport and industry process heat, and seasonal storage of energy using gas network capacity. Biomethane functions as a key driver of the circular economy, transforming organic waste into valuable energy. The process produces useful energy and not only solves the environmental issues inherent in both land fillages and waste incineration. Bio-methane is also a central pillar for establishing a sustainable bioeconomy due to its integration of renewable energy production with waste processing and nutrient recovery by digestate applications such as bio-fertilizer. In Italy, the Department of the Environment and Energy Security (MASE) is in favor of the development of biomethane due to national energy strategy and legislative framework goals such as decarbonization. As part of the national energy plans with integrated biomethane, it shows that decisively to be a solution that is doing good in environmental or economic terms, but also socially what is highly supportive for overall sustainable development. [5]

1.2 Environmental obligations and the Carbon Neutrality Debate

The one most convincing and commonly accepted explanation for the growing importance of biomethane is its exceptional green credentials, not least its ability to cut down significantly on greenhouse gases (GHG) output. Biomethane is made from recently fixed biomass, as distinct from fossil natural gas which is created by combustion, and it causes the emissions of carbon sequestered underground over millions of years. The difference is fundamental and leads to notions such as "closed-loop carbon cycle", whereby biomethane is supposed to be long-term carbon-neutral. However, a full life-cycle assessment of one that its scientifically robust and critically nuanced is necessary to truly comprehend its environmental consequences and to be sure that the deployment is really contributing to net decarbonization. The "carbon neutral" declaration thus needs to be determined over the complete production and consumption life cycle, ensuring that all possible CO2 emissions are considered for both savings and added emissions aka well-to-wheel or cradle-to-grave. [2]

1.2.1 Greenhouse Gas Displacement: A Critical Review and LCA Overview

Biomethane is carbon-credited over its lifecycle and not only during the process of combustion at point of use. The overall environmental assessment is carried out over all from feedstock growing and collecting to digestate utilization including transport, anaerobic digestion and biogas upgrading to biomethane. The greenhouse gas balance of biomethane relies on three key categories, namely: methane emissions during anaerobic digestion, power consumption for upgrading and feedstocks and handling methods. A full Lifecycle Assessment (LCA) is the only way to calculate the true climate advantage of biomethane.

1.2.1.1 Quantitative Potential for CO2 Equivalent (CO2eq) Reduction

Biomethane has great potential to decrease greenhouse gas emissions. According to studies published in Renewable and Sustainable Energy Reviews and Energy Policy (which analysed biomethane production from two waste feedstock, namely animal manure and agricultural residues; and the other one municipial organic waste and sewerage sludge) covering its entire lifeycle chain results in GHG reductions of over 80%, is compared to conventional natural gas. The significant reductions in emissions show that with existing technology, biomethane plays an important role in meeting climate objectives. [6]

1.2.1.2 Addressing the Challenge of Fugitive Methane Emissions (Methane Slip)

The environmental heat-trapping gas methane (CH4) causes 80–86 times the warming as carbon dioxide (CO2) within a 20-year period. [7]

Even a small amount of methane leaking during the anaerobic digestion process is long-term climate forcing thanks to this time scale. Anaerobic digestion is a multi-step process where methane can be lost through mischance, during feedstock maceration, digester filling, operation and collecting biogas. The gas is leaked through fractured pipes as well as valves and broken seals, and when flares or engines burn the fuel incompletely. The fugitive emissions and methane slip associated with biomethane production systems are a significant issue that lessens the GHG mitigation potential of biomethane. Maximum GHG reduction from biomethane is guaranteed only with rigorous inspection technology (OGI, drone-based) and comprehensive LDAR (Leak Detection and Repair) programs, as well as state-of-the-art methane capture systems. Attention to keeping methane losses under control is essential at all stages of the biomass-to-biomethane process. [8]

The abatement of methane emissions relies on the employment of advanced gas-tight seals for digesters and high-tech pressure control systems, as well as highly performing flare systems for emergency cases and off-gas control. In addition to above", where the separated CO2 streams during the upgrading operations are captured and utilized as feedstocks for production and thereby combined with NET at atmospheric CO2 prevention and industrial use of capture results in negative emissions. A sustainable biomethane production needs reducing to zero all fugitive emissions and responsible biomass sourcing that avoid indirect land use change as well as competition with food production.

1.2.1.3 CO2eq Reduction Accounting Techniques: ISO 14040/14044 and European Directives

The true quantity of CO2 equivalent (CO2eq) saving must be cross-checked with an accurate quantification to assess the environmental impact and climate benefits of bio-methane. The field of complete environmental analysis is served by the scientific instrument called Lifecycle Assessment (LCA). There are international standards ISO 14040 and ISO 14044 that define a globally used framework for LCA studies, with respect to both science accuracy, transparency in results as well as comparability between different assessments. The guidelines specify a structured process that requires researchers to define their study purpose and scope, collecting full life cycle inventory (LCI) data from all relevant inputs and outputs, conducting life cycle impact assessments (LCIA) in multiple environmental categories and communicating results for decision making use. [9]

European Union (2018) RED II and RED III will set specific sustainability criteria and methods of accounting emissions for biofuels including biomethane. Under the RED II directive, new biomethane plants must emit at least 60% greenhouse gases than fossil natural gas while existing facilities will have to meet even stricter criteria and comply with specific feedstock regulations targeting sustainable forestry and land preservation. The EU directives define legal and methodological criteria for the environmental assessment of biomethane in all the EU areas, ensuring that only ecologically viable biomethane should be supported by schemes. [10]

The Agenzia nazionale per l' le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA) uses its diversified R&D activities to contribute to the definition and application of such evaluation methodologies. The organization provides key sustainability audits and data and expertise in quantifying the Italian biomethane supply chain through reports and analysis that inform national policy frameworks and best practices. The companies are vital for ensuring that biomethane projects meet stringent environmental requirements, as well as assisting Italy in achieving their domestic decarbonization aims which are consistent with overall EU sustainable policies. Rigorous environmental accounting protects public confidence and investor backing of biomethane as a trusted climate solution.

1.2.2 Waste Management versus Circular Economy Principles: The Synergistic Approach

With the objective to reduce sub-standard waste disposal, renewable potential of biomethane production represents an important but currently underestimated factor to the sustainable treatment of organic waste and recycling by means of circular economy. The method offers a real-world and cost-effective way to turn multiple organic waste streams into valuable energy, instead of sending it to a landfill or incinerator. The circular economy model accomplishes its main goal which is to convert waste into resources rather than producing waste through improvement of resource use efficiency and reduction of waste generation.

1.2.2.1 With respect to the Valorization of Biomass Residues and Organic Waste Streams

The production of biomethane from biomass residues and organic waste offers a new way for transforming the common problem of environmentally hazardous waste disposal into an energy resource utilization. It would serve two purposes by controlling methane emissions produced by decomposition, according to the plaintiffs, and offer a long-term solution for farms and industries needing expensive treatment systems to handle organic waste. The European Union Waste Framework Directive (2008/98/EC as amended by 2018/851/EU) approaches waste management regulating via the waste hierarchy, which ranks hierarchical levels in order of priority and involves prevention in combination with recycling at the top-based levels. [11]

The process of valuing an agricultural waste stream thus allows farmers and waste management companies to create new economic opportunities along the lines of new value chains local to the region. The Italian Ministry of Environment and Energy Safety (MASE) endorses energy recovery from organic waste, as it meets both the requirements of the treatment of waste in accordance with the need for sustainable waste management and those on renewable energy production consistent with national circular economy goals. The integrated approach generates environmental advantages through waste to wealth schemes which have hitherto been discarded as waste products, thus forming a valuable relationship between farming activities and waste management and power generation. [12]

1.2.2.2 Valued Resource Digestate can also contribute to nutrient recycling and agricultural sustainability

The operation diverts significant quantities of waste from being disposed in landfills, reducing the methane generated from organic waste decomposition, extending the life of landfills and creating a saleable nutrient-rich byproduct called digestate. Digestate is a precious organic fertilizer as it comprises of both solid and liquid fractions obtained by anaerobic digestion. Anaerobic digestion converts organic waste into fertilizer with higher nitrogen (N), phosphorus (P) and potassium (K) concentrations compared to raw manure, since the microorganisms decompose the organic matter in the maturation plant. [13]

This is why digestate is such an efficient and easily accessible material as a plant nutrient. Digestate utilization is advantageous for the agricultural sector since it facilitates full nutrient cycles improving soil fertility, organic carbon content and decreasing environmental effects. The holistic contribution of renewables conversion and waste utilization to biomethane production with nutrient recycling systems can then be appreciated in terms of environmental sustainability. Replacing traditional chemical fertilizers with digestate is an added value for the Italian agriculture which benefits from the practice as it makes farming sustainable and lowering the use of external means and related costs.

1.2.3 Air Quality Improvement: A Significant Public Health Dividend

The conversion of motor fuel and industry heating & the decentralized generation to bio methane will bring about significant immediate improvements in local & regional air quality. The incineration of biomethane emits fewer hazardous pollutants into the atmosphere than fossil fuels, leading to a healthier public and cleaner climate.

1.2.3.1 Reduction of Local Air Pollutants (PM, SOx, NOx)

Use of biomethane results in significant abatement of several key air pollutants, which need control because they are deleterious for human health and environment. The World Health Organization (WHO) considers Particulate Matter (PMn) as a major health risk; under this name, its fine size particles 2.5 micrometers and smaller in diameter, that is PM2. [14]

PM emissions from biomethane with the use of optimized engines and burners for conversion, are less than those for diesel and heavy fuel oil as well as coal. There are major benefits for cities and overcrowded areas, who often exceed their PM limits. The primary cause of acid rain is sulfur dioxide (SO_2), an irritating gas that also represents harmful irritation to human lungs. Biomethane is naturally almost free of sulfur, since hydrogen sulfide (H_2S) can be efficiently stripped off during the upgrading to pipeline quality process. The content of sulphur in fossil fuels such as coal and heavy fuel oil and in particular types of diesels cause severe air pollutions problems in certain areas as well as acid rain and respiratory problems. The main air pollutants are Nitrogen Oxides (NOx) comprising nitric oxide (NO) and nitrogen dioxide (NO2) which produce ground-level ozone (smog) and acid rain causing respiratory problems. High temperatures in combustion cause thermal Nox. Heavy-duty vehicles and furnaces though using gaseous fuels including biomethane are equipped with advanced control systems namely lean burn, exhaust gas recirculation and selective catalytic reduction for reducing such emissions. Studies have shown that biomethane powered vehicles have lower NOx emissions than diesel powered vehicles. [15] Gaseous VVOC are continuously evaporated to the atmosphere in its presence, where they readily react with NOx in photochemical reactions under sunlight conditions forming hazardous ground-level ozone. Non-anthrome biogas emits fewer VOCs also with consideration of cases where it is not burned out to completion, compared to liquid fossil fuel combustion. The partial combustion generates the poisonous gas Carbon Monoxide (CO). [16]

Biomethane systems have been optimized for complete combustion and to generate very low CO emissions. Such large reductions in criteria pollutants for urban and industrial areas are of specific importance as those regions are facing heavy air pollution leading to smog and severe health impacts, like respiratory illnesses, cardiovascular effects and early death.

1.2.3.2 Impact on Human Health and Socio-Economic Benefits

Environmental health gains associated with biomethane include lower ambient air pollution levels leading to decreased chronic disease and healthcare costs. The achievable public health benefits of biomethane use provide further incentives to implement the technology in society. The substitution of fossil fuels with biogas/biomethane results in significant urban air quality benefits that enhance public health. Biomethane promotional measures are key components of energy policy, as well for public health improvement and strategies for sustainable development. The economic and social advantages include fewer work absences due to illness and less school days missed, increased productivity at workplace as well as better quality of life for those living in city. Long-term economic benefits of lower healthcare costs and improved social health form a comprehensive value proposition for biomethane driving strong adoption. The potential of biomethane as a greenhouse gas (GHG) mitigating fuel gives strong motivations to governments to incentive development in this area and for public acceptance of the projects. [17]

1.3 Economic Resilience and Policy Frameworks

The country also enjoys the economic return from biomethane, for it secures energy independence, assists sustainable development and rural livelihoods. The economic benefits are larger and quicker to rise owing to the right policy systems as they minimize investment risk, create reliable market conditions and promote essential capital formation.

1.3.1 Enhancing Energy Independence and Security

Several countries are reliant on imported fossil fuels, including gas, face significant geopolitical risks and very serious economic problems. Highly volatile international energy markets and the disruption of supply chains as well as natural price fluctuations reflect goods that have unstable and increasingly costly prices and contribute to destabilized industrial performance. Biomethane provides a national source of energy that contributes to both energy independence and military readiness. Alternative sources of energy that are based on local organic material allow countries to reduce dependence on volatile world markets and insulate their power supply from global shock. Countries attain economic security with the use of native energy resources that shelter them from international energy interruptions to birth an efficient electricity grid. The economic benefits comprise lower balance of payments deficits from reduced imports of fossil fuels, and an increase in the value-added portion of domestic economic activity that helps to create national economic independence. [18]

The decentralized production process provides considerable social and economic benefits, concentrated in rural areas and agricultural communities. The whole value chain of the biomethane produces new job opportunities and these relate also to feedstock collection, plant construction as well as plant operation & maintenance which support agricultural economies within strong regional economic development. Farmers that will make money with waste and sell plant energy businesses on marginal land will benefit from higher revenue and income, leading to improved profitability as well as diversified business management structures. Independent biomethane plants also give rise to decentralized power systems that can enhance grid stability as they reduce the reliance on centralized generation and long transmission lines, both of which are susceptible to sabotage. Biomethane is the foundation for growth in rural areas and strengthens local economies: new jobs are created, and new sources of income emerge.

1.3.2 Financial Instruments and Incentive Policies: Market Dynamics and Investment Drivers

The rapid development of biomethane production is contingent on favorable government policies and incentives that are well-planned and properly implemented. The mechanisms are important tools for decreasing the first cost gap between biomethane and existing conventional fossil fuels by reducing costs of constructing new production plants which lead to a greater probability for market penetration at full scale. Effective implementation of these policies is an important factor to drive market growth and expand the manufacturing base to achieve significant geared-up decarbonization targets. Various market conditions need different incentive systems which are used simultaneously by the organization to reach the target. Under the Feed-in Tariffs (FiTs) scheme, developers receive a set payment for every unit of biomethane they generate and feed into the grid under long-term contracts over 15-20 years. Methanizing becomes profitable by financial public support of biomethane production, attributable to payment schemes that rely on revenues and adjust tariffs on the moment due to natural gas exchange market and sustainability criteria necessary for keeping operations up at play in market. The government should provide tax exemptions and reductions on biomethane production costs, distribution expenses and consumption fees that will make it more cost competitive with conventional fossil fuels.

The GO system certifies the production of renewable biomethane, allowing producers to sell both the physical gas and its associated environmental attribute (the "green certificate"), separately. That new revenue streams are generated, and the green gas market price are made more transparent to assist enterprises reach their sustainability targets [19]. The evaluation of the maturity in the Italian market should be examined by looking at other large European and non-European countries, taking as reference markets following similar growth trend to assess the differences recorded in terms of policy development and market performances. Germany’s EEG established biogas and biomethane production as a frontrunner in the sector with its large feeding tariffs promoting massive industry growth, particularly in agricultural zones [20]. EEG succeeded initially thanks to the long-term reliable nature of its contracts and the high remuneration rates, but the market has evolved, so that now competitive auction systems which reduce incentives costs are used. Denmark made significant strides because of the country’s dedicated national circular economy and its generous funding of large centralized biomethane plants that process manure and industrial waste into gas to be used for heat or injected into the power grid [21]. The Netherlands has also been making significant advancements by way of policies supporting the grid injection and transport applications of biomethane, with SDE+ (Stimulation of Sustainable Energy Production) and investment subsidies, operational support regime [22]. The Italian government has designed a comprehensive structure of incentives to be discussed in

Chapter 2, but the system requires continuous updates for it to be competitive while still attaining its decarbonization targets. Reducing the Levelized Cost of Energy (LCOE) for biomethane, and thus attracting substantial private capital to this sector, is often used as a measure that will further expedite market deployment and ensure long-term sustainability of such policies.

1.4 Technical benefits and Integration into infrastructure

Biomethane has intrinsic technical characteristics which ensure that it is a very relevant and strategically favorable renewable energy not only in terms of high compatibility with existing energetic systems but also through numerous possible utilization’s crossing different levels of demands. These technical features drastically lower the costs for large-scale deployment and integration into the energy system at large, representing a practical and low-cost trajectory for decarbonization.

1.4.1 Leveraging Existing Infrastructure: The "Drop-in" Advantage

The “Drop-in” Benefit Biomethane has a significant economic benefit because it is compositionally not too different from the regular fossil natural gas. Both materials consist of more than 95% purity for feedstock to regulate pipe injection operations and operate with methane (CH_4) as the primary ingredient. Its “drop-in” potential derives from this key feature that it has no requirement for any significant modifications to existing natural gas grids, pipeline systems and/or networks nor compression stations, storage facilities or usage devices. Integrating biogas into established natural gas infrastructures can present cost-effective options to facilitate low-carbon energy transitions as it avoids expensive infrastructure construction work. Biomethane is a technically and economically viable answer for the decarbonization of the gas sector, that does not entail the heavy investments in new infrastructure or wide-scale equipment renewal at consumer’s premises, hence allowing swift implementation of energy transition. The plan allows several billion euros of existing gas infrastructure to continue in operation, and this will avoid unnecessary asset stranding and deliver the maximum economic outcome. The ‘drop-in’ nature of biomethane offers a short-term solution to decreased gas emissions from use and is a convenient route for progression of the wider energy system. The system could be deployed rapidly since it works from existing infrastructure and would not have to spend the time building new energy systems to make quicker progress towards decarbonization goals. The gas grid has storage facilities which allow biomethane sites to run all year around, despite fluctuating demand.

1.4.2 Versatility of Use: Diverse Market Injections and Sectoral Decarbonization

BioCH4 has several applications, not only grid injections but also in other sectors making it possible to contribute to the greatest degree of decarbonization. Biomethane offers advantages to the energy transition when it reaches pipeline quality. The most common and cost-effective method of using the biomethane is Grid Injection. The upgraded biomethane is directly injected into national natural gas distribution and transmission systems, for physical mixing with standard natural gas. It can subsequently be used in a consumer's premises, connected to the grid for residential heating or in commercial building energy applications so as industrial heating requirements and flexible power generation in gas-fired power stations. The solution allows for immediate decarbonization of the demand-side gas system, delivered through existing infrastructure with no requirement for end-user equipment intervention. The GSE (Gestore dei Servizi Energetici) is the central operator in charge of managing the arrangements concerning biomethane grid injection and incentives. The system allows for long periods of seasonal storage of renewable energy at a large scale and grid stability. When bio-methane is compressed to Bio-CNG or liquefied to Bio-LNG, the gaseous and liquid nature of natural gas can be used as vehicular fuels. That would certainly extend to cars, light-duty trucks and long-haul freight vehicles, as well as urban- and intercity buses — even sea-going vessels. One sector which can potentially be majorly decarbonized with this application is transportation, of heavy-duty and long-haul transport where it has challenging technical issues in the electrification due to weighty batteries and limited range on travel and poor recharging facility. The use of Bio-LNG is increasing as a mainstream fuel for long haul road freight and marine shipping due to its capability of offering an immediate low-carbon diesel on heavy fuel oil substitutes that contributes to reducing the pollution in port areas and along major transportation routes. [16]

Biomethane is used, directly or indirectly, on the spot as natural gas, e.g. for remote locations and certain agricultural installations and industrial sites that can't connect to the "domestic" natural gas grid for either economic or technical reasons. It allows for energy independence by removing the reliance on grid power and oil supply lines and supports independent farms of agriculture, independent small scale food processing and industrial operations while reducing their electricity costs as well as environmental footprints. Its decentralized system makes it possible for local energy networks operate stably to solve the problem of no-grid or unstable grid in remote areas, which is conductive to rural development.

Biomethane can also be used for industrial feedstock purposes in industry to be able to utilize the renewable substitute of fossil natural gas for industrial processes. This includes the production of chemicals, like methanol and ammonia for fertilizers, hydrogen and other materials such as certain plastics. Biomethane is a fossil-based feedstock substitute that enables industry to reduce the related greenhouse gas emissions stemming from both direct operations and indirect energy use and supports industrial decarbonization for those sectors not capable of using electricity or other renewable fuel applications. The emerging technologies bring opportunities for industrial carbon reduction and green product development, promoting sustainable industrial operation and supply chain system. The versatility of biomethane can be seen from the variety of its applications validating also within various energy markets a solution to contribute to decarbonization and positioning itself as one of major renewable energy solutions. Technology offers reliable renewable power that can be used to stabilize power grids and to increase the reliability of energy systems.

Chapter 2: The Italian Incentive Framework: Structure, Purpose, and Authoritative Design

2.1 Introduction to Italy's Biomethane Strategy

Italy demonstrates its dedication to build a sustainable energy system through its active development of biomethane as a decarbonized energy solution. The national policy exists as a single initiative which maintains strong connections to European Union directives and global climate targets. Biomethane serves as a strategic resource because it provides three key advantages by operating as a renewable fuel that matches traditional gas systems and enables existing infrastructure use and resolves waste management issues and promotes rural development and enhances national energy security. The following introduction explains how Italy's biomethane strategy supports both national and European renewable energy targets before analyzing the complex incentive systems and regulatory structures that govern Italian biomethane development.

2.1.1 National and European Renewable Energy Targets and Policy Alignment

Italy's biomethane strategy is inextricably linked to, and indeed driven by, a comprehensive set of national and European energy and climate policy mandates. At the apex of the European policy framework stands the European Green Deal, an overarching strategy aiming to make the EU climate-neutral by 2050. The Renewable Energy Directive (RED II, Directive (EU) 2018/2001) serves as a key component of this large-scale goal by setting mandatory renewable energy targets for EU gross final consumption and establishing targets for transport sector renewable energy use. The RED III package under the 'Fit for 55' legislative proposals works to enhance renewable energy targets through specific rules for renewable gases. The geopolitical events created an urgent requirement to decrease fossil fuel usage which made domestic renewable gas production a critical strategic priority. The REPowerEU Plan established a new biomethane production goal of 35 billion cubic meters (bcm) by 2030 because of Ukraine war-related energy supply disruptions. The EU established a new biomethane production target of 35 billion cubic meters (bcm) for 2030 which represents a tenfold increase from 2021 levels. The European Commission states that biomethane serves as a vital component for EU energy security and carbon reduction because it helps reduce fossil gas imports while speeding up the energy transition. [23]

The Integrated National Energy and Climate Plan (PNIEC) serves as Italy's national energy policy framework which sets out 2030 strategic targets and policy actions for five key areas including decarbonization and energy efficiency and security and market integration and research and innovation. The PNIEC and its future revisions will establish progressively challenging biomethane targets because of its ability to help achieving decarbonization goals in heating systems and transportation networks and industrial operations.

The Italian government maintains its dedication to European environmental targets through the Ministry of Environment and Energy Security (MASE) which leads national policy development and legislative framework alignment. The alignment serves multiple strategic functions above compliance because it allows Italy to access major European funding through NextGenerationEU and facilitates borderless energy trading and creates a unified sustainable energy strategy. The legislative environment stays active because it adapts to scientific advancements and technological developments and worldwide political changes while biomethane functions as a flexible solution to address climate and energy security requirements. [5]

The policy design establishes risk reduction measures for private investors while creating a stable regulatory framework that enables biomethane production capacity growth throughout the country.

2.2 The Development of Biomethane Introduced by the PNRR (National Recovery and Resilience Plan)

The National Recovery and Resilience Plan (PNRR) serves as Italy's strategic plan to address the severe economic and social problems which the COVID-19 pandemic intensified. The European Commission has approved the PNRR which receives its primary funding through the NextGenerationEU instrument to become more than a recovery plan because it enables Italy to transform its infrastructure and digitize public services and speed up its ecological transformation. The framework establishes biomethane as its main priority area through which it allocates major funding for development purposes. The Italian government added biomethane to this vital national plan because they see it as a key element for reshaping their energy infrastructure and advancing national growth. [24]

2.2.1 Mission "Green Revolution and Ecological Transition" within the PNRR

The PNRR framework includes biomethane development under Mission 2 which focuses on "Green Revolution and Ecological Transition" (M2). More precisely, it falls within Component 2 (M2C2): "Renewable energy, hydrogen, grid and sustainable mobility," under Investment 1.4: "Development of biomethane, according to the principles of circular economy".

The mission includes precise plans to create a sustainable economy through investments in renewable energy, circular economy, sustainable mobility, national territory and water resource protection. Moreover, this mission includes biomethane to show its importance as a renewable energy source and circular economy enabler. The dual advantage of this process enables the conversion of various organic waste materials into both energy sources and agricultural products which were previously considered waste. The PNRR establishes biomethane as its main objective to build an efficient waste management system which connects agricultural production to industrial activities and environmental sustainability. The government has created a strategic plan to implement biomethane as a solution which addresses various green recovery targets. [24]

2.2.2 Specific Objectives and Financial Allocations for Biomethane Development

The PNRR sets goals and allocates substantial funding to biomethane development for building up domestic production capabilities. The main goal requires reaching 2.5 billion cubic meters of biomethane production annually until 2026. The target aims to produce biomethane from agricultural waste and organic materials because it creates sustainable energy while providing eco-friendly waste disposal solutions. The planned growth will help achieve major reductions in transport sector emissions through Bio-CNG and Bio-LNG and it will boost renewable gas penetration in the national grid.

The PNRR dedicates about €1.7 billion to support biomethane infrastructure development and technological progress through its ambitious funding plan. The organization distributes these funds to support various vital programs.

The program dedicates major funding to support the development of completely new anaerobic digestion facilities which can convert biogas into biomethane. The new facilities need to follow strict sustainability standards which will help them achieve environmental targets without creating adverse effects.

The plan includes strong financial backing to transform current biogas facilities that generate electricity or heat into biomethane production facilities. The strategy works to improve current infrastructure while speeding up the transition process to create fast biomethane delivery systems.

The PNRR requires new and converted plants to achieve superior environmental sustainability standards beyond minimum requirements. This includes strict guidelines on the sustainable sourcing of agricultural and agro-industrial residues such as feedstocks, the environmentally responsible management and utilization of the resulting digestate.

The plan supports the implementation of new technologies across the biomethane production system starting from improved digesting technology to better upgrading equipment to enhance both operational efficiency and environmental sustainability and lower operational expenses.
The government has established these large financial programs to reduce investment risks which will bring in substantial private sector funding and drive technological progress and operational efficiency throughout the biomethane supply chain. The PNRR delivers financial support which creates a robust market signal that strengthens investor trust and speeds up project delivery. [24]

2.2.3 Anticipated Impact of the PNRR on Installed Capacity and the Biomethane Value Chain

The PNRR will experience a major transformative effect through its strategic implementation of biomethane which will reshape both Italy's biomethane infrastructure and its supporting value chain. The plan contains aggressive targets and major financial backing which should drive fast development and industrial transformation of the sector.
Scientists can predict with absolute certainty that the major increase in installed capacity will be the direct outcome. The 2.5 bcm target for 2026 establishes Italy as a major European biomethane market leader through its ambitious growth strategy. This expansion will be critical for moving Italy closer to achieving its national and European renewable gas targets, as outlined in the PNIEC. [5]
The growth will result from new construction activities and the conversion of numerous existing biogas plants which will enable fast expansion of production capacity.
The PNRR includes provisions which will draw substantial private sector funding. The combination of clear policy signals with major financial incentives through grants, premiums and auction mechanisms functions to reduce project risks which makes them highly appealing to private sector investors and financial institutions. Private capital investments will propel industry growth because public funding lacks the capacity to reach the required scale for sustainable long-term expansion. The PNRR established a stable regulatory framework which serves as a major draw for this investment.
The plan will create a positive impact on the entire biomethane value chain. The organization will establish strong connections with various stakeholders while developing fresh possibilities for multiple groups of people.

The growth of the organic residue market will create additional income opportunities for farmers, agro-industrial businesses and waste management organizations which will enhance agricultural infrastructure.

Specialized companies will drive domestic industrial development through their demand for anaerobic digestion, biogas upgrading and gas grid injection technologies.

Biomethane project development will establish a fresh market segment which will draw specialized engineering firms and energy companies to invest in this emerging sector.

Increased availability of biomethane will support the decarbonization efforts of gas network operators and provide end-users (transport, industry, residential) with a renewable alternative to fossil gas.

The PNRR initiative will create a permanent improvement system for the sector through its dedication to innovation. The plan includes financial incentives to promote advanced feedstock pre-treatment methods, better digestion techniques and upgrading systems which will maintain Italy's position as a leader in biomethane technology development. The PNRR needs precise monitoring systems and reporting protocols which the Ministry of Economy and Finance and European Commission monitor to reach all objectives while making sure funds serve their green recovery purpose efficiently and within schedule. [24]

2.3 Operational Procedures of GSE and Ministerial Decrees on Biomethane

The biomethane incentive schemes of Italy operate under Ministerial Decrees which establish the framework while the Gestore dei Servizi Energetici (GSE) handles the operational management and practical implementation of these schemes. The GSE operates as a state-owned company which leads the effort to advance renewable energy development in Italy. The organization operates as the central administrative body which manages incentive programs by conducting complete project verification and operating efficient fund distribution systems. The GSE operates as a key operational entity which brings policy objectives into reality by deploying projects nationwide while maintaining the operational integrity of biomethane support infrastructure.

2.3.1 The Ministerial Decree of May 30, 2024: Innovations and Operational Details

The Ministerial Decree of May 30, 2024 (Decreto Ministeriale Biometano 30/05/2024) serves as the current and most advanced regulatory framework for biomethane in Italy as it was published by the Ministry of Environment and Energy Security (MASE). The new decree introduces major changes which go beyond simple updates because it establishes important improvements to current laws that focus on making applications more efficient and defining better eligibility standards and payment incentives. The design of the project follows the PNRR (National Recovery and Resilience Plan) and European REPowerEU targets to support national biomethane deployment at a fast pace. The decree contains rules which create investment stability and project development predictability to establish a stable framework that enables fast growth of biomethane projects. The policy streamlines administrative operations through its combination of strict sustainability and efficiency requirements which establishes a new approach to renewable gas management. [12]

2.3.1.1 Incentive Mechanisms: Tariffs, Premiums, and Auction-Based Systems

The 2024 Decree establishes new incentive systems which aim to boost biomethane production through multiple support mechanisms for various production levels and operational frameworks. These mechanisms operate to decrease investment risks by establishing financial connections between biomethane market prices and conventional fossil gas market prices.

The following payment methods are available for smaller-scale plants and specific feedstock categories (e.g. small agricultural biogas plants): Feed-in Tariffs (FiTs) or Fixed Premiums. The payment system includes fixed tariffs and guaranteed premiums which pay a set amount for each unit of biomethane that enters the grid. The mechanisms produce dependable long-term financial streams during a specified period of 15-20 years which enable stable financial planning, project funding and minimize market price volatility.

The decree establishes competitive auction procedures for projects with bigger capacities and established project types. Project developers participate in these auctions to secure the lowest incentive level, which represents a premium above market prices for biomethane that makes their projects economically feasible. The competitive mechanism operates to achieve cost efficiency by directing public support toward the most cost-effective projects which reduces the total incentive expenses for the state. [12]

The GSE operates as the main organization which handles intricate auction procedures through tender calls and economic and technical bid assessments and incentive distribution. The European renewable energy policy now uses auctions as its main mechanism because of its market-based efficiency goals.

The decree includes capital grants that support the PNRR objectives by funding new plant construction and the conversion of existing plants. The grants support initiatives that utilize feed stocks including municipal organic waste while implementing state-of-the-art high-efficiency technologies. The main purpose of these grants is to low the first-time financial investment costs for project developers so they can fund innovative or complicated projects. The decree outlines how long incentives will last and sets limits on their value while defining rules for modifying incentives based on market price changes and inflation rates. [12]

2.3.1.2 Eligibility and Sustainability Criteria (MASE Guidelines)

The Ministerial Decree of May 30, 2024, outlines requirements for biomethane projects to receive available incentives through their eligibility and sustainability standards. These criteria are primarily defined by the Ministry of Environment and Energy Security (MASE) in strict accordance with European directives, particularly RED II (Directive (EU) 2018/2001) and its subsequent iterations like RED III. The criteria function to confirm that produced biomethane fulfills environmental requirements through reduced greenhouse gas emissions and sustainable resource management and protection of forests and agricultural resources. Key criteria typically include:

The project needs to follow all established rules which specify the exact origin and type of biomass feedstock. The focus of waste management programs centers on agricultural residues including animal manure and crop residues as well as animal effluents and municipal organic waste (FORSU) and sewage sludge. The cultivation of dedicated energy crops for power generation on land that could produce food or cause indirect land-use change (iLUC) remains prohibited or heavily restricted. The production of biomethane under this system follows a circular economic approach because it uses waste materials to produce energy which then fuels vehicles. This approach makes biomethane production sustainable within a circular economy framework.

The projects need to show at least a certain level of greenhouse gas emission reduction when compared to using fossil natural gas. The calculation of this saving follows RED II/RED III methodologies which assess emissions throughout the entire lifecycle from cultivation through processing and transport to conversion. This method allows users to determine environmental benefits.

The decree provides better financial advantages to facilities which adopt efficient anaerobic digestion systems and advanced biogas treatment solutions. The system promotes technological development while maximizing resource efficiency which results in higher energy production from each feedstock unit and lower operational expenses.

Stringent requirements are often imposed for the sustainable management and utilization of the digestate, the valuable co-product of anaerobic digestion. The product functions as a biofertilizer which enables the recycling of nutrients back into agricultural soil while stopping environmental contamination from incorrect waste disposal.

The MASE, frequently in close collaboration with the ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), provides detailed technical guidelines and specifications for these complex criteria. The organizations support Italian biomethane development through their partnership which upholds scientific standards and practical implementation methods. [25]

2.3.1.3 The Role of GSE in Incentive Management and Monitoring

The Gestore dei Servizi Energetici (GSE) functions as the essential operational body which carries out Italy's biomethane incentive programs with precision. Its responsibilities under the Ministerial Decree of May 30, 2024, are extensive and critical for the efficient and transparent functioning of the entire biomethane sector:

- It functions as the central point for application management through which it reviews all incentive applications from project developers. The decree requires complete verification of each project to confirm it fulfills all technical specifications and economic and sustainability criteria.
- It performs a review of all regulatory requirements before beginning the approval process.
- This authority performs effective evaluation and approval procedures to establish formal contracts with eligible biomethane producers through its contracting and disbursement procedures. The system requires precise delivery of incentives through scheduled payment intervals which should occur either monthly or quarterly to provide ongoing financial backing for project operations.
- It requires a permanent system to track and validate its operations as its main responsibility. This involves ensuring the ongoing compliance of biomethane plants with the terms of their incentive contracts. The process requires thorough checks of actual production amounts and biomethane quality standards and complete adherence to sustainability rules for feedstock acquisition and digestate handling. The process consists of site inspections as well as remote data monitoring and auditing activities.
- The GSE is mandated to provide regular, comprehensive reports to MASE and other relevant national and European authorities on the overall progress of the biomethane sector. The reports contain complete data about installed capacity and actual

biomethane production levels together with evaluations of how different incentive systems affect. The open data structure allows for essential policy evaluation and future planning requirements assessment.

- It provides technical assistance to project developers through its administrative functions which include regulatory clarification and best practice promotion for biomethane production and upgrading. The supportive function works to reduce project risks which enables faster project advancement.
- The GSE executes various functions to ensure public fund management transparency and efficiency for biomethane development and to build investor trust and promote industry sustainability. [26]

2.3.2 The Role of ARERA in Regulating the Gas Market and Grid Injection

The Autorità di Regolazione per Energia Reti e Ambiente (ARERA) plays a complementary but distinct and equally vital role within the Italian biomethane framework. Unlike the GSE, which primarily manages incentives, ARERA is the independent regulatory authority responsible for regulating the electricity, gas, and water sectors in Italy. The system performs essential functions which maintain market equality and competition and improve power grid management and protect consumer rights.

The physical and market integration of biomethane depends on ARERA to function properly. ARERA must create specific technical and economic guidelines which determine how biomethane can enter both Snam Rete Gas's national gas transmission network and distribution networks operated by different companies. The biomethane quality standards need exact definitions of methane concentration and Wobbe Index and specific limits for impurities and odorization requirements to match current infrastructure and appliance systems. The document requires specifications for technical network access and tariff information and connection protocols. The rules function as essential elements which protect the gas system from harm and maintain its operational integrity and operational efficiency.

ARERA needs to create regulatory guidelines that will enable biomethane producers to access the gas network on an equal basis. The system operates to protect competitive market operations through its power to block market distortions and prevent current gas companies from engaging in monopolistic behavior. It ensures that biomethane producers can sell their renewable gas under equitable conditions.

The regulatory authority ARERA sets prices for gas transmission and distribution and metering services. The overall economics of biomethane projects experience indirect effects from these tariffs because they establish the expenses needed for biomethane transportation to end-users.

ARERA exists to ensure that these tariffs stay connected to costs while being transparent and helping the network operate efficiently.

The Authority tracks the development of the gas market through its ongoing observation of the expanding biomethane integration.

ARERA monitors the market through its oversight function to detect potential market failures and growth barriers and supply security risks that need regulatory support for renewable gas development.

ARERA regulations serve as fundamental standards which enable safe biomethane physical injection into existing gas networks through technical compliance and economic fairness and operational efficiency. The independent regulatory oversight system of the Authority works together with GSE incentive programs to establish a complete system for Italy's biomethane deployment. [27]

2.4 Differences Between Ministerial Decrees of 2018 and 2022: A Comparative Analysis

The Italian biomethane sector has developed through multiple ministerial decrees which have continuously updated the policy framework to match changing market dynamics and technological progress and national energy requirements. The Ministerial Decree of 2018 (DM 2018) and Ministerial Decree of 2022 (DM 2022) function as essential guidelines which introduce modern operational approaches to advance the sector. The analysis of these two essential decrees provides complete understanding of Italy's biomethane policy development and its advanced renewable gas market promotion.

2.4.1 The DM 2018: The Initial Phase of Development

The Ministerial Decree of March 2, 2018 (DM 2018) established "Incentivazione dell'uso del biometano e degli altri biocombustibili avanzati per la mobilità e per altri usi" as its official title which translates to "Incentivizing the use of biomethane and other advanced biofuels for mobility and other uses." This decree served as Italy's initial major initiative to advance its clean energy transformation. The policy created the first complete incentive system which targeted biomethane production and its entry into the national gas distribution network. Its primary objective was to catalyze a nascent market, de-risk initial investments, and demonstrate the technical and economic viability of biomethane production on a larger scale. [28]

2.4.1.1 Key Characteristics and Objectives

DM 2018 introduced various crucial components which aimed to establish the first market growth.

The program concentrated primarily on agricultural biogas production through the conversion of animal manure and agricultural residues and dedicated energy crops into biomethane. The strategy used current farming methods together with current agricultural understanding to handle environmental problems stemming from agricultural waste disposal. The decree established a program which united biomethane production with farming operations to develop circular economic systems throughout rural regions.

The decree established fixed feed-in tariffs (FiTs) or direct premiums which offer a set payment rate for each unit of biomethane that enters the power grid. The mechanisms provided dependable long-term revenue streams to producers for fifteen years which minimized financial risks and brought in additional investors to projects. The tariff system applied distinct rates for agricultural waste and industrial waste feedstocks to ensure fair payment for projects based on their operational characteristics and financial requirements.

The policy establishes grid injection as the primary method for biomethane distribution through the national gas network. The process enabled biomethane to enter the existing energy system which made it possible for use in different sectors (heating, industrial, transport) without building new local infrastructure.

The decree established specific conversion incentives for existing biogas plants which operated under previous electricity-based incentive systems to produce biomethane. The existing anaerobic digestion facilities enabled the measure to deploy quickly at lower costs because it converted electricity-based biogas into gas-based biomethane. [28]

2.4.1.2 Market Impact and Early Challenges

DM 2018 triggered market expansion and brought Italy its first large set of biomethane plants creating measurable output - it proved that biomethane could be produced with existing technology plus those early profits appeared when rules favored the fuel. Developers and regulators drew concrete lessons from the period. Yet DM 2018 contained flaws that later forced the state to amend the rules

- Administrative Complexity - Permit but also application paths under DM 2018 were judged lengthy and tangled. Paperwork slowed each project, pushed up spending as well as led some investors to step away.

- Limited Feedstock Scope - The decree opened the door only to farm materials - municipal refuse and industrial residues stayed outside the list. The restriction kept extra waste out of the plants besides capped sector growth.
- Cost of Incentives
- Fixed tariffs delivered steady revenue, yet they risked becoming less. [28]

2.4.2 The DM 2022: Acceleration and Diversification

In 2022 the Ministerial Decree (DM 2022) which put forth "Disciplina degli incentivi per la produzione di biometano immesso nella rete del gas naturale" (Regulation of incentives for production of biomethane injected into the natural gas network) was issued. This took a large step forward in Italian biomethane policy. Careful in its design, it addressed the issues presented by the previous issue of 2018 (DM 2018) and put in place to increase biomethane production in a more efficient and economical way. Also, it is very important in terms of achievement of the ambitions put forth by the PNRR and the European REPowerEU plan. The new decree also marked a shift to more market-based mechanisms for Italy and a larger range of feedstocks. [29]

2.4.2.1 Broadening Feedstock Eligibility and Competitive Mechanisms

One of the most important and transformative changes introduced by the **DM 2022** decree was the significant broadening of eligible feedstocks for biomethane production. While the earlier **DM 2018** decree focused mainly on agricultural biomass, the 2022 update opened the door to a much wider variety of organic waste streams. This shift unlocked a huge, previously untapped potential for biomethane generation.

To give a clearer idea, the decree specifically extended eligibility to:

- **Municipal Organic Waste (FORSU)**: This is a big step forward, because the organic fraction of municipal waste—mainly food scraps and garden waste—represents very large volumes, especially in urban areas. By channeling FORSU into anaerobic digestion, two goals are achieved at once: less waste goes to landfills and more renewable energy is produced. It's a perfect example of circular economic principles applied at the municipal level. In practice, this inclusion also means that biomethane plants are no longer tied just to rural or agricultural areas, but can be developed closer to cities, supporting more localized energy solutions.

- **Industrial By-products**: Waste coming from industries such as food processing, breweries, distilleries, or even paper mills is now considered eligible. These streams are often rich in organic content, ensuring both high methane yields and a steady supply. For large-scale plants, this is particularly attractive. At the same time, industries benefit from lower disposal costs and reduced environmental impact, creating a win-win scenario of industrial symbiosis.
- **Sewage Sludge**: Another significant inclusion is sludge from wastewater treatment plants. This is a continuous and readily available source that has always posed a challenge for municipalities. With DM 2022, it can now be valorized to produce biomethane, helping close another loop in urban sustainability—wastewater management.

Altogether, this broader eligibility greatly increased the technical potential for biomethane production across Italy. It allowed for more geographically distributed plant development and reduced dependence on just one type of feedstock. Importantly, it also promoted better integration with existing waste management systems.

At the same time, **DM 2022 introduced a major shift in how incentives are allocated**, moving from the fixed feed-in tariffs (FiTs) of DM 2018 to **competitive auctions**, especially for larger plants. This change was motivated by three main goals:

- **Cost Efficiency**: In an auction, developers compete to offer the lowest incentive level they would accept for their project, usually framed as a premium over the market price of biomethane. This creates strong competition, pushing developers to innovate, reduce costs, and ultimately lower the financial burden on public support schemes. The idea is to reach decarbonization targets while using public money as efficiently as possible.
- **Market Orientation**: Unlike fixed tariffs, which are administratively set, auctions rely on market dynamics to determine support levels. This makes the incentive system more responsive to real production costs and changing market conditions, ensuring a closer alignment with economic reality.
- **Scalability and Predictability**: Auctions also make it easier to manage larger volumes of capacity allocation. Fixed tariffs can quickly become unsustainable if demand skyrockets, but auctions are designed to scale more effectively. In Italy, the **GSE** plays the central role in organizing these auctions—issuing tenders, evaluating

bids based on cost and technical criteria, and awarding incentive rights transparently. This model follows a broader European trend: as seen in countries like Germany and Denmark, renewable energy support systems evolved from FiTs to auctions as industries matured and competition increased. For policymakers, auctions also bring greater predictability regarding future public spending on incentives.

In short, DM 2022 didn't just expand the range of feedstocks; it also modernized the financial framework for supporting biomethane, making the sector more competitive, efficient, and integrated with waste and energy systems across Italy. [29]

2.4.2.2 Alignment with European Directives and the PNRR

A defining strength of **DM 2022** is how deliberately it lines up with EU policy and Italy's **PNRR**. This isn't just box-ticking: tight alignment keeps national rules coherent, makes investments more effective, and, crucially, safeguards access to major European funding streams like **NextGenerationEU**.

- **Renewable Energy Directive (RED II and RED III):**
  DM 2022 bakes in the sustainability rules and GHG-saving methods required by RED II (2018/2001) and anticipates elements of RED III. In practice, that means every incentivized biomethane project must prove sustainable feedstock sourcing (no conversion of high-carbon-stock land, traceable supply chains), limit **iLUC**, and hit minimum GHG reduction thresholds (typically ≥60% for new plants versus fossil comparators). Meeting these criteria ensures Italian biomethane counts toward EU targets and qualifies for cross-border trade mechanisms.
- **REPowerEU:**
  The decree explicitly supports the REPowerEU push to scale domestic biomethane and cut dependence on Russian gas. By setting ambitious national targets and speeding up incentive delivery, DM 2022 helps Italy contribute to the EU's **3**5 bcm by 2030 biomethane goal, aligning industrial deployment with the broader energy-security agenda.
- **PNRR integration:**
  DM 2022 is also the operational arm of the PNRR's biomethane investments (Mission 2, Investment 1.4). Capital grants and competitive auctions are designed to move projects quickly from pipeline to production, in service of the PNRR's 2.5 bcm by 2026 milestone. The decree provides the regulatory scaffolding, so PNRR funds are spent effectively, and projects meet both national strategy and EU

sustainability/performance benchmarks. In short, it’s a cohesive governance model that links decree, EU directives, and recovery plans into one execution path.

2.5 Authorizations and Permitting for a Biomethane Plant in Italy

Developing a biomethane plant means navigating a multi-layered permitting maze spanning national, regional, and local authorities. Mastering this path is essential for compliance, bankability, on-time delivery and often makes or breaks a project’s economics.

2.5.1 Main Pathways: EIA/SEA, AUA, Building & Fire Safety, and Grid Connection

- **EIA / SEA.**
  Larger or higher-impact projects typically require an EIA (VIA) under Legislative Decree 152/2006. Regions handle most EIAs; MASE takes the largest/strategic cases. The process runs from screening to a full Environmental Impact Study, public consultation, and final determination; complex cases can span 12–24+ months. SEA applies to broader plans/programs to embed environmental objectives upstream.
- **AUA (Autorizzazione Unica Ambientale).**
  For many waste-linked or medium-scale plants, the **AUA** consolidates multiple environmental permits (emissions, water discharges, waste, etc.) into a single act. Managed via the **SUAP** (often at Province/Metropolitan City level), it reduces fragmentation, though still demands comprehensive technical documentation.
- **Building Permit (Permesso di Costruire).**
  Issued by the Comune, this covers compliance with planning, building, seismic, and safety codes for all physical works (digesters, upgrading, storage, buildings, internal roads/pipes).
- **Fire Safety (CPI).**
  The Vigili del Fuoco assesses design and protection systems (detection, suppression, ESD procedures, ventilation) and issue the Certificato di Prevenzione Incendi, typically a final pre-commissioning milestone.
- **Grid Connection:**
  - **Operator:** Snam Rete Gas for transmission; local DSOs (e.g., Italgas, 2i Rete Gas) for distribution.
  - **Steps:** feasibility assessment → connection agreement (tech specs, roles, cost sharing) → construction of metering/quality/pressure assets →

qualification against **ARERA** gas quality specs (e.g., methane content, Wobbe index, impurities) before continuous injection.

Sequencing varies with plant size, feedstock, location, and whether the project is classified as waste treatment or pure energy production. Some permits can run in parallel; others are strictly sequential, careful PM is vital.

2.5.2 Who Does What (Comuni, Province, Regioni, MASE, GSE, ARERA, Vigili del Fuoco)

The main authorities involved in permitting this type of plants are the following:

- **Comuni:** building permits, zoning compliance, local rules (noise, traffic), and front-line community engagement;
- **Province / Metropolitan Cities:** often manage AUA/SUAP and coordinate ARPA/ASL inputs. They are the keys for local environmental authorizations;
- **Regioni:** central for VIA, regional waste/energy planning, and any added regional requirements;
- **MASE:** national-level **VIA** for large/strategic cases; sets national sustainability criteria and crafts incentive decrees (DM 2022/2024);
- **GSE:** qualifies projects for incentives and checks sustainability compliance. It is essential for bankability;
- **ARERA:** defines gas quality specs, connection tariffs and market access rules. Its compliance is mandatory for grid injections;
- **Vigili del Fuoco:** issue **CPI** for fire safety, a prerequisite for operation.

2.5.3 Challenges—and How Italy Is Tackling Them

Key pain points:

- **Long timelines & complexity:** End-to-end permitting can stretch 2–4 years+ for larger projects. Volume of documentation, sequential steps, and fragmented responsibilities add cost and risk, dampening investor appetite;
- **Inter-agency handoffs:** Delays often accumulate between offices. Lack of centralized coordination or shared digital platforms compounds the problem;
- **Technical/grid constraints:** Tight gas-quality specs require robust upgrading; some local networks lack capacity, forcing upgrades or new pipelines that add time and cost;
- **Regulatory churn:** Policy updates improve the system but can create uncertainty for projects mid-development;

- **Administrative capacity:** Staffing, expertise, and digital tools inside public bodies can be stretched, slowing reviews.

Streamlining opportunities:

- **True one-stop shops:** A single empowered counterparty to coordinate all permits and timelines can remove duplication and ambiguity;
- **Digitized, trackable workflows:** Online submission, shared document rooms, and real-time status tracking increase transparency and speed; PNRR digital initiatives are moving in this direction;
- **Clear, harmonized guidance:** Up-to-date, practical checklists and templates aligned across national and regional levels reduce “ping-pong” on documentation;
- **Early pre-application dialogue:** Structured scoping meetings and feasibility reviews surface issues early and prevent costly resubmissions;
- **Task forces / fast tracks:** Dedicated lanes for strategic renewable projects—some tied to **PNRR**—can compress critical paths;
- **Community engagement from day one:** Open houses, odor/traffic mitigation plans, and transparent monitoring build trust and shrink litigation risk.

Successful projects have in common: meticulous planning, early and continuous stakeholder engagement and disciplined coordination with every authority involved. Financial incentives matters but administrative speed often decides who breaks ground and when.

Chapter 3: Biomethane plant project

3.1 Subject of the intervention

This project involves the conversion of a plant that produces biogas from livestock manure and plant biomass to generate electricity into a biomethane production plant with a capacity of 750 Sm^3/h. The total capacity of the new converted plant, located in the municipality of Ravenna, will be 83,860 tons/year of plant biomass and livestock manure.

The anaerobic treatment of wastewater meets the dual need to improve the environmental impact on local components through the stabilization of sewage and to recover the biogas produced, to be used to produce biomethane and electricity for self-consumption. The recovery of heat from the cogenerator's cooling circuit makes it possible to meet part of the thermal demand for heating the digesters and optimizing the anaerobic digestion process. The remaining thermal demand, due to a denitrification system consisting of an evaporator, osmosis, and striping, will be met by a boiler fueled by methane taken from the grid.

Electricity will be supplied both by the cogenerator and by drawing energy from the electricity grid.

The biomethane produced will be compressed to make it compliant with the requirements for injection into the grid.

3.2 Current situation

The plant was built to convert biogas into electricity and feed the energy produced into the grid, except for the portion intended for self-consumption.

The existing plant currently consists of the following main elements:

- 1 underground pre-tank (300 cubic meters);
- 1 fermenter (1,000 m^3);
- 2 post-fermenters (each approx. 2,400 m^3);
- 2 biogas storage tanks (each approx. 2,400 m^3);
- 1 biomass storage area at the inlet with a surface area of 60 m x 30 m;
- 1 biomass loading hopper;
- Technical room for pumps, heating plants, and electrical panels;
- Jenbacher cogenerator with an electrical power output of 845 kWe;
- Jenbacher cogenerator with an electrical power output of 999 kWe;
- 2 rectangular tanks for storing liquid digestate (each with a capacity of 5,000 cubic meters);
- 3 trenches for storing solid waste (4,000 square meters in total);

- 1 separation system with reinforced concrete base for collecting separated digestate;
- Imhoff tank;
- roof-mounted photovoltaic system with a total power of 80 kWe;
- 1 alfalfa treatment and processing system.

3.3 Conversion

The plant conversion project envisages that, in its future configuration, it will be used to produce biomethane. The conversion requires the construction of new structural works and new plant equipment.

The new plant feed recipe is shown below:

Biomass	Quantity (t/a)	Percentage by weight
Corn silage	5,000	5.96
Triticale chaff	6,000	7.15
Broiler manure	30,000	35.77
Turkey manure	1,500	1.79
Mixed vegetables	25,000	29.81
Dry flour by-product	36	0.43
Cattle slurry	10,000	11.92
Cattle manure	6,000	7.15
Total	**83,860**	**100**
Recirculation of liquid digestate	41,845	-
Well water	33,000	-

1 Table: Feedstock for the post-conversion plant

The anaerobic digestion process requires the addition of liquid to ensure that the processed mass is sufficiently fluid to allow it to be moved by hydraulic pumping, as well as to facilitate the mixing of the input matrices. To this end, it is planned to ensure this liquid supply by recirculating part of the treated liquid digestate, for an annual quantity of 41,903 tons; in addition to the liquid digestate fed to the digesters, 33,000 tons per year of fresh well water will also be fed.

<u>This is done to ensure that the dry matter content of the mixture is less than or equal to 22% so that the pumps do not block during the process.</u>

The system will be fed by a total of 74,845 tons/year of liquid added to the process.

The biogas produced by the biomass fermentation process will be sent to the new upgrading unit for conversion into biomethane, before being fed into the measurement and compression system for injection into the grid.

Depending on the different operating modes, part of the biogas will be sent to the cogenerator to produce electricity and heat for the plant's own consumption; however, the cogenerator will only provide part of the electricity and heat required by the plant. The remaining electricity will be supplied by the grid. As regards thermal consumption, a boiler will be installed to produce thermal energy for the denitrification unit. It should be noted that the boiler will be powered exclusively by methane taken from the grid. If necessary, it will be able to cover a large part of the plant's thermal consumption, thus functioning as a partial back-up.

The plant will also be equipped with a 400 kWe emergency generator which, if necessary, will supply electricity to the blowers of the fermentation units, the flare, the upgrading unit, and the REMI cabin.

In addition, the plant will be equipped with a small rooftop photovoltaic system with a total power of 80 kWe: this system already exists and will supplement the electricity supplied by the cogenerator and the grid.

As for the management of the digestate, it will be separated into liquid and solid fractions. However, the liquid digestate will be denitrified using a system consisting of pre-treatment, evaporation, osmosis, and stripping.

3.4 Description of the project layout

In the new configuration, the plant will consist of the following works/systems:

- weighing station;
- offices;
- disinfection arch;
- 3 systems for feeding the palable material;
- 2 feed tanks;
- 4 trenches for storing plant biomass (corn silage, triticale chaff, mixed vegetables, dry meal by-product);
- 5 trenches for storing animal biomass (broiler manure, turkey manure, cattle manure);
- 2 circular digesters with a diameter of 28 meters and a height of 8 meters;
- 1 semi-dry digester with a capacity of 1,000 cubic meters;
- 2 post-digesters with a diameter of 19.50 m and a height of 8 meters;
- 1 post-digester with a diameter of 30 meters and a height of 8 meters;

- 2 tanks with a diameter of 32 meters and a height of 8.50 meters for storing the digestate coming out of the fermentation process, equipped with a biogas-tight cover;
- 1 tank for storing liquid digestate to be treated in denitrification, each with a capacity of 5,000 cubic meters;
- 1 circular tank with a diameter of 19.5 m and a height of 8 m for storing the pre-stripping liquid separated;
- 1 circular tank with a diameter of 19.5 m and a height of 8 m for storing the liquid separated from evaporation;
- 1 rectangular tank for storing denitrified liquid separated, each with a capacity of 5,000 cubic meters;
- 1 trench for storing solid separated material, measuring 135 m x 29.90 m in total;
- pump rooms and control panels/technical room;
- desulfurization system;
- 2 solid-liquid separators placed in series;
- triple-effect evaporation system for denitrification;
- digestate treatment system using osmosis;
- stripping system for digestate denitrification;
- cogenerator equipped with a biogas treatment system to produce electricity and heat;
- upgrading system for biogas purification;
- REMI cabin;
- electrical cabin;
- emergency flare;
- firefighting tank;
- 400 kWe generator set;
- compressor;
- vehicle disinfection system;
- tanks for managing leachate and rainwater;
- fencing and mitigation works;
- roof-mounted photovoltaic system;
- Imhoff tank;
- internal road network.

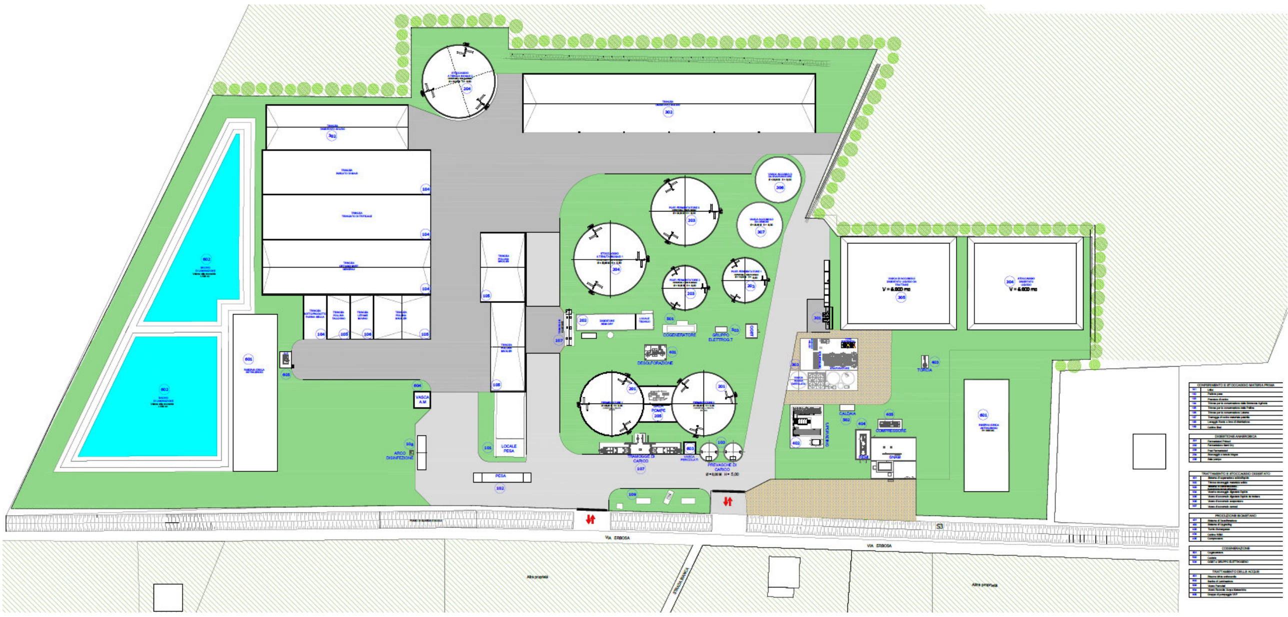

Figure 1 General layout plan of the authorized plant

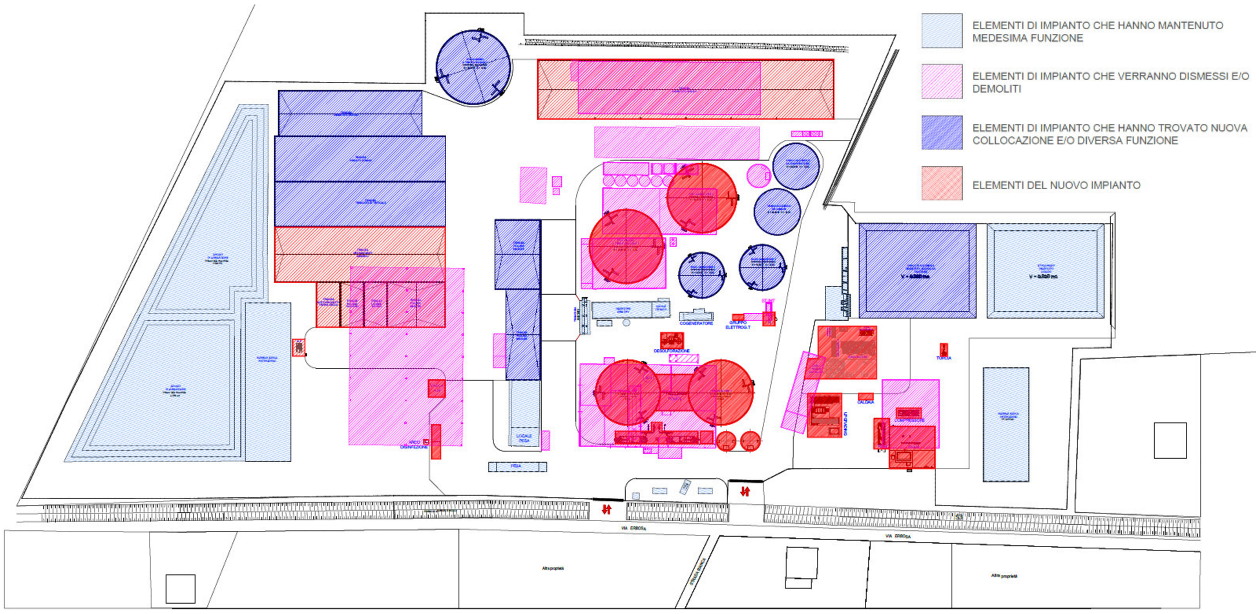

Figure 2 Comparative plan of the pre- and post-intervention plant

Figure 3 3D images of the future plant

3.5 Plant operating phases

The production cycle of the planned plant described below can be divided into the following basic phases:

- Storage and loading of the incoming raw materials;
- Anaerobic digestion process;
- Separation of liquid and solid digestate;
- Denitrification of liquid digestate;
- Recirculation of part of the treated liquid digestate;
- Extraction and treatment of biogas;
- Production of biomethane through an upgrading process;
- Sending biomethane to the measurement and control system for injection into the grid;
- Production of electrical and thermal energy for the needs of the plant and the process.

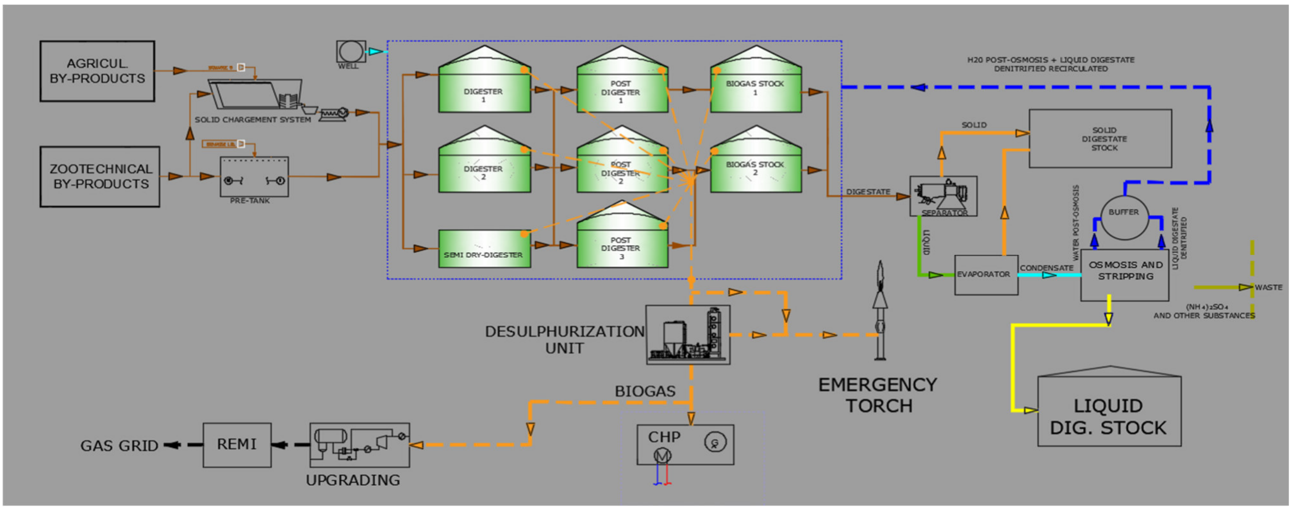

Figure 4 : Process flow

The process will begin with the loading of the wagon/hopper, an operation carried out by company personnel using a wheel loader once or several times a day. This vehicle will only load the solid matrices specified in the recipe into the wagon.

All shovelable matrices are stored in special trenches sized to ensure the required storage time. From the wagon, thanks to the use of screw conveyors, the solid biomass is mixed with the liquid matrices, conveyed into the biomix shredding pumps of the hoppers and from there to the digesters.

The liquid matrix, i.e., cattle slurry, will instead be transferred to mixing tanks, where the chicken manure will also be added. From here, the resulting biomass is transferred to the biomix via a submersible pump and conveyed to the digesters. The poultry manure will arrive at the plant in a more concentrated form, with a variable number of annual loads. Due to this method of entry into the plant, special trenches have been provided to better manage the dosage of broiler and turkey manure.

The volume of the digesters is such as to allow adequate retention times to obtain low organic loads. In this way, potential conditions of digestion overload will be avoided. After remaining in the digesters, the liquid inside is sent to post-digestion, the volume of which allows for a total retention time between fermenters and post-fermenters of approximately 40 days.

The digestate will be transferred to tanks designed for storing digestate as biogas, ensuring a retention time of at least 30 days.

After this retention period, the digestate will be sent to the solid-liquid separation station by means of a pump. Once the first phase of digestate separation has been completed by a helical screw separator, the separation will be further performed by another separator placed

in series: this will make it possible to obtain better yields and a significantly better quality of the separated products. The separated solid fraction will be used for agricultural purposes or, in periods when spreading is not permitted by law, it will be stored in a suitable trench that guarantees a retention time of at least 90 days.
The liquid fraction will first be denitrified using a complex system consisting of an evaporator, osmotic membrane, and stripping, after which it will be partly recirculated to the digesters and partly used for agricultural spreading. It should be noted that during periods when the spreading of digestate is not permitted by law, the digestate will be sent to covered tanks with rapid mobilization, which, together with the time already spent in previous storage, will allow a total retention time of more than 180 days to be achieved.
The biogas, originating from the fermentation of organic matter and consisting mainly of methane (approximately 56%) and carbon dioxide (approximately 45%), will be collected by pressure accumulators located at the top of the fermentation, post-fermentation, and storage tanks for spent digestate.
A flare is provided to ensure the combustion of biogas in the event of cogenerator failure and/or biogas overproduction.
The biogas produced by the plant will be divided between the upgrading system and the electricity and heat generation system within the plant (cogenerator). The plant will also be equipped with a boiler, but this will not affect the plant's production capacity as it will only be fueled by methane taken from the grid.
Before being sent to the recovery sections, the biogas will pass through the desulfurization section.
The upgrading system will be sized for maximum biomethane production capacity of 750 Sm^3/h. The upgrading system receives biogas at the inlet and, using separation technology with methane-impermeable membranes, produces two gas flows at the outlet: a biomethane flow and an "off-gas" flow, i.e., carbon dioxide and other impurities present in the biogas.
The biomethane is then sent to the measurement and analysis system for injection into the grid.
The electricity produced by the cogenerator is intended for self-consumption, as is the heat produced by the heat recovery system.
To support the power supply, albeit to a very limited extent, a small rooftop photovoltaic system with a total power of 80 kWe will be installed: this system already exists and will supplement the electricity supplied by the cogenerator. It should be noted that part of the electricity consumption will be covered by energy absorbed from the electricity grid.

The cogenerator can only be powered by biogas produced by the plant.
The boiler, on the other hand, will be powered by methane from the grid and will meet the thermal energy demand of the denitrification system. In case of need or unavailability of the cogenerator, the boiler can cover part of the plant's thermal consumption.

3.6 Mass and energy balance

The mass balance of the various sections of the plant is shown graphically below, some of which will be described in more detail in this chapter.

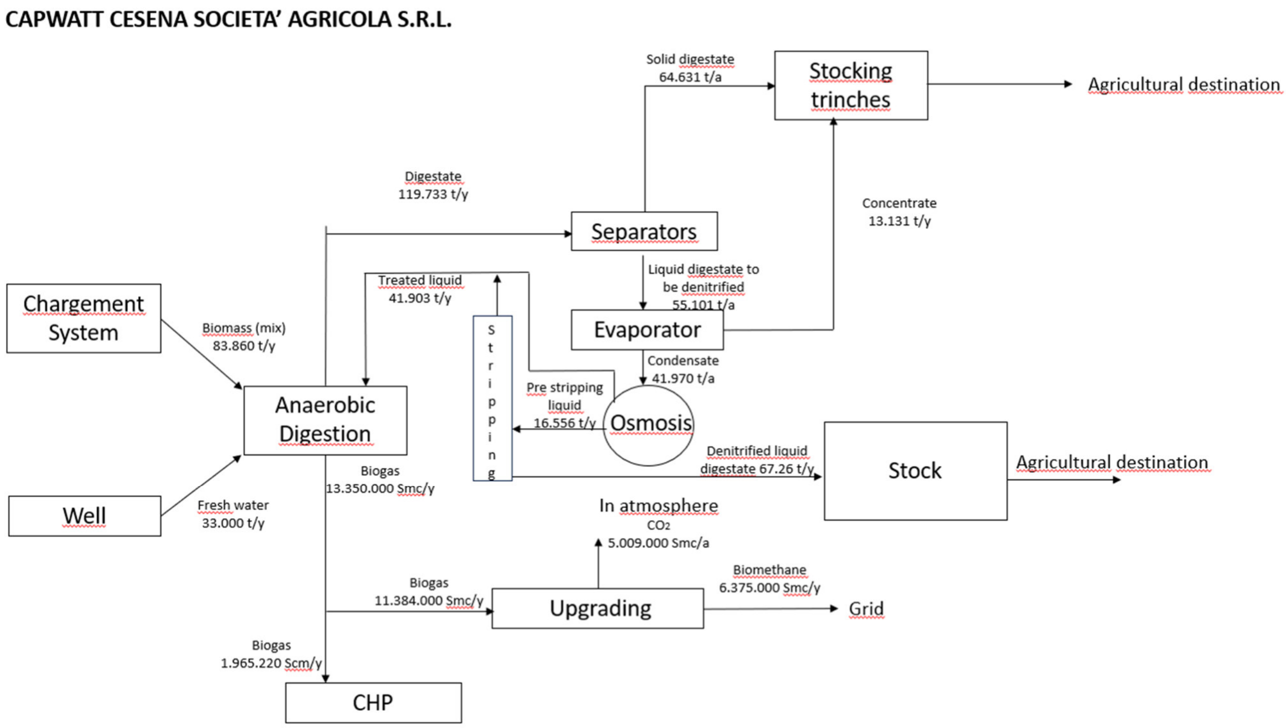

Figure 5 : Mass balance flow diagram

3.6.1 Project quantities

The anaerobic digestion process requires the addition of liquid digestate to ensure that the processed mass is sufficiently fluid to allow it to be moved by hydraulic pumping, as well as to facilitate the mixing of the input matrices. It is expected that approximately 116 tons/day of liquid fraction from the digestate will be added. It should be noted that the liquid digestate sent for recirculation will first undergo denitrification in three steps: evaporation, osmosis, and stripping; therefore, the liquid digestate in recirculation will be denitrified. The liquid digestate, equal to 116 tons/day, will be supplemented with the planned feedstock, approximately 230 tons/day, and 90.4

tons/day of well water: this will result in a total input of approximately 437 tons/day to the digestion system.

The anaerobic digestion plant was designed considering a retention period of approximately 40 days inside the 6 fermenters (3 primary and 3 secondary fermenters), in addition to the further time guaranteed by the biogas-tight storage tanks for the digestate as it is.

The anaerobic digestion envisaged by the project is mesophilic and therefore requires heat input to speed up and optimize the methanogenic processes.

Heat will need to be supplied to maintain the temperature required by the process. The process also requires electricity to operate the pumping, ventilation, and mixing systems and for auxiliary services.

With a view to maximum efficiency, these quantities of energy will be supplied by a biogas cogenerator.

The anaerobic digestion process produces digestate and biogas as outputs; both materials are subsequently subjected to purification processes.

Biogas production:

Considering the characteristics of the input recipe, it is possible to predict an annual biogas production of approximately 13,350,000 Sm^3 /a.

The biogas intended for upgrading first passes through the desulfurization system. Desulfurization allows the precipitation of sulfur through chemical washing, while the purification process with upgrading allows, through processes better described in the following paragraphs, the elimination of CO_2,as well as raising the pressure to the appropriate value for subsequent compression.

The biogas leaving the desulfurization system will be used to feed the cogenerator needed to produce the electrical and thermal energy required to meet the consumption needs of the entire process.

Approximately 11,384,000 Sm^3/a will be allocated to the upgrading system.

Considering the matrices used, the methane content of the biogas is estimated to be approximately 56%; consequently, the annual production of biomethane will be approximately 6,375,000 Sm^3 /a.

The biogas conveyed to the upgrading section first passes through the desulfurization system. Desulfurization allows sulfur to precipitate through chemical washing, while the purification process for upgrading allows CO_2 to be eliminated, as well as bringing the biomethane to network pressure, through processes better described in the following paragraphs.

Estimating an indicative availability of the system of approximately 8,500 hours/year, an instantaneous biomethane production of approximately 750 Sm^3 /h is expected.

The upgrading process will have an estimated specific electricity consumption of 0.30 kWh/Sm^3 of treated biogas.

Digestate management:

The digestate produced, amounting to approximately 119,733 tons/year, is sent to the separation section, which will be carried out by two helical screw separators placed in series. Both steps will allow for the obtaining of a liquid fraction totaling approximately 55,100 tons/year and a solid fraction of approximately 64,631 tons/year.

Once separated from the solid fraction, the liquid digestate will be denitrified using a nitrate stripping denitrification system. To improve the efficiency of the stripping process, the liquid digestate will be pre-treated using evaporation and osmosis. Once separated, the liquid digestate will be sent to a collection tank and then treated by evaporation: the evaporator will be triple-effect and will produce a condensate of approximately 41,970 tons/year and a concentrate of 13,131 tons/year. The concentrated fraction will be used for the storage of solid digestate, while the condensed fraction will be accumulated in an evaporate storage tank, before undergoing further purification in an osmosis system. Two flows will be obtained from osmosis: one, osmotized water, intended for storage and subsequent use in the biological fermentation section; the other, permeate from the osmosis process, will be sent to a buffer tank for collection and subsequent use in stripping. The remaining quantity, the concentrate, can be used for agricultural spreading during the periods permitted by law, or, if analysis shows that it is unusable, it will be classified and disposed of as waste. During periods when spreading is prohibited, the denitrified liquid digestate will be stored in the tank provided for in the project, and then ultimately removed for subsequent management.

Considering the total capacity of the tanks, it is possible to envisage a storage capacity for the separated liquid that exceeds the 180 days of retention required by law during periods when spreading is not possible.

The solid digestate obtained during the double separation, approximately 64,631 tons/year, will be deposited by gravity on a reinforced concrete slab and transferred to storage trenches for subsequent management.

It should be noted that the solid digestate storage section will also house the concentrate from the evaporation process, amounting to approximately 13,131 tons/year.

3.6.2 Estimated electricity and heat generation

Based on the plant configuration described in the previous paragraphs and the dimensions of the main machinery present in it, below is a summary table of **the electrical power** absorbed by the plant per macro-area and the relative daily consumption.

PLANT AREA	POWER CONSUMPTION	ANNUAL ELECTRICITY CONSUMPTION
LOAD SYSTEM	131 kWe	1,140,365 kWh
OXYGENATION DURING ANAEROBIC DIGESTION	17 kWe	143,584 kWh
GENERAL SERVICES	20 kWe	170,000 kWh
DOUBLE SEPARATOR IN SERIES	30 kWe	508,282 kWh
UPGRADING	439 kWe	3,727,112 kWh
STRIPPING	80 kWe	748,000 kWh
EVAPORATOR AND OSMOSIS	133 kWe	1,144,240 kWh
COMPRESSOR	87 kWe	735,959 kWh
TOTAL	**937 kWe**	**8,317,542 kWhe**

As regards electricity requirements, it is planned to cover them by:

- The use of an existing rooftop photovoltaic system with a capacity of approximately 80 kWe;
- Withdrawal from the grid of approximately 3,720,884 kWhe;
- The installation of a biogas cogenerator, already present in the current plant and with the following characteristics:

Nominal electrical power in continuous service	999 kWe
Total thermal power	1,047 kWt
Power introduced with fuel	1,241 kW

With this choice, the cogenerator will also be able to meet part of the plant's thermal energy requirements.

The remaining heat will be supplemented by a 2.5 MWt boiler fueled by natural gas from the grid. The boiler will serve the liquid digestate purification line, consisting of an evaporator, osmosis system, and stripping system; however, in the event of an emergency or unavailability of the cogenerator, or in case of other needs, it can provide back-up operation, also meeting the demand of other thermal users in the plant.

In the event of an emergency, the back-up condition will be met by a 400 kWe generator set that will keep the fermenter blowers, the flare, the upgrading system, and the REMI cabin in operation.

The recovered heat will be reused for company purposes and will be transported from the digester heating collector to the user via a district heating network with polyethylene pipes laid with an insulating perimeter layer to prevent heat dissipation along the way.

3.7 The anaerobic digestion process

Anaerobic digestion (AD) is a biochemical process which, in the absence of oxygen, leads to the degradation of complex organic matter with the production of biogas. The degradation of the organic matter initially present and its subsequent conversion to biogas can vary from 40% to over 90%, depending on the type of substrate, its biodegradability, and the process conditions. The process is carried out by a bacterial consortium and involves a series of biodegradative reactions; no single strain is capable of independently conducting the complete anaerobic degradation of organic matter. Therefore, each population has a well-defined role, producing catabolites of the reaction intermediates that act as a substrate for the next population in the trophic chain. Due to the slowness of anaerobic reactions, the process is carried out under mesophilic conditions (30-43°C). The main energy requirement for digestion is the thermal energy needed to conduct the process at optimal temperatures, which depends on the mass flow rate to be treated and the hydraulic retention time. The biogas obtained in the anaerobic digestion plant operating under the conditions described above has the following composition:

- CH_4: 50%-70%
- CO_2 + CO: 30-50%
- H_2S: 0.1%
- traces of other gases

This composition allows it to be used as a gaseous fuel to power a cogeneration plant to produce electricity and heat.

3.7.1 Stages of the biological process

The process consists of several simultaneous reactions, catalyzed by microorganisms, in which the compounds pass through different states of oxidation until they are converted into methane and carbon dioxide. A diagram of anaerobic digestion is shown in the figure below.

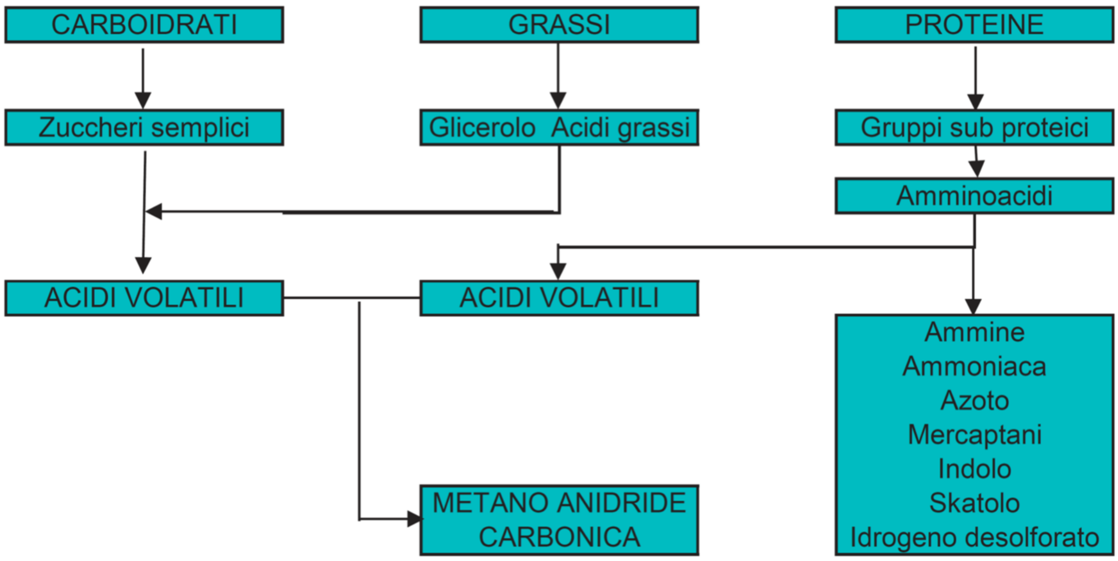

Figure 6 : Schematic representation of anaerobic digestion

The different processes are grouped into three main stages:

- disintegration/hydrolysis;
- acidogenesis;
- acetogenesis;
- methanogenesis.

Anaerobic biodegradation is also regulated by a series of chemical-physical processes, not mediated by the bacterial population, which govern pH, the dissociation equilibria of dissolved species, salt precipitation, and gas-liquid transfer.

3.7.2 Hydrolysis

This is carried out by anaerobic bacteria (which live in an oxygen-free environment) and facultative bacteria (which live in a non-strictly anaerobic environment). This phase leads to the formation of monosaccharides, amino acids, and long-chain fatty acids. The hydrolysis of the various components present in the substrate leads to the progressive formation of soluble substances that can be metabolized by the biomass. The products formed by the hydrolysis of macro-components (lipids, proteins, and carbohydrates) are:

- lipids → glycerol and long-chain fatty acids;
- proteins → amino acids;
- carbohydrates → monosaccharides.

In this phase, close contact between the biomass and the substrate is necessary for hydrolysis to occur effectively; operating conditions characterized by a significant reduction in food size (down to

2-4 mm) and high concentrations of solids tend to favor hydrolysis and subsequent biodegradation. The pH can also have an effect on the maximum rate of hydrolysis, but it can be inferred that a pH close to neutrality can ensure good process conditions for mixed substrates.

3.7.3 Acidogenesis

Acidogenesis, or fermentation of organic monomers, is defined as the anaerobic biological production of organic acids in the absence of electron acceptors or donors. The acid products are volatile fats, acetic acid, H_2, CO_2. The bacteria responsible are facultative anaerobes. Fatty acids essentially refer to propionic, butyric, and valeric acids. The degradation of carbohydrates and proteins produces both fatty acids and acetic acid in varying ratios, while the transformation of long-chain fatty acids leads only to the production of acetic acid. In this phase, the nitrogen salts that form the food basis for methanogenic bacteria are also prepared.

3.7.4 Acetogenesis

Acetogenesis is the process by which volatile acids are converted into acetic acid. Both long-chain fatty acids and volatile fatty acids are degraded by obligate hydrogen-producing acetogenic bacteria, producing acetic acid, carbon dioxide, and hydrogen. The conversion of fatty acids to acetic acid is a fundamental step in the process, and the presence of high concentrations of fatty acids is a symptom of an imbalance in the process. To ensure the balance between the various degradation reactions, it is essential to maintain complete mixing within the digester.

3.7.5 Methanogenesis

There are two phases of this fundamental step in biogas production:

- hydrogenotrophic methanogenesis, in which the following reaction takes place:

$$4H_2 + CO_2 \rightarrow CH_4 + CO_2$$

- acetoclastic methanogenesis, which is based on acetoclastic bacteria that develop by consuming acetic acid and producing CH_4 and CO_2. The reference reaction is as follows:

$$CH_3COOH \rightarrow CH_4 + CO_2$$

The two bacterial strains responsible for converting acetic acid into methane, which produces most of the methane produced in an anaerobic digestion process (about 70%), are the Metanosarcina genus and the Metanoseta genus.

Figure 7 : Methanobacterium

3.7.6 Functional parameters

In order to ensure good anaerobic digestion, the bacterial population must be provided with an optimal environment.
The above biological activities are influenced by various factors, such as pH, alkalinity, the presence of ammonia, temperature, the composition of the organic substance, the presence of antibiotic and toxic residues, retention times, specific load, etc.
The two main factors that influence the entire process are undoubtedly the temperature and the residence time of the biomass in the digesters. In particular, the anaerobic digestion process is favored by maintaining optimal temperature conditions (45-70°C for thermophilic bacteria, 25-45°C for mesophilic bacteria, and 10-25°C for psychrophilic bacteria). As these decrease, it is necessary to ensure a higher hydraulic retention time (HRT) of the biomass in the digester. By complying with these conditions, the energy yields of the plant achieve excellent results in any season.

3.7.7 pH and alkalinity

Dependence on pH has been detected for all bacterial strains involved, although the most marked and important effect is on methanogenic bacteria.
Acidogenesis and acetogenesis are favored by acidic pH values, in the range of 5-5.5. To allow adequate activity of methanogenic bacteria, a value between 6.5 and 7.5 is recommended.
At lower values, methanogenic activity is gradually reduced and, below pH 6, severely compromised, with recovery times of several weeks.

It is therefore very important to monitor and prevent instability and pH reduction, both by avoiding overloads, i.e., feeding the biomass consistently and as evenly as possible over a 24-hour period, and by monitoring the ratio between alkalinity and volatile acids present. This volatile acid/alkalinity ratio should be around the following values:

$$0.2 – 0.5$$

Alkalinity is expressed as calcium carbonate $CaCO_3$, values of 3,000 - 5,000 are considered standard for anaerobic digesters under stable conditions.

3.7.8 Ammonia and the presence of toxins

In the material undergoing digestion, ammonia is in equilibrium with the ammonium ion:

$$[NH_3] \leftrightarrow [NH_4^+]$$

The toxicity limits for total ammonia are:

1,500 - 4,000 mg/liter

Ammonia concentrations within the indicated range inhibit the process at pH values below 7.4, while concentrations above 4,000 mg/l are considered toxic at any pH value.

It should be noted, however, that a gradual increase in ammonia concentration can create a certain habituation in microorganisms and therefore allow the process to take place, albeit with a decrease in biogas production due to inhibition; a sudden increase is more likely to be toxic.

There may also be other substances, natural or xenobiotic, that exert a toxic effect on anaerobic and methanogenic bacteria in particular.

Some substances, particularly metals, can promote metabolism at low concentrations and are even necessary as micronutrients, while at higher concentrations they become inhibitory. Substances reported as toxic to methanogenic bacteria include solvents, halogenated substances, ketones, esters, and pesticides.

In the case of livestock manure digestion, an inhibitory effect can be caused not only by metals but also by antibiotics used to accelerate the growth of livestock, prevent infections, and for targeted therapeutic purposes.

Another important aspect is related to the water flow rate and the methods used to clean the areas where the animals are kept. The most obvious effects are seen in pig farms where heavy antibiotic treatments are carried out.

During periods when such treatments are carried out, the slurry is not sent to the digester but directly to storage for a period sufficient to restore the optimal characteristics of the slurry itself, depending also on the antibiotic used.

		INHIBITION	
(mg/l)	OPTIMUM	MODERATE	STRONG
SODIUM	100 – 200	3,500 – 5,500	8,000
POTASSIUM	200 - 400	2,500 – 4,500	12,000
CALCIUM	100 – 200	2,500 – 4,500	8,000
MAGNESIUM	75	1,000 – 1,500	3,000
AMMONIUM	50 – 1,000	1,500	8,000
SULFIDE	0.1 – 10	100	200
CHROMIUM (%SS)	-	20	3
COBALT	20	-	-
COPPER	20	-	-

2 Table: Optimal concentrations of ions in anaerobic fermentation sewage and inhibition concentration

As regards heavy metals (Cu, Zn, Cr, etc.), antagonism is caused by hydrogen sulfide or sulfides, which cause a precipitation reaction, leading to the formation of insoluble salts of the metals themselves (CuS, ZnS, etc.).

Sulfides also have a concentration limit, indicated as 200 mg/l, above which they are toxic.

TOXIC IONS	ANTAGONISTS
Na^+	K^+
$NH4^+$	Na^+
K^+	All ions
Ca^{++}	Na^+, K^+
Mg^{++}	Na^+, K^+

3 Table: Toxic ions and their antagonists

3.7.8 Temperatures and retention time

Temperature has a decisive effect on the speed and completeness of anaerobic degradation reactions and selects bacterial populations that can operate within the corresponding temperature range and unable to operate effectively outside it. There are three different operating ranges:

- psychrophilic range: 4 to 15°C;
- mesophilic range: 20 to 42°C;
- thermophilic range: 45 to 70°C.

Within each range, there is an increase in process kinetics with a subsequent slowdown near the optimum value, followed by a rapid decrease.

The plant in question operates in the mesophilic range and temperature fluctuations should be limited to a range of less than ± 3°C if possible.

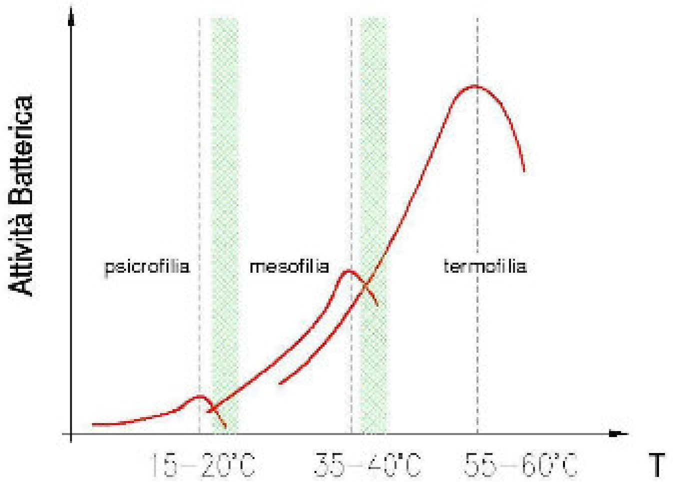

Figure 8 : Effect of temperature on anaerobic degradation kinetics

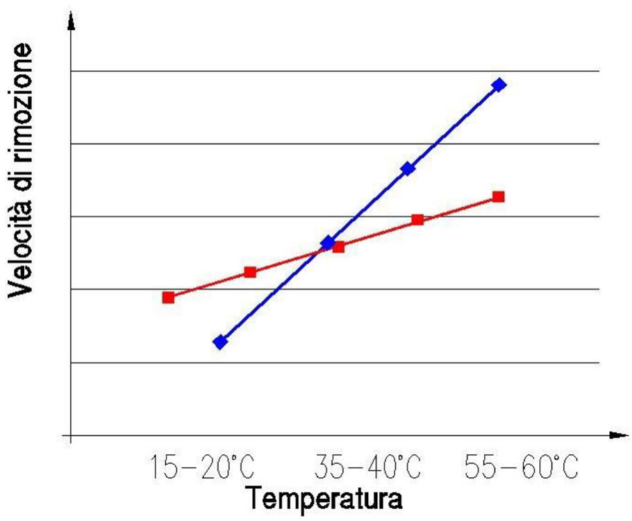

Figure 9 : Qualitative trend of the temperature dependence of the metabolism of methanogens and acetogens

Another fundamental parameter is the average residence time of fermentable material in the digester for the degradation and conversion of organic matter into gas, which is defined as retention time (RT):

$$RT = \frac{V_u}{Q}$$

RT = retention time (days)

Vu = useful volume of the digester (m^3)

Q = volume of biomass and livestock manure loaded daily (m^3/day)

The optimal conditions for each thermal regime are shown in the graph below:

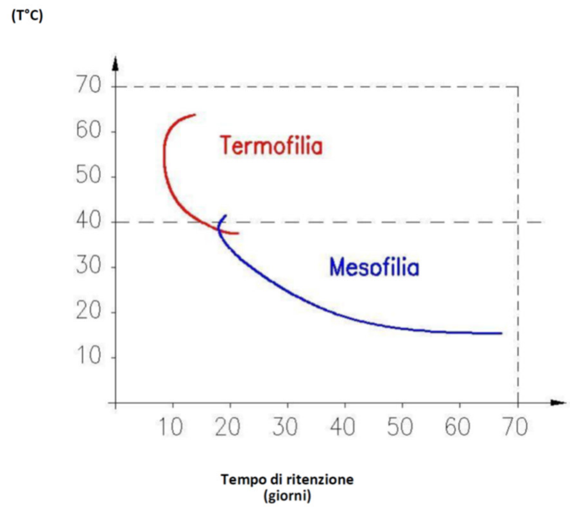

Figure 10 : Correlation between digestion temperature and slurry retention time. There are well-defined optimal temperatures for both mesophilic and thermophilic regimes

The thermophilic process is not widely used for the digestion of livestock biomass because it is biologically less stable than the mesophilic process.

It should be noted that a longer retention time leads to greater degradation of organic matter and, therefore, to greater biogas production, expressed in the graph below as Nl per kg of degraded dry organic matter. The increase in organic matter degradation with increasing retention time also leads to a higher reduction in the pollutant load.

Under normal conditions, it is not easy to reduce more than 80% of BOD5 and more than 50% of COD.

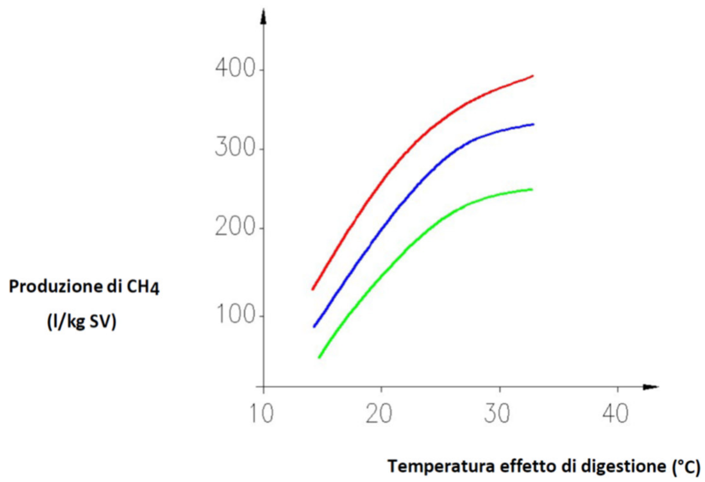

Figure11 : Effect of temperature and digestion time on specific biogas production

3.7.9 Specific digester load

The digester must be fed daily with a predetermined volume of biomass defined as the specific load of the digester relative to the unit volume of the digester.

Exceeding the specific load would lead to the acid phase prevailing over the methanogenic phase, inhibiting the process.

The trend in biogas production per kg of degraded organic matter tends to decrease as the specific load increases.

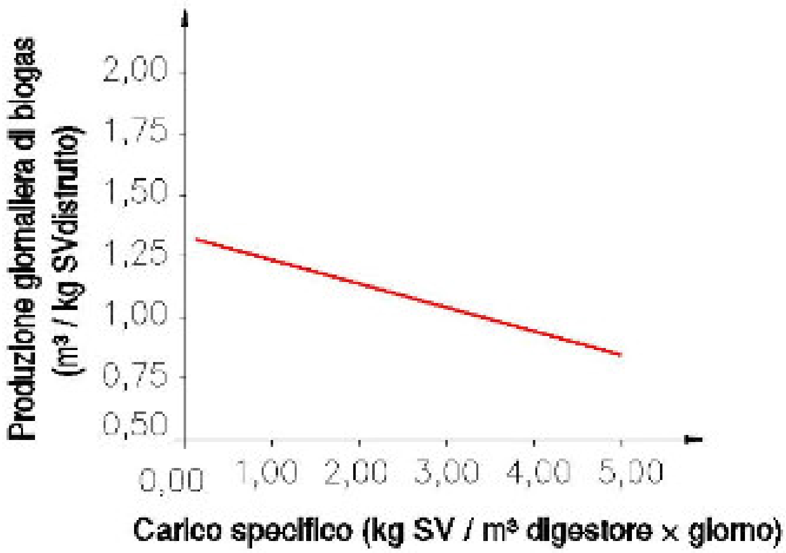

Figure 12 : Correlation between specific load and biogas production per unit of organic matter destroyed

The influence of specific load on overall biogas production per unit of digestion volume is shown in the graph below.

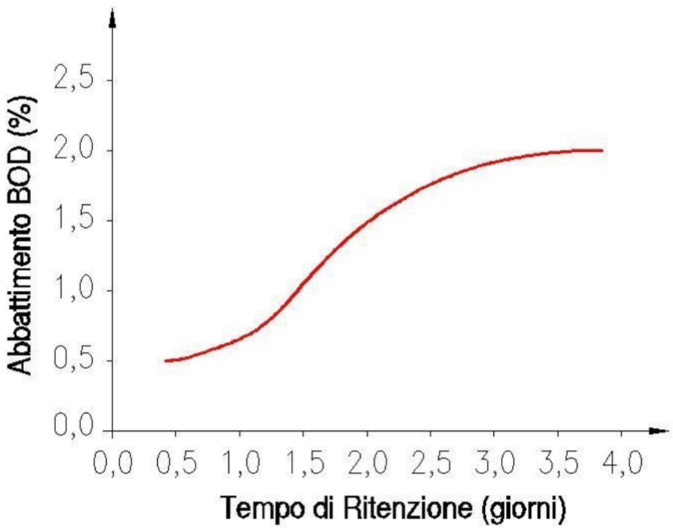

Figure 13 : Correlation between specific load and daily biogas production per unit of digestive volume

Based on the above, a value of 4-5 kg SV/m^3 of digester should be respected in the mesophilic range.

LOWER LIMIT	UPPER LIMIT
1.0 – 1.5	4.0 – 6.0

Table 4: Specific organic load of digestion

3.7.10 Metabolic substrates

The products used in anaerobic digestion must be suitable for ensuring the availability of the metabolic substances necessary for bacteria.
The biomass must have a total solid content (dry matter) of between:

$$3\% < SS < 18\%$$

If the percentage of dry matter is too low, there is a risk of not having a sufficient supply of nutrients for the metabolic activities of the bacteria; if it is too high, there is a danger of reaching toxicity thresholds.
An excessive solids content creates problems in handling the biomass itself during loading into the digester; to avoid this, appropriate mixing systems are used, and dilution wastewater is added in sufficient quantities to comply with this dry matter percentage limit.
The carbon/nitrogen (C/N) ratio can also be important; if there is an excess of carbon in the slurry, some of it remains unused; with a low C/N ratio, on the other hand, the carbon is completely metabolized and the excess nitrogen is reduced to ammonia, with the risk of reaching a level that is toxic to bacteria.
The optimal ratio is:

$$\frac{C}{N} = 20 - 35$$

All these info & data about the anaerobic digestion process are given by the company's biologist.

3.8 CO2 emissions balance

To assess the CO_2 balance of the initiative in question, it is necessary to consider the biomethane production process, from biomass generation to end uses, especially when compared to the production of methane from fossil sources.

It is well known from literature and confirmed by the regulatory guidelines represented in the European Directives that biomethane contributes to the achievement of decarbonization objectives as it does not add greenhouse gases to the atmosphere.

In the case of biomass, the balance is defined as neutral because it is considered that the CO_2emitted during combustion and/or transformation is the same as that accumulated/absorbed by the biomass during its life cycle.

Furthermore, if the substrate (the fermentable material loaded) were not used in the digester but were used in another way or abandoned in the environment, it would still degrade, producing climate-changing gases, without this emission being associated with a useful effect such as the production and use of methane for transport. Therefore, the use of these materials would help reduce or avoid greenhouse gas emissions associated with their management.

The process also produces digestate, which can be used as a soil conditioner, avoiding the use of chemical fertilizers and the associated greenhouse gas emissions.

On the other hand, there are emissions associated with biomethane production, in the purification process, as well as with the transport of biomethane, which must be considered. Nevertheless, the overall impact of biogas and biomethane production results in a significant reduction in greenhouse gases compared to fossil fuels.

This circumstance is reflected in the principle of "Sustainability" introduced by European directives, transposed at national level, which is a necessary requirement for biomethane production plants.

The calculation of sustainability, or savings compared to fossil emissions, based on the feedstock recipe is in fact the only objective tool for calculating CO_2 emissions savings for the environment and therefore it is considered appropriate to refer to it.

The issue of sustainability was initially introduced by European Directive 28/2009 – known as RED I – and transposed in Italy by Legislative Decree 28/2011. Initially, the directive concerned only compliance with sustainability requirements for the transport sector. With the transposition of European Directive 2018/2001 – hereinafter RED II – the extension of compliance with sustainability requirements ( ) to produce biomethane was introduced, regardless of whether it is intended for transport (biofuels) or other uses, as in the case in question.

Sustainability means that bioenergy (see Biomethane) must be produced with a reduction (GHG saving') in CO_2 eq. emissions of less than a significant and pre-established percentage (depending on its destination: transport sector or other uses) compared to that associated with the so-called 'reference fossil fuel' or 'fossil fuel comparator (FFC).

In particular, the issue of sustainability is addressed in the new Ministerial Decree on Biomethane of September 15, 2022, which specifies the GHG savings percentages required to obtain sustainable biomethane certification, with the consequent possibility of accessing the incentives provided. The savings are calculated essentially based on four parameters:

- The recipe for the plant;
- The reference FFC emissions;
- Digestate type (open or closed);
- The upgrading system installed (advanced/with or without off-gas combustion).

In particular, the reference FFC emissions for calculating the savings achieved in biomethane production are as follows:

- 94 gCO2eq/MJ for biomethane used in transport;

- 80 gCO2eq/MJ for biomethane intended for other uses.

According to the Biomethane 2022 Ministerial Decree, for transport use, the biomethane produced must guarantee GHG savings (CO2 savings) of 65%, calculated based on the provisions of UNI/TS11567/2020, compared to the reference FFC emissions. For other uses (residential, industrial), the biomethane produced must guarantee GHG savings of 80% compared to the reference FFC emissions. GHG savings are calculated by considering the STANDARD emissions set out in the UNI/TS 11567/2020 standard relating to emissions released during the cultivation, processing, transport, transformation, compression, and possible liquefaction of the raw materials used to fuel the plant. The calculation of savings is weighted and considers the volume of biomethane produced from each individual raw material.

In this case, to verify the sustainability of the recipe, the tool provided by the GSE was used, which reports the estimated emissions (in terms of g CO_2 -equiv per MJ of biomethane) and the outcome of the assessment.

The estimated emissions must be compared with the Fossil Fuel Comparator (FFC = 80 g CO_2 -equiv per MJ of biomethane, in the case of use for other purposes).

In the case in question, the estimated emissions are -15.04 g CO_2 -equiv per MJ of biomethane, representing a reduction of 90.9% compared to the comparator, which is greater than 80%.

The plant's fuel recipe is therefore sustainable to produce biomethane for other uses.

During the certification of the recipe's sustainability, carried out by a specific Certification Body, the actual emission benefit will be calculated.

The results, as per the GSE tool, are as follows:

DATI GENERALI IMPIANTO	
Regione Impianto	Emilia Romagna
Zona geografica	Nord
Gestione del digestato	Chiuso (almeno 30 gg)
Rendimento upgrading e combustione offgas	Upgrading a basse perdite (<1% perdite metano) senza combustione offgas
Destinazione biometano	Altri usi
Valore del comustibile fossile di riferimento [gCO_{2eq} / $MJ_{Biometano}$]	80
Liquefazione	NO
Percentuale di biometano liquefatto [%]	0,00%

Id	Materie prime autorizzate (per ciascuna materia prima autorizzata occorre compilare una riga della presente tabella)	Dettaglio materie prime (riportate l'esatta denominazione della materia prima autorizzata solo se nella colonna "Materie prime autorizzate" si è indicato "Residui / sottoprodotti a basso/medio/alto contenuto di umidità")	Quantitativo annuale materia prima, In [t/a]	Resa in biogas, riferita all'umidità standard, Pn [MJ_{biogas} / kg]	Umidità Standard [$kg_{acqua}/kg_{materia}$]	Il valore di umidità media annua della specifica materia prima è presente nel titolo abilitativo?	Umidità Media Annua [% $kg_{acqua}/kg_{materia}$] (se la cella si evidenzia in rosso controllare la congruenza del valore di umidità inserito rispetto alla materia prima indicata)	Fattore di ponderazione, Wn	Emissione standard, Es [gCO_{2eq} / $MJ_{Biometano}$]	Quota matrice su base energetica, Sn [%]	Es x Sn [gCO_{2eq} / $MJ_{Biometano}$]
1	Mais	Insilato di mais	5000,00	4,233	65%	SI		0,17	39,33	8%	3,30
2	Triticale insilato	Trinciato di Triticale	6000,00	3,837	65%	SI		0,20	36,89	9%	3,37
3	Effluente zootecnico umido	Pollina Broiler	30000,00	0,730	85%	SI		2,38	-102,44	20%	-20,78
4	Effluente zootecnico umido	Pollina Tacchino	1500,00	0,730	85%	SI		0,12	-102,44	1%	-1,04
5	Residui / Sottoprodotti a medio contenuto di umidità (30% < U <= 80%)	Ortaggi Misti generici	25000,00	2,857	80%	SI		1,49	22,22	50%	11,03
6	Residui / Sottoprodotti a basso contenuto di umidità (U <= 30%)	Sottoprodotto Farina Secca	360,00	9,998	30%	SI		0,01	22,00	1%	0,16
7	Effluente zootecnico umido	Liquame Bovino	10000,00	0,730	85%	SI		0,79	-102,44	7%	-6,93
8	Effluente zootecnico umido	Letame Bovino	6000,00	0,730	85%	SI		0,48	-102,44	4%	-4,16
		TOTALE:	83860							DA COMPILARE	-15,04

ESITO DELLA SIMULAZIONE:	RIDUZIONE GHG CONFORME

Risultati della verifica di riduzione delle emissioni di GHG

CONFORME: sulla base dei dati inseriti è rispettato il requisito di sostenibilità calcolato a partire dai dati standard riportati nella UNI 11567. In tal caso, il Soggetto Richiedente può procedere con il caricamento del presente file (formato ".xls" o ".xlsx") sul Portale e con il completamento della Richiesta di partecipazione alla procedura. Si ricorda che il presente modello di verifica non può essere utilizzato nel caso in cui si intenda beneficiare del criterio di priorità relativo alla riduzione delle emissioni di GHG.

NON CONFORME: sulla base dei dati inseriti non è rispettato il requisito di sostenibilità calcolato a partire dai dati standard riportati nella UNI 11567. In tal caso, se il Soggetto Richiedente intende comunque partecipare alla procedura competitiva, il rispetto del requisito deve essere attestato mediante una certificazione rilasciata da un organismo di certificazione accreditato o dal progettista dell'impianto e/o agronomo iscritti ad albo professionale (come indicato al paragrafo 2.3.5.3 delle Regole Applicative al DM 2022). Tale attestazione deve essere caricata sul Portale ed è quindi possibile procedere all'invio della richiesta di partecipazione.

DATI INCOMPLETI: non è possibile procedere alla verifica del rispetto del requisito, controllare il corretto inserimento di tutti i dati richiesti nei fogli precedenti.

3.9 Tanks dedicated to anaerobic digestion

This plant will have:

- 3 digesters: two circular digesters with a diameter of 28.0 m and a height of 8.0 m, and one rectangular digester with semi-dry operation. Both circular digesters will be newly built;
- 3 post-digesters: two of these already exist and have a diameter of 19.50 m and a height of 8.0 m; the third post-digester will be newly built and will have the same characteristics as the digesters: a diameter of 30.0 m and a height of 8.0 m;
- There are plans to build one covered storage tank for the digestate as it is, with a diameter of 32.0 m and a height of 8.5 m; One storage tank already exists: it has a diameter of 32.0 m and a height of 8.5 m, and its structural and functional restoration will be part of the revamping project covered by this report.

Structurally, all tanks will consist of thermally insulated walls, gas-tight covers, and internal/external heating. The tanks will be heated using the heat produced by the cogenerator.

The pipes used in the section from the cogenerator to the fermenters will be made of polyethylene with an insulating perimeter layer to prevent heat dissipation in the underground section. From the main manifold located in the masonry pump room, a circulating pump will pump the hot water mixed with antifreeze glycol to the secondary manifold, where it will be divided into heating circuits before entering the digester.

The interior of the digesters will be heated and maintained at a temperature of 42°C (mesophilic range) by a heat exchanger located along the walls. The hot water produced by the cogenerator and boiler is used, fed into the system at a temperature of approximately 80°C and returning to the engine circuit at a temperature approximately 10/15°C lower. The thermal energy required to heat the mixture entering the digester and to maintain the internal temperature of the tank is taken from the thermal production obtained from the cooling circuit of the cogeneration engine unit.

Figure 14 : Example of internal mixer details in the digester

Figure 15 : Example of specific mixers inside the digester

The water temperature in the digestion plant will be guaranteed by existing control systems, which will be integrated as necessary based on the specific requirements for monitoring and controlling the correct operation of the plant. The control system must communicate the temperature of the biomass to ensure that it does not exceed the set operating range (normally between 30°C and 47°C).

Figure 16 : Example of a coil placed on the walls for thermostating the digester

The level of material inside the digester will be guaranteed by existing control systems, which may be integrated according to the specific requirements for monitoring and controlling the correct functioning of the plant. The pressure in the biomass circuit pipes is controlled by pressure sensors installed on the delivery and suction lines of the pump that draws and relays the digestate, to prevent overpressure due to line blockages.

To ensure that the digestion process proceeds with the best efficiency, it is essential to ensure constant and homogeneous mixing of the material inside the digesters. In fact, the solid and fibrous parts form a supernatant inside the fermenters that hinders the formation of biogas and significantly reduces the decomposition of organic matter. 's digesters are equipped with paddle mixers to prevent the formation of "dead zones" where the material settles and is not heated and brought into contact with the bacterial flora that develops in the upper layers.

The circular tanks will be covered and equipped with a double-membrane gasometer dome. The first inner dome is an elastomeric gasometer cover made of class II fireproof PVC material. The second dome is more external and conical in shape, featuring a pneumatic support that is resistant to UV rays and weathering, and acts as a cover for the entire tank. A gas leak detector is located between the two domes.

This membrane is capable of storing biogas and, thanks to the type of material used, can handle variable volumes of biogas, thus compensating for any inconsistencies in production. The cover is fixed to the concrete digester by means of an anchoring system that absorbs the forces resulting from overpressure and wind loads and ensures a gas-tight seal between the profile and the concrete and between the profile and the cover sheet. The digesters are equipped with a biogas overpressure and underpressure safety valve with a hydraulic guard operating system. The hydraulic guard is a safety device with the following characteristics:

- Flow rate: approximately 250 Nm^3/h;
- Maximum overpressure: adjustable between 3.5 and 5 mbar;
- Minimum vacuum: 1.5 mbar;
- Material: 316 and 304 stainless steel for components not in direct contact with biogas.

Figure 17 : Example of a double-membrane gasometer dome

3.10 Biogas treatment system

Before being used, biogas undergoes a series of treatments to remove hydrogen sulfide, water vapor, and all impurities that could cause problems during its subsequent uses.

To eliminate part of the hydrogen sulfide, an abatement tower is used where redox reactions take place. The biogas flow is sent to a tower where it is washed in countercurrent by a chemical solution containing soda, which is distributed evenly through a system of spray nozzles. The liquid obtained is rich in sulfur-containing compounds and is sent to a specific machine that allows the regeneration of the solution used in the desulfurization tower.

Figure 18 : Graphical representation of the desulfurization system

The biogas will undergo dehumidification by condensation. The biogas produced by the digestion process will be passed through underground pipes and the water obtained will be collected in special wells from which it will then be conveyed to storage via a special pump. For this purpose, a condensate well will be built from which the condensed water can be extracted (through rapid cooling of the biogas). This also prevents condensate from forming in the gas pipes.

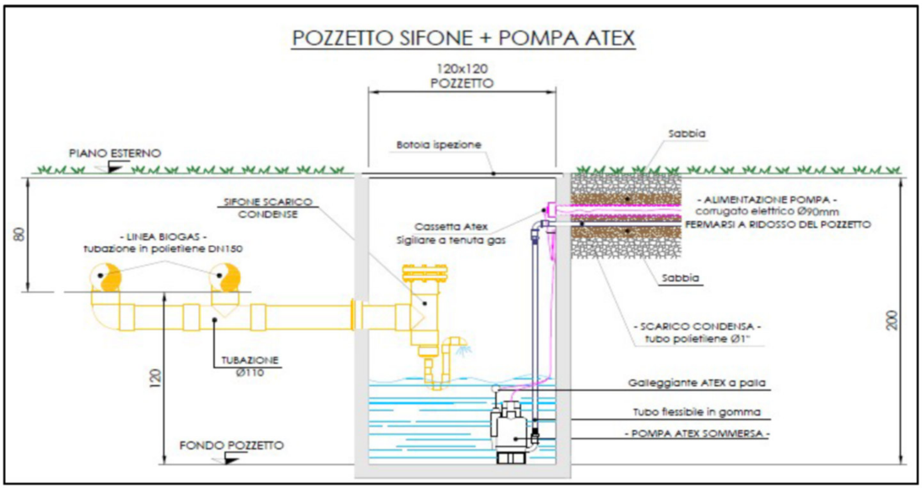

Figure 19 : Diagram of a condensate drain well – type

After the treatments described above, the biogas is conveyed to an activated carbon filter via a polyethylene pipe for the underground section and stainless steel for the above-ground section, which represents the final stage of the biogas treatment process. It consists of a stainless-steel tank with loading and unloading hatches, inlet/outlet valves, bypasses, and connecting pipes. The flow to be treated enters from below and passes through a layer of activated carbon that absorbs contaminants. The filter removes the percentage of sulfur compounds still present in the gas flow, which causes corrosion, and organic silicon compounds, in particular siloxanes. Siloxanes are converted into silicon dioxide on the surfaces of gas engines and turbines, damaging the equipment. The temperature and humidity of the gas affect the separation efficiency of the activated carbon. Appropriate drying by means of a chiller ensures its long-term operation, preventing rapid saturation that would occur in the presence of water.

Figure 20 : Activated carbon filter

3.11 Cogeneration system

The plant will be equipped with a CHP module with a synchronous generator to produce 400V, 50Hz electricity and heat. The emissions values of the cogenerator must fully comply with the TA-Luft regulations for internal combustion engines.

The technical data for the typical cogenerator is shown below.

General data	
Machine type	COGENERATOR
Service	Production of energy at 400V, 50Hz and heat
Applied standards and directives	- Design, drawings, and documentation Metric system, ISO, IEC - Electromagnetic compatibility 2014/30/EC - Low voltage 2014/35/EC - Machinery Directive 2006/42/EC - Health and safety protection in the workplace Legislative Decree No. 81 of 09/04/2008

Process data	
Machine positioning	Outside the building

Minimum ambient temperature	~ - 15	°C
Maximum ambient temperature	~ + 35	°
Design ambient temperature	~ + 25	°C
Barometric pressure	1	bar
Ambient air humidity	0 to 100%	
Fuel	Biogas	
No. of days of activity per year	365	

Technical reference data			
Operating cycle		4 strokes	
Unit displacement (12 cylinders)		48.67	lt
Fuel type		Biogas	
Barometric pressure		1 bar or 100 m above sea level	
Relative humidity		30	
Min/max operating temperature		-15 / +35	°C
Total thermal power		1,047	kW_t
Nominal electrical power		999	kWe
Power introduced with fuel		1,247	kW
Approximate dimensions of cogenerator (LxWxH)		12.20 x 2.50 x 2.3	m
Exhaust gas emissions	NOx (referring to 5% O_2)	< 450	mg/Nm^3
	CO (referenced to 5% O_2)	< 500	mg/Nm^3
	Chimney height	10	m

Reference electrical data		
Supply voltage	40	Volt
Frequency	50	Hz

Table5 : Example of cogenerator operating data

The plant's gas engine must be developed and designed for continuous operation in accordance with ISO 8528. The characteristics of the machine will be optimized through a two-stage intercooling system, improvement of the exhaust channel, geometry of the turbocharger unit, and power regulation system. Optimization of the combustion process significantly lowers exhaust gas temperatures, with a positive effect on the service life of all mechanical components. Using an oxidizing catalyst is required.

The CHP module will consist of:

- Gas supply ramp (biogas produced by the plant);
- Gas mixer;

- Generator;
- Voltage regulator;
- Power factor regulator;
- Electrical management and control cabinet.

A stainless-steel exhaust gas silencer suitable for processing the entire exhaust fume flow rate will be installed. The exhaust silencer must reduce noise emissions at the chimney to approximately 65 dB(A) at 7 m.

The hydraulic system for heat recovery will include the installation of circulation pumps and the various pipes required for the system, as well as all hydraulic components, including control units. The heat recovery module must be located inside the CHP module and will be thermally insulated. The system will also include all auxiliaries such as three-way mixing valves, control valves, expansion tanks, and heat exchangers according to the required architecture.

The flue gas heat exchanger removes the thermal energy contained in the still-hot exhaust gases and transfers it to the coolant (water/glycol mixture). The exhaust fumes will be cooled to a temperature greater than 120°C through this exchanger. The exchanger will be of the smoke tube type. It is necessary to comply with the maximum pollutant concentration values indicated for the catalyst, as exceeding these values would quickly destroy not only the catalyst, but also the flue gas heat exchanger and all the piping connected to it.

The cogeneration system will be installed inside a soundproof container with the following characteristics:

- walls and ceiling covered with an adequate layer of mineral wool acoustic insulation;
- container floor in welded steel sheet;
- the container has an integrated sealed collection tank;
- user circuit delivery and return flanges;
- electrical installations (lighting, service electrical outlets);
- the container will achieve an average noise emission value in open field conditions of 70 dB(A) at 1 m.

3.12 Emergency torch

The emergency flare is used to burn biogas when the purification (upgrading), cogeneration, or boiler systems, which are the end users of the biogas mixture, are not functioning. Therefore, in the plant layout, the flare is a plant component with an emergency function.

In the context of biogas and biomethane production plants, the regional legislation of Emilia-Romagna specifies the need to install this type of device through D.R.G. 1495 of 10/24/2011, which states the following regarding the flare:

2 REQUISITI PROGETTUALI E GESTIONALI DEGLI IMPIANTI BIOGAS

2.1 Premessa ed ambito d'applicazione

In genere, gli impatti richiamati al paragrafo precedente si manifestano in corrispondenza di una deficitaria progettazione, realizzazione o gestione degli impianti, pertanto possono essere efficacemente prevenuti o ridotti mediante l'adozione di particolari accorgimenti costruttivi, di opportuni dispositivi di abbattimento degli inquinanti ed, infine, tramite una corretta pratica gestionale di tutte le attività connesse all'impianto.
Le presenti disposizioni definiscono i requisiti che devono essere rispettati dagli impianti per la produzione di biogas al fine di contenere e ridurre il loro impatto.
Esse si applicano agli impianti di digestione anaerobica finalizzati alla trasformazione della sostanza organica contenuta in: materie prime, materiali naturali vegetali di origine agricola e forestale, sottoprodotti agricoli ed agroindustriali (di seguito *biomasse*) ed effluenti di allevamento.
Alcuni dei requisiti riportati nel presente atto sono in linea con quanto previsto dalla Norma tecnica UNI 10458 "Impianti per la produzione e l'impiego di gas biologico (biogas). Classificazione, requisiti essenziali, regole per l'offerta, l'ordinazione, la costruzione, e il collaudo".
Si evidenzia che, in tale contesto, vengono fatte salve le specifiche norme di settore come, ad esempio, quelle legate alla prevenzione incendi.

2.2 Requisiti costruttivi e di utilizzo

Nella progettazione di un impianto a biogas è necessario considerare aspetti di carattere costruttivo quali ad esempio l'obbligo di dotare l'impianto stesso di dispositivi di sicurezza per la combustione del biogas quando quest'ultimo non è avviato ai consumi finali. Tale sistema deve essere costituito da una torcia o da qualsiasi dispositivo alternativo (ad es. una caldaia o un motore aggiuntivi) tale da garantire lo stesso livello di sicurezza. In particolare, esso deve essere dimensionato per consentire l'eventuale svuotamento rapido di tutti gli stoccaggi (5 - 6 ore).
In fase di avviamento dell'impianto, quando il biogas prodotto non ha sufficiente contenuto di metano per essere inviato al cogeneratore, è necessario prevedere un sistema che eviti la sua immissione in atmosfera, come, ad esempio, l'utilizzo di combustibili supplementari (es. gpl, gas di rete) per sostenere la torcia, nel caso sia prevista, o l'invio ad idoneo impianto di trattamento prima dello scarico in atmosfera (es. cartucce con filtri a carbone attivo).
Altro requisito da rispettare se l'impianto di biogas è situato in o accanto ad un allevamento e l'impianto non utilizza solo gli effluenti zootecnici da esso prodotti, è che vi sia una totale separazione fisica tra l'impianto, da un lato, e il bestiame e il mangime dall'altro.

2.3 Provenienza e trasporto dei materiali in ingresso alla Digestione Anaerobica

Al fine di minimizzare gli impatti derivanti dalla fase di approvvigionamento delle biomasse in ingresso all'impianto, in fase autorizzativa si fa riferimento a quanto indicato al punto 3 lettera G) a) della Delibera di Assemblea Legislativa n 51 del 26 Luglio 2011

Figure 21 : D.R.G 1495 of 24/10/2011 – Extract

In terms of emptying, the torch will be capable of emptying the biogas storage units (gasometer domes/gasometer accumulators) in less than 6 hours.

About the operating time of the torch, both regional legislation and Legislative Decree 183/2017 do not require emissions to be measured using "machines" or "quasi-machines" for which an operating time of ≤ 500 hours/year is specified.

It should be noted that to comply with this limit, the flare is equipped with a timer that counts the hours of operation. This timer is connected, via its PLC, to the plant control and supervision device. Operating logic requires the torch PLC to inhibit the burner's operation: once the limit of 500 hours/year of operation has been exceeded, the control system receives a signal from the torch PLC, inhibiting the supply of biogas.

It should be noted that the biogas fed to and burned by the burner, even before reaching the flare, will be purified through chemical washing in the desulfurization tower.

However, a bypass of the desulfurizer on the biogas line is provided for the sole purpose of facilitating the start-up phases of the plant.

Combustion takes place in the flare, therefore its Nominal Thermal Power, depending on the biogas that can be burned, will be equal to:

- Maximum Nominal Thermal Power of approx. 9,690 kW (1,900 Nm^3/h x 5.1 kW/m^3 equal to the PCI of biogas with a methane concentration of 55% by weight), therefore > 1 MW.

Therefore, it is to be considered an emission point for all purposes. However, the device will only come into operation in an emergency.

The flare will be equipped with redundant devices designed to prevent failure to ignite in the event of emergency use.

The flare is designed to ensure maximum safety during normal operating conditions and during normal maintenance. Under all operating conditions, the flame produced by the combustion of biogas is contained within the combustion chamber; therefore, radiation to the ground is negligible.

As previously mentioned, national legislation represented by both Legislative Decree 152/06 and Legislative Decree 183/17 does not specify any emission limits to be complied with for this type of device. This position is formalized by some regional regulations, such as that of Emilia-Romagna through Regional Decree 1496 of October 24, 2011. The document imposes emission limits on all equipment designed for energy production with nominal thermal power of between 3 and 10 MW powered by BIOGAS. In point 16, the document clarifies *that "excess biogas or biogas emitted during periods when the engines are stopped must be sent to a flare, with a pilot, capable of ensuring a minimum combustion efficiency of 99% expressed as CO2/(CO2+CO). The limits set out in the table in point 7 - Limits for new plants do not apply to these emissions."*

Figure 22 : Safety flare

The specifications of the flare are as follows:

- Estimated biogas flow rate: 1,500 Nm^3/h
- Nominal biogas flow rate of torch: 1,900 Nm^3 /h
- Methane content in biogas: 40-80%
- Biogas pressure: 10/35 mbar
- Combustion temperature: ≥ 1,000°C
- Flue gas outlet height: 8 m
- Gas residence time in chamber: >0.3 s

It should be noted that the biogas flow rate, depending on the total gas storage due to the domes on the digestion tanks, post-digestion tanks, and biogas-tight digestate storage tanks, will be 27,775 m^3 , or 1,900 Nm^3 /h; **therefore, in order to empty the digesters of the biogas produced, approximately 4 hours will be required, thus satisfying the 6-hour emptying time, as required by regional regulations**.

3.13 2.5 MW boiler

The project involves the installation, in a special container, of a boiler powered by methane gas taken directly from the network with a power of 2.5 MWt. The boiler will be aimed at supplying the thermal consumption required for the denitrification system consisting of evaporation, osmosis, and stripping s. It should be noted that in the event of an emergency, the boiler can function as a back-up for part of the thermal energy required by the plant.

3.14 Upgrading system

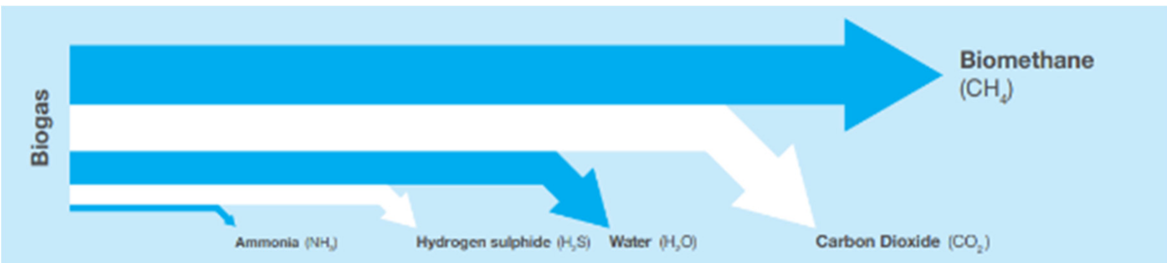

Figure 23 : Visualization of biogas composition

Biogas

Biogas is a mixture of various natural gases, mostly methane (55-60% CH_4) and carbon dioxide (40-45% CO_2).

Biogas is therefore an extremely valuable economic resource, as it allows waste to be disposed of and transformed into a versatile source of energy (biomethane). From an environmental protection perspective, biogas production has two further advantages. The first is that during the fermentation process, no "new" carbon dioxide is produced, but rather the return of CO_2 to the atmosphere is simply accelerated, which can then be reabsorbed by plants, restarting the cycle. The second is that combustion prevents methane, which has a much higher greenhouse effect than CO_2, from being released into the atmosphere.

Biomethane

The term biomethane refers to biogas that has undergone a refining process (called upgrading) to achieve a methane concentration of over 99%. Biomethane can be used in a variety of ways, from combustion in boilers to electricity generation and vehicle fuel.

Biomethane self-production plants therefore offer a new and very interesting opportunity for the valorization of agricultural biomass and, at the same time, a real opportunity to reduce environmental impact. The percentage of methane contained in biogas depends both on the raw material used and the conversion technology employed.

This plant is expected to use ultra-high selective polymeric refinement membranes (HPSM), which allow significant refined gas flow rates and high yields to be obtained without the use of chemicals. The proposed upgrading technology makes it possible to obtain high-quality biomethane with an extremely low CO_2 content and therefore with a significantly increased calorific value compared to the original biogas.

The biogas produced by the plant will have conditions like those shown in the following table:

Variable	**Project values**	**UoM**
Temperature	35	°C
Pressure	5	mbar (g)
State of H_2 0	saturated	
Maximum wet biogas flow rate	710	Nm^3/h
CH_4 content	50-60	% V/V (=%mol)
N_2 content	< 0.8	% V/V (=%mol)
O_2 content	< 0.6	% V/V (=%mol)
CO_2 content	40-50	% V/V (=%mol)

Table 6 : Example of characteristics of biogas produced by the anaerobic digestion system

After treatment of the biogas in the upgrading system, the resulting biomethane will have characteristics like those shown in the table below.

Variable	Project values	UoM
Temperature	30	°C
Pressure	15	bar (g)
Max BioCH4 flow rate	750	Sm^3 /h
CH_4 content	>99	% V/V (=%mol)
CO_2 content	<1	% V/V (=%mol)
N_2 content	<0.8	% V/V (=%mol)
O_2 content	<0.6	% V/V (=%mol)
H_2S content	<6.6	mg/Nm^3

Table 7 : Characteristics of biomethane produced downstream of the upgrading system

The gas must comply with the requirements for injection into the network ref. UNI/TR 11537:2016 "*Injection of biomethane into natural gas transport and distribution networks*". The verification/certification of the quality of the biomethane output will be the responsibility of the customer.

The off-gas flow, i.e., the waste from the upgrading process, will have characteristics like those indicated in the following table.

Quantity	Design values	Unit
Temperature	25° C	°C
Pressure	0.1	mbar (g)
Max flow rate	521	Nm^3 /h
CO_2	>99	% V/V (=%mol)
CH_4	<1	% V/V (=%mol)

Table 8 : Characteristics of the off gas produced downstream of the upgrading system

The upgrading module is preceded by the biogas treatment system. This will consist of a primary filtration system complete with condensate drain and a sized biogas dehumidification system.

H2S FILTRATION

The treated biogas will be fed into the activated carbon filtration system to remove any pollutants present (H_2 S). The system will be suitably insulated and covered with shaped aluminum sheet metal.

VOC FILTRATION - PREPARATION

The system will also be prepared for the potential future installation of a filtration system for Volatile Organic Compounds (VOCs).

The conversion of biogas into biomethane requires a refining process (known as upgrading) to achieve a methane concentration of over 99% and comply with the required technical specifications.

The technology used in the plant is membrane refining. The process consists of separation by permeating high-performance polymeric materials.

Membrane upgrading technology makes it possible to obtain high-quality biomethane with an extremely low CO_2 content and therefore with a significantly higher calorific value than the original biogas. Membrane technology is extremely simple, being able to separate methane from carbon dioxide with high efficiency through permeation on high-performance polymeric materials. Moisture is practically eliminated, as water together with CO_2passes into the permeate gas.

The system will be equipped with a continuous analysis device that, through a series of sampling points located at strategic points in the plant, will maintain the quality of the biomethane produced and monitor the levels of contaminants present, to facilitate maintenance and modification of the plant.

The advantages of the membrane technology adopted are numerous:

- Simplicity of installation: the only machines required are compressors;
- Flexibility: it is possible to adjust the purity of the output gas if a high grade is not required, thus achieving greater volumetric production thanks to the special multi-stage membrane system;
- Almost instantaneous start-up: up and running in a few minutes;
- Sustainability: no consumption of chemicals and no liquid effluent from the plant (except for non-polluting compressor condensate);
- Chemical-physical parameters of biomethane: biomethane is produced at a pressure that allows it to be fed into most natural gas networks and with a water content lower than the line specification (therefore, no dryer installation is required);
- Extremely compact, fully pre-assembled plant: any auxiliary equipment that cannot be housed inside is positioned on the roof of the building.

The system will check the composition of the biomethane coming out of the upgrading process to see if it's good enough to sell or if it needs to be recirculated back into the upgrading system because there are too many elements that mess up its composition.

The upgrading system is designed for outdoor installation.

The plant will be equipped with an integrated control and monitoring system, which can also be easily managed remotely via a computer platform, allowing every sensitive element of the operation to be monitored. It will also be equipped with a fire and gas leak detection system.

The membrane upgrading system will have a maximum conversion capacity of 750 Sm^3/h of biomethane. The characteristics of the system are as follows:

General data	
Machine type	UPGRADING
Service	Transformation of biogas into biomethane
Applied standards and directives	Design, drawings, and documentation: - Metric system, ISO, IEC - Ministerial Decree of April 16, 2008 - Ministerial Decree of April 17, 2008 - CEI EN 60079-0 - ATEX Directive 2014/34/EU - ATSM/API - ASME VII Div.I - ASME V - ANSI B31.8 - Protection of health and safety in the workplace Legislative Decree No. 81 of 09/04/2008

Process data		
Minimum ambient temperature	~ - 10	°C
Maximum ambient temperature	~ + 35	°
Fluid to be treated	Agricultural biogas	
Maximum treatment capacity	1,267	Nm^3 /h
Inlet pressure	5	mbar g
Maximum biomethane flow rate	750	Sm^3 /h
Biomethane outlet pressure	8	bar g
CH_4content range	50÷60	%
No. of days of activity per year	365	

9 : Example of upgrading operating data

3.15 Cabin REMI

The project involves the installation of a cabin for the regulation, measurement, and analysis of the biomethane produced, in accordance with UNI/TR 11537/2019 specifications. That would be carried out in accordance with the local DSO in the executive phase.

The cabin will be built in reinforced concrete, structured with two areas forming part of a single structure: one dedicated to piping, control valves, components necessary for fiscal flow.

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